Optimising female athletes' sleep: The role of sleep hygiene interventions on performance and recovery

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ABSTRACT

Sleep has been shown to affect many parameters of physical performance and female athletes commonly demonstrate worse sleep indices than male counterparts. This thesis aims to present applied research investigating novel areas of sleep hygiene (SH), with the overarching aim of improving sleep factors for female athletes. Study 1 first investigated whether chronotype affects SH status, with secondary aims to investigate which areas of SH were most problematic for female athletes, also considering potential differences in sleep between sport types. Morning chronotype predicted for an improved SH status, whilst conversely, being an evening chronotype predicted for a worse SH status. Investigation of secondary aims concluded team sport athletes demonstrated a significantly worse SH status than individual sport athletes, whilst common to all participants, three areas of SH were identified as being most problematic – sleep regularity, active behaviours in the evening and psychological factors. Considering the prevalence of self-reported sleep parameters across many sports, Study 2 assessed agreement between self-reported and actigraphy reported sleep duration and quality. For sleep duration, evident disagreement was observed between the two methods, with a tendency for participants to overestimate their self-reported sleep duration by 32 min (mean bias -0.54), and a potential disagreement range of ~2 hours (limits of agreement +24 min to −90 min). For sleep quality, number of wakings was the only actigraph reported variable that significantly predicted self-reported sleep quality, suggesting low self-report scores of this factor could indicate the need for SH interventions. Study 3 and 4 investigated methods of SH education, using evidence from Study 1 in the development of SH interventions, and evidence from Study 2 in the development of methodological approaches. Study 3 was novel in investigating whether SH interventions can affect strength and power outcomes, and also in the comparison of SH education methods. Individualised SH education was superior to group-based interventions for improvement of sleep factors. Furthermore, improved sleep affected jump performance, whilst maximal strength was not significantly affected. Study 3 findings led to considering time-efficient methods of individualised SH education, given potential constraints to individualised approaches in many settings. Study 4 developed an individualised, media-based SH intervention. Significant improvements in multiple sleep parameters were observed post-intervention, whilst also presenting the novel finding that SH improved sleep factors for female athletes' mid-season. Collective findings present the importance of SH education in improving female athletes sleep and suggest this should be delivered in an individualised manner. Additionally, practitioners should consider objective sleep monitoring, and chronotype screening within athlete monitoring. This thesis presents a branch of female athlete-specific sleep research, which has the potential to be highly impactful in the field of performance sport.

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LIST OF ABBREVIATIONS

~	Approximately
°	Degrees
η_p^2	Partial eta squared
ASBQ	Athlete Sleep Behaviour Questionnaire
CV	Coefficient of variation
d	Cohen's d effect size
h	Hours
HC	Hormonal contraceptives
ICC	Intraclass correlation coefficients
IER	Insufficient error responding
MC	Menstrual cycle
min	Minutes
PSG	Polysomnography
PSQI	Pittsburgh Sleep Quality Index
r	Pearson's correlation
rMEQ	Reduced morningness:eveningness questionnaire
RPE	Rating of perceived exertion

SD	Standard deviation
SE	Sleep efficiency
SFI	Sleep fragmentation index
SH	Sleep hygiene
SHI	Sleep Hygiene Index
TEM	Typical error of measurement

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DECLARATION

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree and does not incorporate any material already submitted for a degree.

Signed: J.Gooderick

Date: 10/12/24

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1. INTRODUCTION

In recent years, there has been an exponential rise in the professionalism, growth, and interest of female sports globally (Emmonds et al., 2019). In football, the Women's Super League (WSL) has raised the media profile of women's football in England, which predictably, has resulted in many clubs benefiting from greater sponsorship investment, allowing further professionalisation of the women's game. Additionally, the development of a cohesive and strategic effort by the Football Association (FA) has succeeded in building pathways from recreational to elite, with the aim of developing the game from grassroots to international level (Fielding-LLoyd and Woodhouse, 2023). This in turn has seen an increase in training time per week and a more congested fixture schedule for female players, coupled with increased pressures on sustained peak performance. Whilst the increased professionalisation and growth of women’s sport, such as football, is undoubtedly positive for both sport and wider society, scientific research to support these athletes has unfortunately not kept pace with the increased demands of the sport and a distinct lack of research on female athletes can be observed across many aspects of Sports Science and Strength and Conditioning (Smith et al., 2022).

Practitioners such as Sports Science professionals, Strength and Conditioning coaches and technical coaches, should aim to apply evidence-based approaches to optimise athlete performances, derived from research, whilst also being mindful of holistic athlete well-being. However, with the distinct lack of research on female athletes, operating with best practice can often be challenging (Smith et al., 2022). The challenges of applying research derived from male athletes into practical performance adjustments for female athletes, entails a lack of appreciation of physiological differences (for example, hormonal fluctuations), anatomical differences, biomechanical differences, specific responses to interventions, training or protocols, or contextual factors (for example, scheduling, provision), which may lead to suboptimal coaching practice (Smith et al., 2022). Of primary concern is a notable lack of female high-performance athletes within Sports Science literature; indeed, the majority of female representation within the literature base comes from recreational athletes (Emmonds et al., 2019). Again, making strategic physical performance decisions for high level athletes based on data from a recreationally active cohort, necessitates a lack of appreciation for the contextual nuance between recreational athletes and those operating at national or international level.

Cowley et al. (2021) examined 5261 studies across six journals in the field of Sports Science and Sports Medicine, a sample which included 12.5 million participants, and found only 6% of studies focused exclusively on female participants. Similarly, Paul et al. (2023) reviewed 12,364 published articles from 6 top Sports Medicine journals between 2017-2021. They found 70.7% of publications investigated solely male participants, whilst only 8.8% of studies investigated solely female participants (20.5% using a mixed -sex cohort). Additionally, in a 5-month audit of 3 Sports Science journals, Brookshire (2016) highlighted the lack of female athlete representation as most striking in studies attempting to enhance athletic performance, with female athletes accounting for only 3% of all participants within this sector. Many authors have expressed concern over the evident stark bias between male and female athletes in research (Paul et al., 2023, Sims et al., 2023) and suggested societal and individual biases as contributory causative factors. Additionally, potential financial considerations may have been historically preventing female-specific research. Given the aforementioned increased training time and competition frequency amongst female athletes, ensuring optimal evidence-based scientific methods of both training and recovery seems fundamental.

Therefore, research investigations involving high level female athletes as participants are needed to fill this void, and this thesis provides novelty in focusing solely on female athletes as a participant group. Research involving female participants is likely to involve additional methodological considerations, namely reporting on menstrual cycle phase, hormonal contraception status and potentially additional screening considerations in participant recruitment (Areta et al., 2021; Logue et al., 2020). The series of studies presented within this thesis addresses methodological considerations highlighted by Elliot-Sale et al. (2021) as best practice in study design with female participants. The recruitment process of female participants within this thesis screened for clinical pre-menstrual syndromes, menstrual cycle length and hormonal contraceptives with the aim of reducing physiological menstrual cycle-related variance amongst participants which could have affected results. The availability and recruitment of female athletes can also be challenging due to the tendency for smaller team sizes and the disproportionately low number of professional female athletes (Emmonds et al., 2019). For example, in the Premier League, allowable men's first team squad size is 25 players (2023/24 season), although with many teams drawing on U21 players who are not required to be named as part of that squad, and additional players being brought in for European competition, in reality, the first team set-up is often much larger. Comparatively, the allowable squad size in the WSL is 23, yet anecdotal observations suggest many teams are operating with a lower number of players than the maximal allowance. Despite these challenges, it is crucial to develop high-quality research outputs to support the increased professionalism of female sport, with the additional aim of reducing the observed inequality in the research base. It is for this reason, work in this thesis chose to focus solely on female athletes.

With increased training demands being placed on female athletes, increased recovery demands will follow. Sleep should be considered as a key macro recovery strategy for athletes (Gooderick and Fisher, 2011) and has been suggested as the most important strategy for both physiological and psychological recovery (Cunha et al., 2023). Furthermore, there is evidence to suggest sleep status may impact performance factors, such as strength, sports-specific skills and aerobic performance (Mah et al., 2011, Reilly and Piercy, 1994, Oliver et al., 2009).

Sleep deprivation at varying severities is common amongst athletes of all ages and levels, with evidence suggesting 50-78% of elite athletes report regularly experiencing sleep disturbance (Vlahoyiannis et al 2020). This is likely to be compounded by the fact 59.1% of team sport athletes state they lack any strategies to address sleep issues (Juliff et al., 2015). Furthermore, in a review of 12 articles investigating sleep of Olympic athletes (n=596), over half of all participants reported poor self-reported sleep quality (de Mello et al., 2024). This is suggestive of the fact key recovery components may often be sub-optimal for many athletes, reducing training availability, whilst additionally, performance gains may be being missed both directly, and indirectly, as a result of reduced training time. This thesis addresses the novel question around whether sleep indices affects strength and power performances for female athletes. Coaches need to be able to support the sleep status of athletes to optimise both athletic performance and wider health (Miles et al., 2022), via accurate monitoring and appropriate interventions where needed, which may consider sleep education or manipulations to routines. The efficacy of different methods of delivering sleep education has been given minimal consideration within previous literature, therefore this thesis aims to address the question around what should be considered the optimal approach to sleep education.

With regards to athlete monitoring, current professional practice commonly adopts an approach of athletes providing subjective reports of sleep parameters, likely due to the ease and low cost of this method (Caia et al., 2018). However, there is a notable lack of research around the efficacy of a subjective approach in this remit. Considering the aforementioned importance of the need for accurate monitoring of sleep parameters for female athletes, this thesis addresses that key research question of the accuracy of subjective monitoring. Caia et al. (2018) compared the reporting of subjective and objective sleep parameters in male rugby players and suggested there was good agreement between the methods. However, this conclusion was based on a sub-optimal methodological approach; Furthermore, Power et al.

(2024) suggested physiological and lifestyle differences between male and female athletes should preclude the application of male-derived sleep data to female athletes. Therefore, work in this thesis builds upon these considerations, providing research to direct optimal monitoring approaches for female athletes; work which is novel in both participant demographic and methodological design.

In recent years, there has been a growth of interest around sleep considerations for athletes, and sleep is becoming increasingly recognised as central for health, wellbeing, and athletic performance (Pedlar et al., 2024). Whilst this is a positive adjustment in practical terms, further research investigating female athletes is needed in this remit (Walsh et al., 2021), with sleep patterns and behaviours of female athletes less understood than that of males (Power et al., 2024). Therefore, this thesis aims to gain an understanding of current sleep habits and practices of female athletes, investigating current sleep hygiene practices with a view to providing evidence-based sleep hygiene recommendations to improve the sleep of female athletes, whilst considering optimisation of both recovery and performance. The experimental studies within this thesis were field based, with the aim of maximising both external and ecological validity and presenting direct practical applications. Methodologies and general approaches were considered with respect to feasibility of the work within the field, and the integration of findings into professional practice.

2. LITERATURE REVIEW

The aim of this literature review was to summarise existing literature on the topic areas of sleep and athlete performance, presenting relevant physiology in order to firstly demonstrate physiological rationale for the importance of sleep, and secondly, determine underpinning mechanisms of performance moderations in response to sleep manipulations. Current literature on sleep extension and SH practices are reviewed, demonstrating application within an athletic cohort, with the additional aim of highlighting gaps in the literature base. With limited available research on female athlete sleep, this literature review has drawn on research from non-athletic female cohorts where necessary, in order to detail notable aspects of female physiology and female-specific sleep adjustments. Similarly, some evidence from male athletes has been presented with the aim of demonstrating concepts specific to athletes, but the limitations of the application of this data to a female athlete cohort has been highlighted. Indeed, some of these considerations provide further rationale as to the direction of study within this thesis. To conclude this section, research aims of this thesis are presented (**Section 2.14).**

2.1 Introduction

Research around exercise recovery is of paramount importance for female athletes, given the increasing physiological and psychological demands following the growth in female sport. The concept of recovery is central to athletic performance, via the restoration to homeostatic state and the realisation of physiological adaptation (Selye, 1946). In terms of recovery, Halson (2008) suggested sleep to be the single best recovery strategy available to athletes. **Figure 2.1** below presents a theoretical consideration of recovery strategies for athletes, with sleep, nutrition and hydration suggested as primary foundations, and the most important recovery strategies.

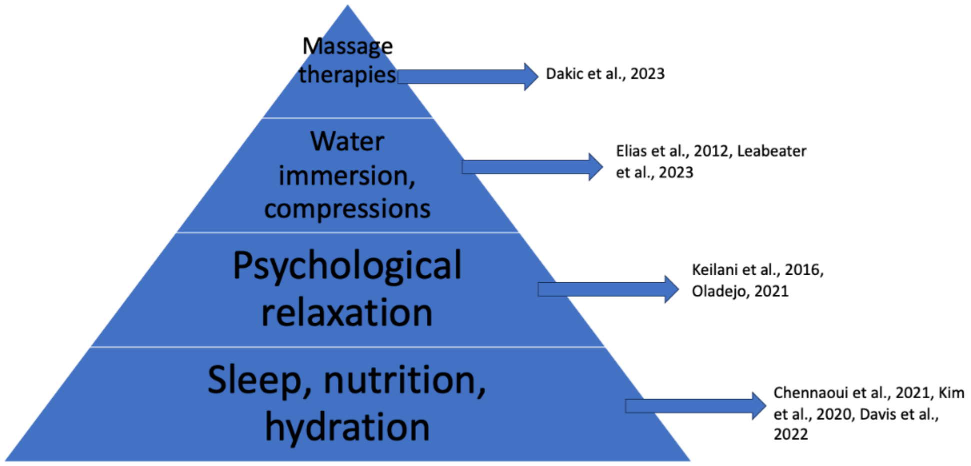

Figure 2.1: Recovery pyramid, adapted from Jarvis (2013) to account for the inclusion of contemporary evidence. Jarvis (2013) presented identical base of sleep, nutrition, and hydration.

Yet despite the consideration that sleep, nutrition and hydration should be considered as the foundations of recovery for athletes, sleep is still an area where many athletes are operating sub-optimally (Gong et al., 2024, Vlahoyiannis et al., 2020). A fundamental difference between other popular recovery strategies (i.e., ice baths, compression garments) and sleep, is that sleep initiation does not depend solely on the willingness of the athlete or instruction of the coach (Nedelec et al., 2015), rather can be limited by current physiological state. For this reason, sleep monitoring, sleep education and sleep awareness are areas of increasing interest within sport (Costa et al., 2022). Whilst considering hierarchical importance of recovery tools is necessary in the gross appreciation of magnitude of benefit, additional considerations must be given to the available “window” of recovery (likely pre-determined by scheduling constraints), logistical feasibility of the strategy, and also, athlete belief and choice. The last point is fundamental, given any recovery strategy will only be effective should the athlete choose to engage with it.

Furthermore, there is evidence to suggest optimising sleep factors may have positive effects on physical performance (Mah et al., 2011). When considering physical performance, an appreciation of underpinning mechanisms contributing to performance loss is key in the implementation of successful remedial strategies (Halson, 2008). Physiologically, sleep deprivation induces increased levels of pro-inflammatory markers (Danillo et al., 2020), whilst changes are also evident at a metabolic level, namely increasing concentrations of neuromodulators, which generally inhibit neural activity (Boonstra et al., 2007); concepts discussed further in section **2.7 Sleep deprivation**. Concerningly, sleep deprivation amongst athletes of all ages and levels is common (Vlahoyiannis et al 2020), with female athletes reporting greater difficulty initiating and maintaining sleep than male athletes (Schaal et al., 2011). Many aspects of physical performance have been demonstrated to be affected by sleep, including speed and sport-specific skills (Walsh et al., 2021, Mah et al., 2011, Schwartz and Simon, 2015). Additionally, Costa et al. (2022) highlighted the importance of sleep for emotional regulation and maintaining overall mental health in athletes, as well as reducing potential illness and injury risk. Despite clear evidence presenting the importance of sleep within athletic cohorts, sleep continues to be problematic for many athletes, and many athletes operate with sub-optimal sleep daily. Sleep requirements change throughout life stages and **Table 2.1** presents the suggested durations at each stage, for healthy individuals (Hirschkowitz et al 2015, Crowley et al., 2016).

Table 2.1: Optimal sleep durations throughout life stages.

Stage of life	**Amount of sleep needed within 24 hours**
Newborn	14-17 hours
Babies	12-15 hours
Toddlers	11-14 hours
Pre school	10-13 hours
School age (up to teenage)	9-11 hours
Teenagers	8-10 hours
Young adulthood	7-9 hours
Older adulthood	7-8 hours

The sleep needs of athletes have been suggested to be greater than the non-athletic individuals due to additional recovery needs (Halson, 2013), so it could be sensible to assume athletes should aim for the upper end of these recommendations. However, in a recent systematic review, Vlahoyiannis et al., (2020) concluded average sleep durations amongst professional athletes were only 7.2 hours (n=230 females, n=1040 males, n=560 mixed sample groups). Similarly, in a review of 12 studies of Olympic athletes (n=596), mean sleep duration across pooled data was 6 hours 10 minutes (de Mello et al., 2024). In collegiate athletes, a population where sleep problems are commonly reported due to training and lifestyle factors, the average sleep duration was 7 hours 4 minutes (Morita and Sasai-Sakuma, 2021); the same study went on to report that athletes needed an average sleep duration of 7 hours 58 minutes to maintain physical and mental health-related quality of life, as analysed by receiver operating characteristics curve analysis (Morita and Sasai-Sakuma (2021). The question of how much sleep athletes need is an important one; Sargent et al. (2021) surveyed 175 elite athletes (n=30 women, n=145 men) and found only 3% of athletes stated they regularly obtain enough sleep to satisfy their self-perceived needs; there was an average sleep deficit (self-assessed sleep needs minus objective sleep measure) of 60.6 minutes. The authors concluded athletes need 8.3 hours of sleep per night to report satisfaction with their sleep. In all the aforementioned studies, a lack of sub-analyses on sex presents difficulty in accurately assessing female athlete sleep status, and further research is needed with a specific focus on female athletes in this remit.

As well as collegiate and professional athletes reporting low sleep durations, of more concern perhaps is the fact that adolescent athletes report even lower sleep durations than senior athletes, despite adolescents having greater sleep needs than adults (Caia et al., 2017). Without intervention, this demonstrates the potential for systemic issues to arise, with potential impacts on both performance and health markers, warranting the need for further research on athletes across a range of ages and environments. Not only is sleep duration commonly insufficient in athletes, but athletes also showed poorer sleep quality than age and sex-matched controls (Leeder et al., 2012), often demonstrating more disturbances within the night. Interestingly, in a study which posed the question to coaches and athletes about which is the most important recovery strategy, sleep was confirmed as the most popular answer for both cohorts (Fallon, 2007), yet as previously evidenced, is not a strategy which is performed successfully in many athletes (Halson, 2013).

Practitioners have a growing range of methodologies at their disposal to support athletes sleep, and the number of studies investigating sleep and athletic performance has grown exponentially over recent years (Lastella et al., 2020). Interventions targeting sleep improvements range from mindfulness (Murawski et al., 2018), thermoregulatory adjustments (Aloulou et al., 2020), cryotherapy (Douzi et al., 2019) or sleep hygiene education (Caia et al, 2018), aiming to facilitate behaviours conducive to promotion of sleep (Driler et al., 2019). Sleep hygiene (SH) can be defined as environmental and behavioural considerations to optimise sleep (Irish et al., 2015). Sleep hygiene interventions have been shown to improve various sleep parameters for athletes (Caia et al., 2018, Driller et al., 2019), and may be popular within the remit of sports due to the low-cost, and relative ease of administration of the intervention compared to other methods. Furthermore, this approach has the added benefit of providing education to the athlete, with evidence suggesting behavioural change is more likely to occur if education is provided alongside the suggested change, rather than a dictatorial approach of eliciting change (Lindbladh et al., 2002). Additionally, with consideration to a holistic athlete development, SH education may be a valuable tool in supporting sleep requirements of athletes throughout their career.

2.2. Sleep Regulation

The process of sleeping involves many complex physiological mechanisms, which have been studied extensively, yet all of which is not fully understood (Troynikov et al., 2018). Various models have been proposed to account for the process of internal sleep regulation, but commonalities between multiple models describe the basic concept of a two-state regulatory process, that of circadian rhythm and homeostatic sleep drive (Borbely, 1982, Borbely, 1992, Doherty et al., 2019). Human physiology is organised around a daily cycle of activity and sleep, with the sleep: wake cycle being perhaps the most obvious of the 24-hour human circadian rhythm (Foster and Krietzman, 2017). Circadian rhythm describes physiological changes across a 24-hour period, which can be modulated in response to internal and external cues (Reddy et al., 2023). The circadian rhythm of the body is controlled by the suprachiasmatic nucleus (SCN); an internally generated clock entrained to external cues, which can have a significant impact on sleep factors (Vitale et al., 2015). The SCN is responsible for generating cyclic neuroendocrine mechanisms which promote wakefulness and sleepiness. Circadian rhythms alter throughout life stages: for example, the circadian timing of an individual in their teenage years will be phase-delayed by around two hours in comparison to an individual in their fifties (Crowley et al., 2007). Throughout adolescence, the circadian clock continues to get later, reaching peak lateness in women at around 19 years of age, and men, around 21 years of age (Foster and Krietzman, 2017). Up until this age, individuals tend to want to get up later and go to bed later, therefore coaches of adolescent athletes should be mindful of scheduling training interventions at appropriate times to support the teenage body clock, rather than working against it. The reality is however, that this is not always practically possible, with competing demands from education and social constructs. Into early adulthood, the circadian clock moves to an earlier phasing. Awareness and recognition of these changes, along with subsequent adjustment of evening routines in conjunction with sleep drive, is key to the maintenance of appropriate sleep durations, and highlights the importance of regular sleep monitoring.

Homeostatic sleep drive describes the rise in sleep pressure that accumulates as a function of time since waking (Borbely, 1992). Various molecular mechanisms of homeostatic sleep regulation have been presented across the literature (Urade et al., 2011), but the recognition of Prostaglandin (PG) D_2, as a potent sleep promoting substance and therefore as a key component in sleep regulation is widely accepted (Urade et al., 2011), along with the interplay of melatonin and adenosine (Emet et al., 2016). Adenosine is a neurotransmitter that regulates sleep drive and is widely accepted as a sleep regulator (Reichart et al., 2022). Melatonin promotes adenosine signalling (Gandhi et al., 2015), resulting in increased adenosine levels in extra-cellular space (Benington and Heller, 1995); the breakdown of ATP in energy metabolism also contributes to this increase (Benington and Heller, 1995). Adenosine levels in the basal forebrain are suggested to be of particular importance to sleep-wake regulation (Porrka-Heiskannen et al., 2000), with receptors in this region stimulated by PGD_2, which in turn triggers further release of adenosine (Urade et al., 2011). Notably, as adenosine concentration increases in the basal forebrain in response to time awake, increased sleep pressure is evident (Reichart et al., 2022) via the stimulation of A_{2A} receptors, which express sleep-promoting neurons (Urade, 2011). Sleep regulation may partially be due to a function of the ratio between extracellular adenosine concentration to adenosine receptor density (Johnson et al., 2004), which may partly account for congenital individual differences in sleep factors. The regulation of both homeostatic sleep drive and circadian rhythms can account for differing sleep-wake patterns, daytime fatigue profiles and internal desynchronisation (Borbely, 1992).

2.3. Sleep physiology

To understand the importance of sleep on various physical properties, it is necessary to review some of the physiological processes which occur during sleep. Sleep does not begin "in a moment", rather is an end process of a series of interwoven physiological changes, beginning with relaxed drowsiness (Ogilvie, 2001), requiring several physiological processes to co-align. The starting point for the initiation of sleep, that of a state of relaxed drowsiness, demonstrates the importance of evening routines to be conducive to supporting this process, for example, the introduction of bright light in the evening can supress melatonin secretion, reducing adenosine signalling, whilst similarly excessive psychological stimulation can also impair the process (Ogilvie, 2001); concepts which will be further discussed within **Section 2.5**. Before transitioning into a sleep state, core body temperature drops (Harding et al., 2019), and this temperature drop continues into the first two sleep stages, known as non-rapid eye movement (NREM) sleep stages 1 and 2 (**Figure 2.2)** (Harding et al., 2019). Unfavourable environmental conditions can disrupt this process. Stage 2 is characterised by bursts of coordinated neurological activity, known as sleep spindles, and it is thought it is during this stage when short term memories become transferred to long term memory in the cerebral cortex (Mizusecki et al., 2017) (**Figure 2.2**).

The third stage of sleep, NREM stage 3, marks the beginning of deep sleep, when muscle recovery and regeneration are at their highest (O’Donnell and Driller, 2017), primarily through a notable release of growth hormone (O’Donnell et al., 2018). This stage is also known as slow wave sleep, due to the occurrence of low frequency waves observed on electroencephalographic (EEG) activity, believed to represent an expression of underlying cortical synchrony (Amzica and Steriade, 1995). During stage 3, metabolic biproducts are cleared from neurological tissues and further consolidation of long-term memory occurs (Xie et al., 2013). The fourth sleep stage is rapid eye movement sleep (REM): during this stage, oscillations of brain activity are seen on EEG, together with higher frequency synchronous activity (Steriade, 1996). This stage of sleep is when dreams occur and is also associated with memory consolidation (Delmas, 2019). These sleep cycles repeat throughout the night around every 90-120 minutes and the organisation of these cycles are known as sleep architecture (Walker, 2009; Delmas, 2019). If sleep needs are being met, the average individual should cycle through sleep stages 4-6 times per night (Ogilvie, 2001). The ratio of NREM to REM sleep changes throughout the night, although the cycles remain stable: early in the night, stage 3 NREM is more dominant, whilst later in the night stage 2 NREM and REM prevail (Walker, 2009). The reasons behind this organisational principle are, as of yet, unknown. **Figure 2.2** demonstrated the cyclic nature of sleep stages.

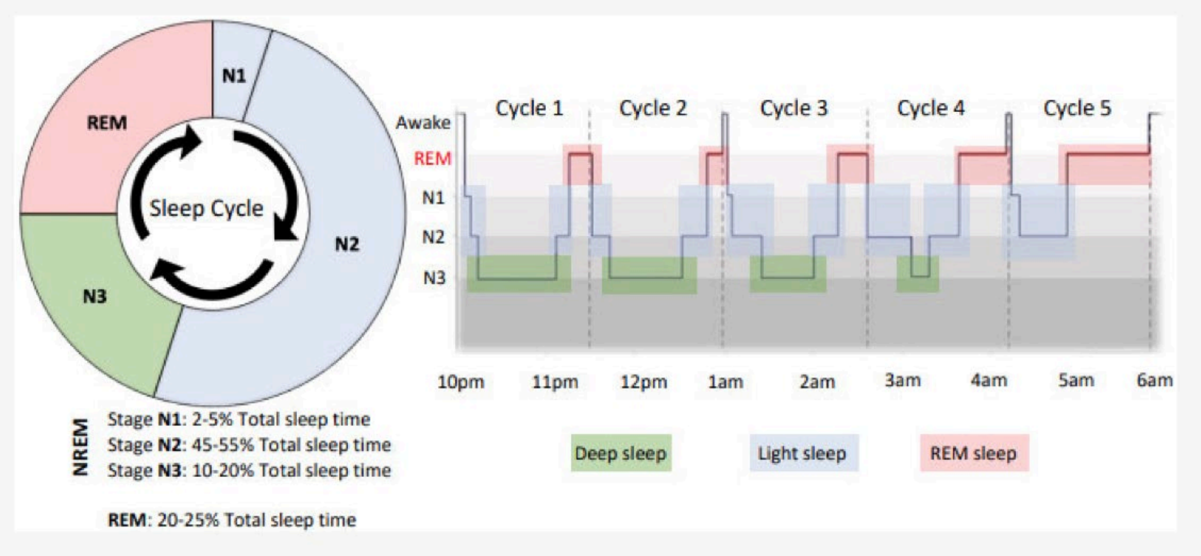

Figure 2.2: Sleep architecture and the typical % spent in each stage (Driller et al., 2023)

Adjustments in brain neurochemistry occur as sleep stages progress. Subcortical cholinergic systems become less active during NREM sleep (Lydic and Baghdoyan, 2005) whilst neuron firing rates are reduced compared to waking levels. During REM sleep, cholinergic systems become more active compared to during waking levels, resulting in a chemical adjustment, most significantly, a notable increase in acetylcholine, the primary neurotransmitter of the parasympathetic nervous system (Marrosu et al., 1995). This increase of acetylcholine has been suggested to be beneficial for cognitive functioning and many mental health markers (Moran et al., 2019), thus presenting one of the key underlying physiological mechanisms as to the observed decrease in many aspects of psychological wellbeing with sleep deprivation (Wong et al., 2013). The observations of biochemical and neurological differences between sleep stages serve to highlight that sleep cannot be treated as a homogeneous entity, and that sleep quality can be largely affected if sleep stages are interrupted or unfulfilled (Marrosu et al., 1995). When monitoring athletes' sleep, this highlights why investigating multiple parameters are of interest, rather than just observing a simple duration measure, which may fail to appreciate other contributory parameters, all which could affect the potential for progressions into the deeper stages of sleep, thus affecting recovery and future physical performance potential (LaGoy et al., 2023). Sleep continuity, determined by PSG, has been significantly correlated with self-reported sleep quality (Onofrio et al., 2023), which seems logical given that key physiological processes will be impaired in the presence of multiple disturbances or wake periods during a sleep period (Nelson et al., 2022).

2.4. Chronotypes

Chronotype can be described as the circadian rhythmicity in an individual (Vitale et al., 2017), with three primary types generally identified: morning, intermediate/neither or evening types. Horne and Ostberg (1976) identified that people had tendencies towards "morningness" or "eveningness", i.e., a preferred time of day when individuals perceived their "optimal functioning". Horne and Ostberg (1976) developed a 19-point questionnaire, which aimed to categorise circadian preference. The authors assessed the questionnaire against oral temperature fluctuations, bedtime and rise times. Significant differences in temperature fluctuations were evident between those reporting as morningness, neither and eveningness according to questionnaire scores; furthermore, oral temperature fluctuations and questionnaire scores were found to correlate with bed and wake times. For each category, the authors then identified circadian peak times from temperature fluctuation curves, and concluded the 19-point morningness:eveningness questionnaire was a valid method of determining chronotype preference in individuals.

The idea of chronotype preference of athletes has received much attention over recent years, with many aspects of sporting success affected by chronotype preference (Vitale et al., 2017). Furthermore, chronotype preference of an individual has the potential to affect sleep parameters. Roenneberg et al. (2003) demonstrated a spectrum of chronotypes across 3000 participants, from those who favoured extreme early rising - "morning larks" - (sleep times 8pm-4am) to those favouring extreme late rising - "night owls" - (sleep times 4am-12pm). This study demonstrated that light was the primary driver of human circadian rhythms, which is further supported by more recent research (Youngstedt et al., 2019). Roenneberg et al. (2003)

concluded “extreme” morning larks were rare, as indeed were “extreme” night owls, and most people operate somewhere on a continuum between these two extremes. Differences between morning and evening types in terms of personality, mood and cognitive performance has been identified (Diaz-Morales, 2007), and interestingly, females have been shown to have a greater predisposition towards morningness compared to males (Vitale et al., 2017; Muzni et al., 2020). Individuals with evening circadian preference are commonly shown to have more problematic sleep, in particular, worse sleep quality (Van der Heijen et al., 2018; Chung et al., 2009). Bender et al. (2024) demonstrated athletes reporting an evening chronotype had worse sleep quality (r = -0.17), than those reporting a morning chronotype. As of yet, no associations have been presented between chronotype and sleep hygiene factors.

Chronotype is determined by genetics, age, sex, and environment (Roenneberg et al., 2012), with around 37% of chronotype variance suggested to be attributable to genetic predisposition (Watson et al., 2013). Rome et al. (2021) studied the sleep of 3787 participants during the 2020 pandemic lockdown, where in the absence of social or economic boundaries, sleep was largely self-selected. They found 66.8% of participants shifted towards evening preference, leading to the conclusion chronotype is changeable according to lifestyle and environmental situations. Evidence of chronotype shift in athletes, in response to training times, is also evident (Vitale et al., 2017). It would seem the understanding of chronotype as a transient concept, adjustable in response to external cues, is key, and is suggestive of the importance of regular screening and monitoring of an athletes’ individual preference throughout the year.

Many studies have investigated the effect of chronotype on various sporting parameters. Hill et al. (1988) investigated the effect of chronotype on a maximal cycling test in the morning (6-8.30am) and evening (3.30-6pm). Participants who had been classified as evening types achieved greater VO_2 max scores in the evening than in the morning, whereas for morning types there was no significant difference in any measured parameters between the conditions.

Similarly, Burgoon et al. (1992) concluded there was no statistical effect of chronotype on a maximal treadmill challenge. However, more recent research has found a greater strength of evidence between chronotype and RPE, with the consensus being the closer exercise is aligned to the individuals' chronotype, the lower reported RPE (Vitale et al., 2013; Kunorozva et al., 2017; Abbad et al., 2023). The practical relevance of this could suggest screening athletes for chronotype preference to be important, yet whilst in reality, training and competition may not always be optimised in response to this, where situation allows, this could be considered. Facer-Childs and Bandstraetter (2015) grouped participants into morning-types, evening-types, and neither-type, and asked them to carry out the multi-stage fitness test at 7am, 10am, 1pm, 4pm, 7pm and 10pm. There were significant differences in peak performance time for morning types (12.19pm ± 1.43h), neither-type (15.81pm ± 0.52h) and evening types (19.66pm ± 0.67h). In a novel approach, they evaluated data as a function of time since awakening and stated that peak performances of evening types were significantly delayed compared to the other two groups. The authors concluded that evening types need a longer wake up time to prepare the body for activity and peak performance and suggested that both chronotype and hours after waking are key factors for performance, rather than time of day as an absolute.

2.5. Factors affecting sleep

Sleep can be affected by a multitude of internal and external factors, with light and exercise being two primary drivers. Exercise-induced circadian adjustment has been evidenced, notably with the novel findings from Youngstedt et al. (2019) who attempted to assess the phase-response curve of circadian adjustment in response to exercise. Across 3 days, participants (n=26 females, n=22 males) were asked to perform an hour of treadmill exercise at 8 different times of the day. Evening exercise (7-10pm) induced a phase delay, whereas morning or early afternoon exercise (7am or 1-4pm) induced a circadian phase advance, as measured by a melatonin response. The exercise response was comparable to bright light exposure of equal duration, demonstrating that exercise timing plays a significant role in impacting sleep indices. This information may be of use in shifting athletes towards a potentially more favourable chronotype preference that is conducive to their current scheduling demands. Consideration should also be given to the above factors in the scheduling of training plans, travel, and competition preparation.

Evening light exposure has been demonstrated to be one of the key factors which can potentially disrupt sleep (Costa et al., 2019), with evidence suggesting evening light exposure may negatively affect sleep factors, causing an increased sleep latency time (Munch et al., 2006) and disruption to sleep architecture (Green et al., 2017). All light goes through the eye, with rods, cones and intrinsically photosensitive retinal ganglion cells in the retina conveying information to the brain for visual processing (Prayag et al., 2019). When light hits the eye, optic nerves transmit information to the suprachiasmatic nucleus, which then suppresses melatonin release from the pineal gland (Prayag et al., 2019). Monochromatic light in the range of 446-477nm is the peak wavelength range for melatonin suppression in humans (Brainard et al., 2001). An interesting consideration is the fact that prior light exposure can impact melatonin suppression (Jasser et al., 2006), with the suggestion that "light history" can have an impact on physiological response (Jasser et al., 2006; Prayag et al., 2019). Prior illuminance history has been shown to influence the magnitude of response to a light stimulus (Prayag et al., 2019), which serves to highlight the need for education to athletes who may be looking to adjust their evening light exposure to enhance sleep; there may be a delay in adaptation, and consistency is key in attempting to reverse and retrain this physiological response. In order to manage expectations, it may perhaps be prudent to pre-frame attempts to adjust sleep variables of athletes with comparison to physical training adaptations. It is for this reason, strategies around sleep hygiene may be preferable to other sleep adjustment methods (for example, supplement use), providing the education component aiming for long-term response. It is important to note that daytime light exposure, especially in the morning, can help mitigate the negative impact of light at night (Hebert et al., 2002), thus demonstrating the value of a holistic approach to sleep education, with considerations wider than solely an evening focus, still relevant.

With the growth of smartphone use, the levels of blue light exposure in society have rapidly increased since the early 2000's (Mortazavi et al., 2018). Considering 77% of athletes reporting using their phone throughout the evening, this may be problematic from a sleep perspective (Monma et al., 2023), given there is some evidence to suggest blue light suppresses melatonin expression to a greater extent than other wavelengths. Jones et al. (2019) concluded pre-bed screen use delayed sleep onset, whilst Watkins et al. (2021) stated athletes with high social media use reported worse sleep quality. Oh et al. (2015) suggested reducing blue light on screen displays can improve sleep quality, and blue light glasses, smartphone "night modes" and blue light screen filters are all methods commonly used to negate the stimulating effects of blue light. However, to focus on solely the visual aspects of blue light as a sleep hindrance over-simplifies the problem, failing to acknowledge the psychological stimulation that may occur from smartphone or tablet use (Weiss et al., 2011). Education around sleep hygiene is one way to initiate good habits around sleep, raising awareness around the aforementioned hindering factors for sleep and promoting evening routines which optimise the preparation for sleep.

However, Ellithorpe et al. (2022) highlighted that not all media use is the same, and the type and context of the media use matters. The "media use for recovery" hypothesis (Reinecke, Hartmann, & Eden, 2014) states that individuals using media for needs satisfaction could lead to greater wellbeing and greater overall recovery from daily stressors. Given the relationship between sleep quality and psychological strain (Van Laethem et al., 2015), this recovery hypothesis could suggest that certain types of media, rather than being detrimental to sleep, may indeed be beneficial for sleep indices. It would appear the timing of such use is key, with the need for a balance between needs satisfaction, and supporting sleep physiology, with considerations for both light exposure and psychological arousal.

2.6. The role of sleep

Sleep has many important biological functions, and almost all human physiological processes change at the onset of sleep (Chokroverty, 2017). It has been proposed that sleep remains essential for energy conservation, brain detoxification, and tissue restoration (McGinty et al., 1990, Inoue et al., 1995), whilst additional evidence suggests sleep periods are favourable for brain plasticity, providing evidence that sleep plays a key role in effective learning and cognition (Marquet, 2001). This would seem supported by evidence of the disruption of REM sleep impairing memory consolidation and disturbing the retention of newly learnt tasks (Rauchs et al., 2005), with the degree of deterioration determined by the complexity of the task (Hobson and Pace-Schott, 2002). Furthermore, poor sleep has been shown to negatively affect cognitive learning (Al-Khani et al., 2019), whilst many studies have demonstrated the negative effects of sleep deprivation on mood and mental health markers (Al-Khani et al., 2019; Rosen et al., 2006; Milojevich and Lukowski, 2016).

Without sufficient sleep, the ability to adequately regulate emotions is compromised, both from a neurological and behavioural perspective (Goldstein et al., 2014). From a metabolic perspective, failure to meet sleep needs may result in increased weight gain via disruption of glucose tolerance, increased ghrelin, and decreased leptin (Leproult et al., 2010). In terms of immunity, evidence suggests a lack of sleep increases susceptibility to illness, with Wilder-Smith et al. (2013) demonstrating a lack of sleep to increase risk of respiratory infections; specifically, the increase in pro-inflammatory cytokines observed following sleep loss is suggested as being likely to lead to subsequent immune dysfunction (Fullagar et al., 2015). Irwin et al. (1996) also suggested immune deficiencies with lack of sleep, specifically impairments in natural killer cells and T-cell cytokine production. Additionally with respect to athletes, the role of growth hormone during sleep must be appreciated. Growth hormone is a powerful anabolic hormone which plays a key role in muscle repair and growth (MacIntyre, 1987). The secretion of growth hormone follows a circadian rhythm, with sleep and exercise being the primary drivers of secretion; indeed, the biggest secretion of growth hormone usually observed during sleep (Godfrey et al., 2003). Considering the physiological mechanisms detailed above, it is evident that sleep plays a key role in both athlete recovery and physical performance (Walsh et al., 2021); skill acquisition, skill consolidation, sports performance, recovery, and adaptation are all likely to be affected by sleep, with athlete availability secondarily affected via potential immune deficits. From a wider perspective, mental wellbeing must also be considered when recognising the importance of sleep for athletes.

2.7. Sleep Deprivation

Sleep deprivation occurs when a person fails to meet their sleep needs, and can be acute or chronic, both of which negatively affect both health and performance (Taheri and Arabameri, 2012; Delmas, 2019). Total sleep deprivation can be defined as a restriction of sleep for a minimum 24 h period (Kolowsky and Babkoff, 1992). A more common issue for athletes, however, is the experience of many acute bouts of partial sleep deprivation (Halson, 2014); partial sleep deprivation can be described as obtaining sleep less than a usual habitual duration (Reynolds et al., 2010). Physiologically, neural changes can be observed when operating in a state of sleep deprivation, with reductions in functional MRI signal in the dorsolateral prefrontal cortex and intraparietal sulcus evident whilst performing attentional tasks (Krause et al., 2017). Previous research has demonstrated the behavioural manifestations of such neural changes with athletes incurring reduced reaction time, focus, psychomotor performance, determination, and vigilance (Davenne, 2009; Edwards and Waterhouse, 2009; Underwood et al., 2010) in response to lack of sleep.

Furthermore, evidence exists attributing sleep deprivation to observed reductions in muscle force output (Phillip et al., 2003), concentration lapses (Degennaro et al., 2001), cognitive slowing and memory impairment (Himashree et al., 2002), all of which are likely to impact athlete performance. With rising sleep pressure in response to insufficient sleep, increased adenosine concentration can be observed, which inhibits neural drive and may account for some magnitude of loss of muscle force (Boonstra et al., 2007). Sleep deprivation negatively impacts immunity and overall psychological well-being (Itani et al., 2017), factors conducive to athlete availability and holistic development. From a meta-analysis of 69 studies, Craven et al. (2022) concluded that any form of sleep loss (partial or total) had a consistent negative influence on performance when tasks were performed in both the morning and afternoon, although the magnitude of effect was larger for afternoon tasks. From a practical perspective, this may aid with planning and scheduling for situations when sleep loss is unavoidable.

Substantial individual differences in response to sleep deprivation has been previously evidenced (Rupp et al., 2009), and underlying physiological rationale for this may be multifaced. Rupp et al. (2009) demonstrated those who had longer sleep durations prior to a period of sleep deprivation (3-hour sleep allowance) were less affected than those with shorter sleep durations prior to sleep deprivation, thus the notion of “sleep banking” was considered a strategy to mitigate known instances of forthcoming sleep disruption. Furthermore, individuals with PER3 clock gene polymorphism are suggested to be more susceptible to performance degradation following sleep disruption (Viola et al., 2007), suggesting genetics may also play a role in an individual’s resilience to sleep loss. Sleep banking may be recommended to offset the physiological degradation in performance (Janušauskaitė et al., 2022), however, this strategy should be considered as an acute response to the anticipation of short-term sleep deprivation, and not as a long-term solution to counteract regular periods of sleep deprivation (Janušauskaitė et al., 2022). With Phillips et al. (2017) highlighting the importance of sleep regularity in the development of positive habitual sleep patterns, it should be recognised that the use of sleep banking strategies in the long term would likely negatively impact sleep regularity. Whilst in the short term this strategy may go some way to repaying the observed sleep debt, regular inconsistency in sleep timings is considered unfavourable and are thought to disrupt the synchrony of circadian rhythms (Irish et al., 2015). Therefore, athletes should be encouraged to maintain regular sleep timings, and work within their training or competition constraints to establish a regular sleep routine. In this instance, the prevention of sleep debt in the first place via positive habitual sleep behaviour should be considered the priority action point, rather than the subsequent irregular sleep timings required to repay sleep debt. This presents rationale as to why sleep hygiene interventions may be favourable as an intervention strategy.

2.7.1. Total sleep deprivation

Total sleep deprivation can have significant effects on physiology and psychology. It has been suggested that females are more vulnerable to the effects of sleep loss (Miles et al., 2022), presenting greater and more prolonged increases in inflammatory markers (Suarez, 2008), up-regulation of inflammatory cytokine expression (Irwin et al., 2008) and higher fasting insulin levels (Suarez, 2008) than males, post-sleep deprivation. Total sleep deprivation modifies inflammatory and hormonal responses to exercise-induced muscle damage. Danillo et al. (2020) used a 48-hour sleep deprivation following eccentric exercise and demonstrated increased levels of IGF-1, cortisol and altered cortisol: testosterone ratio in sleep deprived participants compared to controls. In terms of strength performance, Knowles et al. (2018) concluded that sleep deprivation impairs maximal muscle strength in compound movements when performed without additional motivational strategies.

However, the impact of sleep deprivation on anaerobic performance is less clear, with Taheri and Arabemiri (2012) suggesting sleep deprivation has less effect on the physiological mechanisms underpinning anaerobic capacity. This theory supports earlier work from Symons et al. (1988) who asked participants to perform a Wingate test following 60-hours of sleep deprivation and found no differences in performance compared to when participants were not sleep deprived. Of note, Taheri and Arabemiri (2012) used "strong verbal motivation" during their anaerobic testing, which could account for lack of performance alterations between the sleep deprivation and controlled conditions, as Knowles et al. (2018) noted motivation could potentially override the physiological decrements of sleep deprivation on performance. However, with Fasanghari et al. (2014) concluding 24 h sleep deprivation to significantly reduce selective and sustained attention in female athletes, overriding motivational attempts are likely to be modulated by the athletes' ability to maintain attention to a task. Halson (2014) stated that the effects of sleep deprivation are task-specific, a statement that would appear to be supported by the mixed consensus in this area.

2.7.2. Partial sleep deprivation

Whilst studies presenting information regarding total sleep deprivation are of interest in describing the relationship between sleep and performance parameters, few athletes are perhaps ever likely to experience total sleep deprivation, and perhaps even less likely to experience prolonged total sleep deprivation. When chronic partial sleep deprivation occurs, it is commonly stage 2 and REM sleep that become proportionally decreased in response to restricted sleep time (Van Dongen et al., 2003), thus explaining the negative cognitive impacts seen following this. Partial sleep deprivation is common in athletes, due to unfavourable scheduling, travel, unfamiliar sleep environments, pre-competition anxiety, and post-competition arousal (Gong et al., 2024; Halson et al., 2019). O'Donnell et al. (2018) showed how match nights for female netball athletes can induce bouts of partial sleep deprivation, with results comparing match night sleep vs training night sleep presenting mean differences in sleep duration of -118 ± 112 min ($p<0.01$). Similarly, in male Australian Football players, Sargent and Roach (2016) demonstrated how competition timing can affect sleep parameters. Evening competition resulted in a later initiation of sleep (+2.5 hours, $p<0.0001$), and a subsequent shorter sleep duration (-2.1 hours, $p = 0.02$) compared to day competition. Considering competition regularity amongst team sport athletes, is it easy to appreciate the prevalence of partial sleep deprivation amongst athletic cohorts. Performance and alertness following partial sleep deprivation are generally degraded in a dose-dependent manner (Rupp et al., 2009).

Partial sleep deprivation can either be characterised by restricted sleep in the first part of the night (early restriction), or restriction within the later part of the night (late restriction). The type of restriction may have some influence on the magnitude of effect that insufficient sleep has on physical performance (Craven et al., 2022). In a meta-analysis of 27 studies, Gong et al. (2024) suggested sleep loss at the end of the night to have a greater impact on various sporting performance metrics than sleep loss at the beginning of the night, supporting earlier work from Soussi et al. (2013). Soussi et al. (2013) compared whether 4 hours sleep deprivation at the start of the night was different to sleep deprivation at the end of the night in terms of anaerobic performance the following day. They concluded a 4-hour sleep deprivation at the end of the night had larger negative impacts than a 4-hour sleep deprivation at the start of the night. The authors demonstrated temperature-related circadian adjustments were only evident following sleep deprivation at the end of the night, whilst additionally force capabilities demonstrated larger fluctuations; both mechanisms are likely to have contributed to the observed decrease in peak power.

Additionally, Halson (2013) suggested perception of effort and pain tolerance to be a key contributory factor in performance decreases following sleep loss. In a meta-analysis of 31 studies, Chang et al. (2022) concluded moderate evidence (ES: 0.30) could be observed that partial sleep deprivation increased subjective pain intensity in healthy individuals. Similarly, in a meta-analysis of 32 studies investigating sleep and athletic performance, Clemente et al. (2021) noted increased perception of exertion was evident with any level of sleep loss.

Despite being a commonly observed issue in athletic populations, relatively few studies have examined partial sleep deprivation on athletic performance, compared to total sleep deprivation. In one such study, Reilly and Deykin (1983) reported decrements in a range of psychomotor functions after one night of restricted sleep, where only 3 hours of sleep was permitted; however, muscle strength and endurance performance were unaffected. It would seem that repeated bouts of exercise are affected to a greater degree by partial sleep deprivation than one-off, maximal efforts (Reilly and Hales, 1988; Reilly and Piercy, 1994; Reilly and Edwards, 2007). Perhaps unsurprisingly, greater impairments of physical performance later in the day following a night of partial sleep deprivation have been observed (Reilly and Piercy, 1994), suggesting an accumulative effect of fatigue from sleep loss, which could be significant for coaches aiming to minimise performance loss following partial sleep deprivation. Sufrinko et al. (2016) found significant reductions in neurocognitive performance (visual memory tests and speed of response to a stimulus) were observed across over 7000 athletes who had sleep deprivation of less than 5 hours per night. Cullen et al. (2019) restricted participants to 4 hours sleep and found negative impairments on a countermovement jump and aerobic performance. In terms of the endocrine response, Leprout et al. (2011) also demonstrated that partial sleep restriction, specifically going from 8 hours sleep per night to 5 hours sleep per night for one-week, decreased testosterone levels by 15% in young men. This decrease in anabolic hormone status negatively affects protein synthesis and overnight muscle repair (Leprout et al., 2011), thus affecting future training potential and performance, and delayed recovery status could be indirectly indicative of sleep deficits.

Interestingly, comparisons between males and females indicates females to have greater slow wave activity during sleep following a period of partial sleep deprivation, potentially indicating differences in responses to sleep debt compared to males (Miles et al., 2022). In terms of psychological responses, females present increased risk of depression and mood disturbances compared to males following sleep loss, thus presenting collective evidence that suggests sleep loss could have large detrimental effects on overall health of female athletes, as well as affecting athletic performance. With bouts of partial sleep deprivation common amongst female athletes (O'Donnell et al., 2018), this is a concerning observation.

2.8. The measuring and monitoring of sleep

Given the importance of sleep for many facets of athletic performance, there is a need to ensure appropriate monitoring of sleep variables to accurately identify issues. The 'gold standard' of sleep monitoring is polysomnography (PSG), a lab-based technique whereby the participants' eye movement, brain activity, heart rate, muscle activity, oxygen saturation, breathing rate and body movement are all assessed during sleeping (Hausswirth et al., 2014). This creates an in-depth view into many sleep variables, including sleep architecture. However, PSG is an expensive and complex procedure, requiring the participant to sleep away from their usual home-based environment, which could cause variability to initial results, thus it is advocated to use PSG across multiple nights (Van der Water et al., 2011). Whilst PSG may provide a detailed insight into all aspects of sleep, it is impractical for longitudinal monitoring, and there are sizeable expense considerations if monitoring for an entire team. It is for those reasons that actigraphy is a more practical, and therefore common, method for sleep monitoring of athletes.

Actigrahs are small, wearable devices which record movement as a function of time (Quaite et al., 2015), using algorithmic calculations of movement counts to differentiate sleep states from that of wakefulness (de Souza et al., 2003). These devices are portable, meaning sleep monitoring can be carried out in an individuals' usual home-based environment, giving data high ecological validity and minimising disruption to usual routines (Halson, 2019). Actigraphy has been validated against PSG in multiple populations, including athletes (Sargent et al., 2016), with epoch-to-epoch comparisons showing good agreement (81-90%). Research grade actigraphs are often given favourable consideration for use within scientific research compared to commercial-grade devices (eg., Apple watch, Fitbit) due to their underlying technology having undergone scrutiny through peer-review, and a sampling rate which is often higher than many commercial devices (Miller et al., 2022). However, Miller et al. (2022) attempted to validate six common commercial grade devices (Apple, Fitbit, Oura, Whoop, Garmin, Somfit) against PSG, with the aim of understanding their usefulness from a research and applied perspective. They found for two-state analysis (i.e., sleep or wake), all six devices demonstrated >90% sensitivity for sleep detection, with agreement to PSG ranging from 86-89%. The authors concluded that all devices tested were valid for field-based assessment of sleep duration. For the detection of sleep stages however, agreement to PSG ranged from 50-65%, leading to the conclusion that the tested devices were not appropriate for multi-state analysis. This is an interesting conclusion from both a research and practical perspective, reducing costs and availability of research-grade devices as limiting factors for monitoring sleep durations, for both research and applied practice.

Self-reporting is another option for monitoring athletes' sleep, and is a commonly used tool within elite sport, primarily due to the low cost and ease of administration (Saw et al., 2016). Girschik et al. (2012) aimed to determine the agreement between self-reported sleep data and actigraph reported sleep data amongst women aged 18-80 years. They concluded responses to sleep questions showed poor agreement with actigraph measured sleep (kappa's ranging from -0.19-0.14). In a mixed sex participant group of 669 young adults, Lauderdale et al. (2008) demonstrated moderate correlation (0.47) between self-reported sleep duration and actigraph reported sleep duration. The authors noted the tendency to overestimate sleep by a mean of 34 minutes. To the authors knowledge, Caia et al. (2018) provides the only comparison between self-reported and actigraphy reported sleep data in an athletic cohort, using n = 63 male rugby players. They reported a large, positive correlation between self-reported and actigraphy reported sleep duration ($r = 0.85$, $p < 0.0001$) and suggested the two methods could be used interchangeably with confidence. It is not yet known whether the same conclusion is true of female athletes. There is a lack of strong evidence to determine whether athletes are accurately reporting sleep parameters, despite the widespread use of self-reported sleep measures within elite sport.

2.9. Measured sleep indices

Given the physiological complexities of sleep as a concept, “sleep” cannot be evaluated from a singular parameter, and multiple aspects must be considered when measuring sleep, in order to gain an accurate perception of an athlete’s sleep status.

2.9.1. Sleep duration

Sleep duration can be defined as the length of the sleep period minus any wake periods during that period (Kline, 2013). This can be either self-reported or determined via actigraph measurement. Self-reporting of sleep duration is a common approach within professional sports as part of daily wellness reporting (Rebelo et al., 2023). However, despite the widespread use, it is yet to be determined whether this is a reliable and valid method of obtaining such data. Considering the aforementioned information regarding the importance of sleep for athletic performance, accurate monitoring of this component is essential amongst athletes to ensure recovery needs are met, as well as wider well-being considerations. Early detection of regular short sleep durations may be central in the prevention of systemic issues arising.

2.9.2. Sleep efficiency

Sleep efficiency is calculated as the total sleep duration divided by the total time in bed and is usually expressed as a percentage (Ohayon et al., 2019), and is a reported metric from most actigraph data (Caia et al., 2018). Troynikov et al. (2018) suggested a sleep efficiency percentage of >85% is considered acceptable for this metric, and sleep efficiency is often considered as an objective marker of sleep quality (Leeder et al., 2012, Caia et al., 2018). Leeder et al. (2012) noted the difference between sexes in this parameter; with female athletes demonstrating a higher sleep efficiency than males (83.9 ± 6.4 compared to 81.5% ± 7.4 respectively, $p<0.05$). Interestingly, this supports earlier work of the same conclusion (Goel et al., 2005), despite females commonly reporting an overall worse sleep status, especially in terms of duration and quality (Leeder et al., 2012). It is unknown why females often show greater sleep efficiency, but reasons could be multifactorial encompassing psychological and societal factors. Sleep efficiency of athletes seems variable in response to circumstance, with decreases observed pre-competition (up to 4% decrease, Roberts et al., 2019), and improvements observed following sleep education interventions (2% increase, $p<0.05$, Van Ryswk et al., 2017).

2.9.3 Sleep latency

Sleep latency, or sleep onset latency, can be defined as the time taken to transition from wakefulness to sleep (Ohayon et al., 2019). If monitoring this parameter via actigraph data, depending on the device used, this can either be directly reported, or calculated via sleep diary reporting "lights out" time, to the start of actigraph-determined beginning of sleep interval. Furthermore, in some practical settings, sleep latency can be a self-reported parameter; polysomnography-derived sleep latency has been significantly correlated with self-reported sleep latency (Onofrio et al., 2023), however not in an athletic cohort. When considering athlete schedules, sleep latency is an important factor in achieving required sleep demands, and the ability for an efficient transition from wake to sleep states can be one factor in meeting required sleep durations. Halson et al. (2021) demonstrated sleep latency was longer for female athletes compared to male athletes, though underlying reasons for this difference between the sexes were unclear. This supports earlier work by Leeder et al (2012), who presented similar findings. Given that poor sleep latency can be attributed to poor evening routines, excessive stimulation in the evening or psychological stress (Albqoor et al., 2021), it could be a reasonable assumption that female athletes are sub-optimal in one or many of these areas. A sleep latency time of >30 minutes is suggested to be problematic for athletes, whilst sleep latency times <30 minutes are generally considered acceptable (Halson et al., 2021). Daytime exercise has been shown to decrease sleep latency (Davenne, 2008), whilst sleep latency times have also been shown to decrease in response to sleep hygiene education (Caia et al., 2018, Driller et al., 2019).

2.9.4. Sleep quality

Sleep quality is generally thought to encompass satisfaction with sleep, feelings of being rested and interruptions during the night (Buysse et al., 1989, Ramlee et al., 2017, Pilcher et al., 1997), yet a lack of consensus on definition is evident across the literature (Fabbri et al., 2021). Specific to athletic success, poor sleep quality is associated with poor daytime concentration, decreased reaction times, decreased concentration, decreased attentional focus, and reduced cognitive performance (Fullagar et al., 2015; Monleon et al., 2018; Fox et al., 2020; Grandner et al., 2021), thus highlighting the importance of this component of sleep for athletes. Across the research base, it appears common to employ a mixed methods approach incorporating both subjective and objective measures for the monitoring of sleep quality, giving a broad scope of interpretation (Nelson et al., 2022), and highlighting the fact that the notion of sleep quality does indeed encompass many different constructs. Nelson et al. (2022) summarised sleep quality as having the attributes of sleep duration, latency, efficiency, and wake after sleep onset, and also stated a subjective interpretation of sleep to be vital in the consideration of this parameter.

Ohayon et al. (2017) suggested a sleep efficiency of <64% should be considered as poor sleep quality amongst young adults, whereas Troynikov et al. (2018) suggested sleep efficiency of <85% is indicative of poor sleep quality. In a systematic review of 77 studies, Claudino et al. (2019) concluded that sleep efficiency (actigraph-derived), Pittsburgh Sleep

Quality Index (PSQI) or self-report on a Likert scale were all indicated to monitor sleep quality in team sport athletes, and indeed, a mix of these approaches can be seen across the literature. Interestingly, in a study of n = 63 professional male rugby players, Caia et al. (2018) reported the relationship between self-reported sleep quality and actigraphy reported sleep efficiency to be limited, with the two parameters demonstrating a small, but not statistically significant, positive relationship (r = 0.22, p=0.73); the authors suggested sleep quality was not directly indicative of sleep efficiency. The relationship between these parameters for female athletes warrants further investigation.

2.10. The effect of sport type on sleep factors

The type of sport an individual partakes in, can have a significant impact on sleep parameters, with variations between the athletes from individual sports, and those from team sports, evident across a range of sleep indices. Lastella et al. (2015) reviewed the sleep durations of athletes from individual and team sports (n = 104 male, n = 20 female) and concluded those from individual sports had significantly shorter sleep durations than those from team sports (mean 6.5 h vs 7.0 h respectively). Additionally, this adds to aforementioned considerations regarding many athletes operating with sleep durations well below recommendations, regardless of sport. In contrast, Driller et al. (2022) (n = 237 male, n = 170 female) concluded those from individual sports to have higher sleep durations and sleep efficiency than team sport athletes. Driller et al. (2022) also reported that ASBQ scores were worse for team sport athletes, suggesting poorer sleep practices, which would seem logical given that individual sport athletes are often in greater control regarding their own scheduling, training and generally compete less. The conflicting consensus in the literature between the effects of sport type on sleep is likely due to the contextual nuance around the categorisation of athletes, with scheduling, environmental and behavioural factors all causative factors towards a high degree of inter-individual differences (Driller et al., 2022). Furthermore, this may suggest an individual interpretive approach, given the tendency for some sports, such as swimming, to habitually train during early morning, thus potentially providing an additional time-based constraint to optimising sleep (Da Costa et al., 2023).

Fullagar et al. (2015) noted a lack of published literature on sleep and team sport athletes, and suggested further research is needed within this area. It is likely this area of research is lacking due to the additional complexities involved with methodological design for team sport athletes in this remit. However, the mixed consensus with regards to comparisons between individual and team sport athletes, is suggestive that further research in this area is indeed warranted. Of additional note, is the lack of female athlete representation within the current literature base. Whilst the aforementioned studies both chose a mixed sex cohort, no sub-analyses were done on the sexes, suggesting inferences made into professional practice may be based upon inaccuracies for female athletes, thus highlighting the need for female-specific research in this remit. This is warranted due to the previously explained variability between males and females, thus by solely mixed studies being the point of reference, important nuance regarding female athletes may not be being observed.

2.11. Athlete-specific considerations for sleep

Athletes face a unique set of lifestyle stressors which may negatively contribute to sleep issues and the prevalence of poor sleep habits amongst athletes has been reported to be high (Walsh et al., 2021). Whilst sleep disruption may not always be of multiple hours on a daily basis, it can certainly be observed that many athletes are habitually below suggested optimal markers for many components of sleep (Sargent et al., 2021; Walsh et al., 2021), with issues being magnified post-competition (O'Donnell et al., 2018). Factors which may affect athletes' sleep include muscle soreness, injury, circadian disruption (jetlag), competition arousal or psychological stress. This combination of lifestyle factors and stressors is commonly characterised by habitually short sleep durations (Sargent et al., 2021), self-reported dissatisfaction with sleep (Rodriguez et al., 2015), increased sleep latency (Caia et al., 2018) and high incidences of daytime fatigue (Sargent et al., 2014). Specific to the considerations of soreness and injury, pain has been reported as being a factor which may affect sleep (Shearer et al., 2015), with nocturnal pain associated with poor sleep quality (Bleyer et al., 2015). Pro-inflammatory cytokines post-match or training may affect both sleep regulation and sleep architecture (Vgontzsas and Zhorousos et al., 2002). Chronic sleep disturbances, in addition to restricted sleep opportunities, may be contributing to increased daytime fatigue and performance deficits (Gupta et al., 2017). Leeder et al. (2012) compared sleep indices of Olympic athletes to non-athletes and reported shorter sleep duration and worse sleep quality for athletes compared with age and sex-matched controls. Additionally, empirical evidence indicates clinical sleep problems may also be common amongst elite athletes, with a systematic review demonstrating a high prevalence of insomnia symptoms within this cohort (Gupta et al., 2017).

Psychological stress, particularly during pre-competition periods, has also been highlighted as a key cause of sleep disruption for athletes (Pradzynka et al., 2023). There is a significant body of research demonstrating excessive stress and anxiety to negatively affect sleep (Pires et al., 2016). The role of competition stress must be considered when reviewing athletes' sleep (Halson, 2019), whilst a holistic approach is advocated to support psychological wellbeing (Saw et al., 2016), thus supporting sleep status. In a survey of 283 elite athletes, 64% indicated they had worse sleep than normal pre-competition (Juliff et al., 2015). Furthermore, the most reported issues impacting sleep factors within that cohort were those of increased latency (82.1%), underpinned by "thoughts about the competition" (83.5%), and nervousness (43.8%). Given the regularity of competition many athletes face, proactively addressing this via psychological support, with a view to potential mitigation of these factors appears prudent, particularly in sports such as football, where weekly competition is common throughout the season. Halson (2019) also noted the need to appreciate other areas of potential stress for athletes, and the need for a holistic view across the athlete's lifestyle when aiming to improve sleep factors.

Many athletes routinely tolerate training and competition schedules which are not conducive to supporting healthy sleep habits, whilst amongst elite athletes, the addition of travel requirements can often provide an additional stressor (Halson, 2019). The timing of training and competitions are often factors which are not within direct control yet can significantly negatively affect overall sleep. Sargent and Roach (2016) reported late night games in team sports resulted in shorter sleep durations and later sleep onset. The use of caffeine both pre- and within matches and competitions are widely reported within elite athlete cohorts (Dunican et al., 2018), thus education around the potential negative effects of this strategy, the dosage and implementation of down-regulation strategies post-match must be considered. Furthermore, building on evidence presented in section **2.5: Factors affecting sleep**, it has been highlighted that light exposure from evening training or competing could be enough to stimulate wakefulness (Cajochen, 2007), which when considered in combination with potential evening screen use, may cause significantly disruption to athletes sleep (Costa et al., 2022).

2.12. Female athlete sleep

There is overwhelming evidence that more research is needed into the sleep of female athletes. In a recent systematic review, Craven et al. (2022) evaluated 77 studies to assess the effects of acute sleep loss on physical performance; within that review, 89% of participants were male, demonstrating the gender gap across this area of research. Similarly, Gwyther et al. (2022) conducted a systematic review examining sleep interventions for performance and noted underrepresentation of female athletes, with male representation four times as high. Similarly, Power et al., (2023) highlighted the fact that female athletes are underrepresented in sleep studies focused on athlete participants, with female athletes accounting for only 24.7%

of all participants in reviewed sleep studies. This is a problem identified across published literature which many authors suggest requires immediate improvement (Walsh et al., 2021, Power et al.,2024). The additional complexities around the use of female participants, specifically the integration of a consideration of menstrual cycle factors, could be one such factor that prevents some researchers from working within this cohort, whilst undoubtedly as considered in **Chapter 1, Introduction**, funding, and athlete availability may also be limitations.

Female athletes have been shown to have a worse sleep status than male counterparts, reporting a variety of negatively impacted sleep indices compared to males (Leeder et al., 2012). Differences in males and females sleep is perhaps expected, given the physiological and psychological differences between the sexes. With Walsh et al. (2021) citing female gender as a risk factor for sleep issues amongst athletes, further research must investigate methods of sleep improvement amongst this cohort. Cain et al. (2010) found women display a shorter circadian rhythm in terms of melatonin and temperature, two important modulators of sleep. Cain et al. (2010) found women slept at a later biological time and therefore needed higher sleep efficiency to fulfil sleep needs. This delayed biological time of sleep may be a contributing factor for this higher incidence of sleep issues amongst females and serves to demonstrate the potential use of strategies which enhance sleep indices, such as sleep hygiene education. Therefore, female athletes may be sleeping at a later biological clock time compared with male athletes following a comparable stressor (Cain et al., 2010), which may account for some of the differences in sleep variables between the sexes.

Lund et al. (2010) found sleep quality was worse for female students compared to males, and Cheng et al. (2018) concurred with these results: both studies used large sample groups of over 1000 participants, although both were sampling non-athletic populations. Kawasaki et al. (2020) found females athletes were more likely to have poor sleep quality and score significantly lower on the Epworth Sleepiness Scale compared to male athletes. Logically, Kawasaki et al. (2020) also demonstrated that those with poor sleep quality were more likely to have lower sleep efficiency. The researchers identified the following factors as being associated with poor sleep quality in female athletes: lower sleep efficiency, habitual drinking, disruption by noise and menstruation. This study is key in presenting the variety of issues which could be underpinning a self-reported score, supporting the notion that sleep quality is a multifactorial construct, and suggesting the need for further individualised discussions to follow from this basic self-reported indicator.

In one of the few studies to directly compare male versus female athlete sleep characteristics, Leeder et al. (2012) reported sleep duration of male athletes was 54 minutes longer than that of female athletes, as determined by actigraphy. However, Carter et al. (2020) presenting conflicting results when making comparisons of male vs female collegiate athletes sleep, with results showing male collegiate athletes presenting a worse sleep efficiency and longer sleep latency compared to female collegiate athletes, as measured by actigraphy. Carter et al. (2020) only monitored sleep for 3 days, which is a limitation of the generalisability of these findings, nevertheless, may suggest nuance in sleep differences between the sexes across both age and situational environments. Halson et al. (2022) stated female athletes experience longer sleep latencies than male athletes, with the consideration that difficulties in initiating sleep may be concurrent with increased psychological stress (Halson et al., 2021). Furthermore, discrepancies may exist between subjective and objective sleep quality of female athletes (Kawasaki et al., 2024), which may direct the need for objective monitoring where possible.

2.12.1. The menstrual cycle

The female menstrual cycle (MC) has been suggested as one of the causative factors in poor sleep indices, notably sleep quality (Kawasaki et al., 2020) and sleep duration (Baker and Lee, 2022). The MC involves a fluctuation of hormone production and secretion, repeating monthly, which is subject to large inter and intra individual variation (Elliot-Sale et al., 2020). It has been hypothesised this may be one such causative factor to the differences noted between male and female sleep. Considering an average 28-day cycle, the MC can be broken down into different stages: follicular (day 1-14), ovulation (day 14) and luteal (14-28) (Vrublevskiy and Kozhedub, 2018; Thyagarajan et al., 2018). Menstruation occurs from day 1 of the cycle and generally lasts between 3-7 days (Smith, 2018). Each phase of the MC has vastly different hormonal profiles. During early follicular phase, oestrogen and progesterone are both low; late follicular phase can be characterised by the highest oestrogen peak; during ovulation, oestrogen is generally at a medium level with progesterone remaining low; and mid-luteal phase is characterised by high oestrogen and progesterone (**Figure 2.3**) (Elliot-Sale et al., 2020).

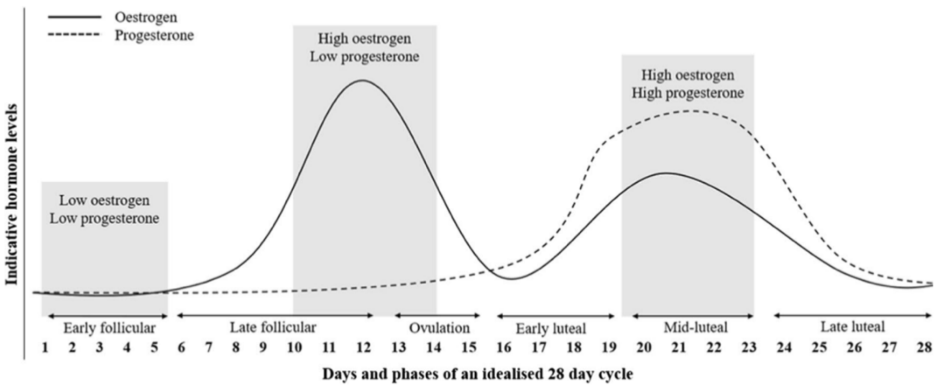

Figure 2.3: Hormonal fluctuations throughout a 28-day menstrual cycle. (McNulty et al.,2020).

An additional temperature rhythm is present as a function of menstrual phase. Progesterone, a thermogenic hormone, causes changes in basal body temperature, which demonstrates a biphasic curve across the MC (Maijala et al., 2019). Basal body temperature rises post-ovulation and generally remains high throughout the luteal phase, with increases suggested to be as little as 0.2-0.4℃ (Maijala et al., 2019) or as great as 0.5-1℃ (Steward and Raja, 2020). Body temperature rhythm amplitude decreases in the luteal phase and consequently, body temperature remains relatively higher during sleep (Hamanishi et al., 2019). With body temperature a key modulator of sleep initiation, this rise in body temperature during the luteal phase has the potential to affect sleep latency and sleep quality (Kawasaki et al., 2024). Indeed, research has demonstrated a blunting of the nocturnal decline in body temperature during the luteal phase compared to the follicular phase (Shibui et al., 2000).

The consensus around how sleep is affected by the MC presents mixed views, most likely due to the level of intra and inter individual variation of the MC. Early work by Driver et al. (1996) found objective sleep data was unchanged throughout the MC, except for REM sleep percentage, which was greater in the follicular stage compared to late luteal. Baker and Driver (2004) reported self-perceived sleep quality was worse during menstruation, however, with the exception of a non-significant decrease in REM sleep during the luteal phase, the timing and composition of sleep remained relatively stable across the menstrual cycle. This is suggestive of a potential disconnect between subjective and objective sleep factors during menstruation. Shorter sleep durations have been reported around ovulation (Michels et al., 2020), yet evidence of unchanged sleep timings across the entire monthly cycle also exists (Laessle et al. 1990). The level of hormonal fluctuations can significantly affect the sleep of some athletes, whilst others do not notice a perceptible difference (Hrozonova et al., 2021). Kawasaki et al. (2024) suggested 28.9% of naturally menstruating female athletes (reporting a MC of 21-35 days) report poor sleep quality, with previous evidence suggesting this percentage to be much higher amongst athletes with an irregular MC (Kawasaki et al., 2020). When poor sleep quality was subjectively reported, Kawasaki et al. (2024) demonstrated objective changes in core temperature consequently affected arousal levels, leading to increased sleep disturbances. It is evident that the influence of the MC on sleep parameters is unclear and is likely to be specific to each individual.

The effects of the MC on melatonin secretion are also conflicting. When comparing the luteal phase to the follicular phase, there are reports of increased melatonin secretion, decreased melatonin secretion and no change (Mamber and Bootzin, 1997; Baker and Driver, 2007; Shibui et al., 2000), again, suggesting high degrees of individual variation within this parameter. The measurement of melatonin secretion during the MC presents many challenges, the primary challenge being controlling for light exposure in order to isolate the effects of MC. Controlling for light using routine modification and limiting light exposure to <88 lux, Wright and Badia (1999) found no significant differences in nocturnal melatonin secretion between women in the follicular phase and women in the luteal phase. Similarly, Shibui et al. (2000) controlled for light exposure and found no significant difference in melatonin rhythm between the follicular and luteal phases, however they did demonstrate reduced melatonin concentration in the luteal phase. Both the aforementioned studies used small sample sizes (8-9 subjects in each group), thus are potentially underpowered and require further investigation. In the absence of support for altered melatonin secretion in the luteal phase, it could be suggested that temperature changes may be the primary physiological focus for MC based sleep disruption of female athletes.

2.12.2. Hormonal contraceptives

Hormonal contraceptives (HC) are exogenous steroid hormones which inhibit ovulation and are used to prevent unwanted pregnancy, treat dysmenorrhea or other hormone-related health issues, such as acne (Martin et al., 2018). Hormonal contraceptives can be administered orally, via injection, implant, or transdermal patch. Athletes taking HC present a different hormone profile across a month compared to those with a natural MC. Martin et al. (2018) surveyed 430 elite female athletes and found 49.5% were using hormonal contraceptives. From a research perspective, this presents additional complexities for researchers, with issues previously mentioned in **Chapter 1, Introduction**, prevalent, alongside the potential variation induced by different types of HC. When considering the MC as a primary variable, the number of potential participants taking a variety of HC has the potential to shrink the pool of available participants, increasing the complexities of conducting research with female athletes.

Combined contraceptives (oestrogen and progesterone) were most widely used (68.1%) with progesterone-only contraceptives accounting for 30.0% (Martin et al., 2018). A study of Australian elite female athletes presents a similar picture, demonstrating 47.1% of athletes surveyed to be using hormonal contraceptives (Larson et al., 2020). Guida et al. (2020) was the first study of its kind to investigate the use of HC on sleep indices. They investigated the association between hormonal contraceptive type, administration route and sleep quality and duration across 31 days. Results demonstrated that women using a progesterone-only oral contraceptive, had the longest sleep duration and improved sleep quality, compared to combination pills and contraceptives with alternative administration routes, and controls. These results seem logical given that high doses of progesterone (>300mg) are commonly used to re-establish normal sleep timings in post-menopausal women with sleep disturbance (Caufriez et al., 2011). Women taking hormonal contraceptives demonstrate a significantly different hormonal profile than naturally menstruating women, yet very few sleep studies report this parameter, which could be key in the interpretation of results or in the replicability of the study. Elliot-Sale et al. (2021) stated when a study is not directly examining the effects of MC on an outcome, a description of the population is solely sufficient, yet many published studies lack this clarity in presentation of the sample population.

2.13. Interventions to optimise sleep

Understanding the potential of different sleep interventions to improve sleep is of value to coaches and practitioners aiming to address sub-optimal sleep amongst athletes, from a perspective of enhancing physical performance, overall health and athlete wellbeing. Bonnar et al. (2018) explored the association between sleep interventions and performance in elite athletes, concluding that improving sleep was the most beneficial strategy for improving performance compared with other interventions such as post-exercise recovery strategies.

2.13.1. Sleep Extension

Sleep extension can be described as an increase in habitual total sleep time, either from nocturnal sleep or via the addition of daytime naps (Silva et al., 2021). Daytime napping can be an effective way to offset partial sleep deprivation (Reilly, 2009), with a systematic review concluding a 30-60 min nap post-lunch was highly beneficial on physical performance, and producing a moderate improvement in reported fatigue and cognitive performance (Mesas et al., 2023). Evidence suggests a minimum of 60 min is required post-nap to avoid sleep inertia (Mesas et al., 2023).

Nocturnal sleep extension can be done by a variety of methods, such as setting rigid times which participants must spend in bed, with the aim of habitually adjusting sleep time, the addition of napping to serve as "top ups" to night-time sleep, or via sleep hygiene interventions. Mah et al. (2011) implemented a sleep extension intervention, by setting collegiate basketball players a target of 10 h in bed per night. They found that increasing sleep durations resulted in significantly improved sprint times (16.2 ± 0.61 sec at baseline vs. 15.5 ± 0.54 sec at end of sleep extension), shooting accuracy (free throw percentage increasing by 9%), reaction time (decreased psychomotor vigilance task scores) and enhanced self-perceived mental wellbeing. Supporting this finding, a study carried out in collegiate tennis, indicated increasing nightly sleep durations improved serving accuracy by 17% (Schwartz et al., 2015). This suggests optimising sleep can help to improve objective markers of sports performance, and thus education around methods of optimising sleep could be of value.

Roberts et al. (2019) used a counterbalanced crossover design, over 7 days of data collection, to assess differences in endurance performance between three groups: one group who maintained their normal sleep patterns throughout, one group who reduced their sleep by 30% from baseline values, one group who aimed to extend their sleep by 30% from baseline values. Compared to the normal sleep group, endurance time trials on all testing days were slower in the sleep reduction group. Sleep extension for 3 nights led to better maintenance of endurance performance compared to normal and restricted sleep groups, leading to the conclusions that cumulative sleep time affects performance at a given exercise intensity. In the absence of testing for physiological markers of fatigue, it was hypothesised this performance reduction was due to the alteration of RPE. Although there is a lack of substantial evidence to support these conclusions, this study is of value in providing recommendations for the use of sleep extension to improve performance, demonstrating a 3-day adjustment was necessary to produce an improvement in performance. This is also worthy of consideration in the preparation for performance peaks for key sporting events.

Whilst the above studies demonstrate methods of sleep extension via the dictation of time in bed over a short-term period, the absence of longitudinal studies in this remit presents doubt over whether this technique could be maintained over the course of longer periods of time. Furthermore, this technique fails to offer any sort of education to the athlete about the development of positive, sustainable habits, which have the potential to aid longevity and overall wellbeing.

2.13.2. Sleep Hygiene

Sleep hygiene (SH) education involves the promotion of habits that facilitate sleep, and suggested avoidance of behaviours that inhibit sleep (Mastin et al., 2006). It is a simple, non-invasive, low-cost strategy which can be used to enhance both sleep quality and quantity of athletes. Sleep hygiene has been cited as an integral factor in the promotion of healthy sleep habits (Mastin et al., 2006) and improving the SH of athletes can also result in increased sleep duration, efficiency, and latency (Caia et al., 2018; O’Donnell et al., 2018). Therefore, the use of SH interventions within an athlete population is becoming recognised as an important part of an overall training programme, with the aim of reducing sleep deficit and preventing chronic sleep deprivation. Key aspects of SH education include but is not limited to, education around the impact of evening light exposure (Bender et al., 2024), maintaining regular sleep timings (Phillips et al.,2017), reducing technology use in the evening from the perspective of both light reduction and psychological stimulation (Ellithorpe et al., 2022; Fullagar et al., 2016), reducing caffeine consumption (Drake et al., 2013), and maintaining a cool, dark and quiet bedroom environment (Caddick et al., 2013).

Central to the benefit of SH interventions compared to sleep extension delivered via set timings, is the distinction between self-determined and controlled motivations from a coaching perspective (Bartholomew et al., 2009). Self-determined motivations are to act with a sense of volition and choice, with behaviours endorsed by the individual (Ryan and Deci, 2002). This commonly results in more persistence and effort in continued engagement with the specific behaviours, whilst additionally increases in self-esteem are evident with this practice (Bartholomew et al., 2009). From a SH perspective, this could be hugely beneficial in the maintenance of the strategy and the development of positive lifestyle habits. In contrast, controlled behaviours, such as giving rigid sleep timings to stick to, reflect a lack of personal endorsement or engagement in the process (Ryan and Deci, 2000), and is suggestive of a more dictatorial approach.

Miles et al. (2019) surveyed 86 Australian sport coaches and sports science staff, all of whom worked in a high-performance environment, and found only 43% had promoted SH to their athletes. The 57% of coaches who had never used SH education with their athletes stated this was due to lack of knowledge and a lack of resources. This serves to highlight the potential gap in the working practices of sport coaches and the need for educational resources around sleep hygiene to be easily available to coaches. Bonnar et al. (2018) stated identifying and addressing poor sleep amongst athletes is a key clinical and research concern, with potential impacts on athlete performance, recovery, and long-term wellbeing (Bolinger et al., 2010; Halson, 2013). A summary of sleep hygiene studies aiming to affect sleep parameters for athletes is detailed in **Table 2.2** below.

Table 2.2: A summary of sleep hygiene studies demonstrating protocol and results of the intervention.

Study	**Participants**	**Experimental Design**	**Protocol**	**Main findings**
Fullagar et al. (2016)	20 male semi-professional footballers	Crossover study	3-day baseline sleep measurements. Group SH delivery post-match or normal post-match routine. One week washout between conditions. Sleep monitoring for two nights post-match.	Significant increase in sleep duration for SH intervention post-match. No difference in sleep quality
Harada et al. (2016)	84 male footballers	Single group pre-post design	SH leaflet of 8 recommendations, with one month of suggested intervention.	Sleep quality significantly increased, and irritation decreased post intervention. Football performance

				showed initial improvement post intervention.
O'Donnell and Driller (2017)	26 elite female netballers	Single group pre-post design	One week baseline sleep monitoring. 1 hour SH presentation to all. One week post intervention sleep monitoring	Significant increase in sleep duration and wake variance
Van Ryswyk et al. (2017)	25 male Australian rules football	Single group pre-post design	2 x 1 hour SH group sessions and individual progress updates	Significantly improved sleep efficiency. Mood improvements observed for fatigue and vigour.
Caia et al. (2018)	24 male rugby league players	Median split	2-week baseline sleep monitoring. 2 x 30 min SH sessions. 2 weeks post intervention sleep monitoring. 1 month follow up.	Significant increase in sleep duration and earlier bedtime. All sleep variables comparable to

				baselines in 1 month follow up.
Driller et al. (2019)	9 elite male cricketers	Single group pre-post design	3-week baseline sleep monitoring. 50 min group SH session and 30 min individual session. 3-week sleep monitoring post intervention	Sleep quality, sleep latency and sleep efficiency all significantly improved post SH education.
Vitale et al. (2019)	29 recreational male footballers	Randomised controlled trial	One night sleep baseline. Experimental group – 45 min group SH session post-match. 2 nights follow up post intervention.	Sleep latency and sleep quality post-match significantly increased when receiving acute SH intervention.
Jenkins et al. (2021)	14 male rugby union players	Single group pre-post design	3-week baseline. 30 min SH education presentation to all. Sleep monitoring for 3 weeks post, plus final follow up 2 weeks later.	No significant changes in any sleep variables throughout 8 weeks.

Edinborough et al. (2023)	1 Professional footballer	Case study	7 days baseline. Individualised SH provided based on baseline data. 8 days post-intervention monitoring.	Number of wakings per night improved post SH intervention. Improved subjective scores on Pittsburgh Sleep Quality Index and Epsworth Sleepiness Scale
Dunican et al. (2023)	24 masters swimming athletes (n = 13 female)	Prospective pre-post design	42 days baseline. 2-hour SH group presentation, with 30 min questions in group setting. 42 days monitoring post-intervention	No significant improvements in any measures of sleep post-intervention.

To the authors knowledge, only two studies have suggested SH interventions to have no impact on sleep indices. Jenkins et al. (2021) implemented a 30-min SH presentation to elite male rugby players mid-season which failed to improve sleep indices (**Table 2.2**) The authors attributed their non-significant findings to the fact that the competitive season has potentially greater stress and distraction than pre-season, and subsequently suggested that sleep hygiene education should be carried out in off-season or pre-season, to maximise the potential for changing sleep behaviours. Similarly, Dunican et al. (2023) implemented a 2-hour sleep education session with 30 minutes questions and found this to be insufficient to create significant changes to sleep indices (**Table 2.2**). The authors attributed this to the fact that the mean sleep duration of participants pre-intervention was already close to optimal recommendations, potentially suggesting a ceiling effect for improvements towards sleep duration and sleep efficiency. Additionally, it is interesting to note the two studies presenting unsuccessful SH interventions, delivered the intervention in a group-based presentation, perhaps suggesting this may not be the optimal method of delivering this information, and neither study presented any consideration regarding the potential impact of individual delivering the SH session. Dunican et al. (2023) stated “The sleep education session was provided by an expert (PhD) qualified in sleep and performance in athletes”, whilst Jenkins et al. (2021) stated “The SH intervention was delivered by the lead researcher”. Both descriptions failed to detail the level of familiarity of the educator to the participant group, or additional compounding factors such as cultural literacy, professional identity, or the proximity to either insider or outsider research spectrum (Burns et al., 2012; Dwyer and Buckle, 2009), key considerations why may have contributed to the lack of success of the intervention.

The effects of SH education have sometimes been described as transient, with sleep improvements seemingly dissipating post-intervention. Indeed, sleep improvements demonstrated by Caia et al. (2018), were not maintained one month post sleep hygiene education. Short term improvements were also found by Vitale et al. (2019), who found sleep hygiene education to be useful to reduce sleep onset latency and increase sleep duration following a late-night football match, but these sleep improvements were not maintained two nights following the education. Further research is needed into how these acute improvements can be maintained. For the implementation of successful behaviour change in any discipline, Sutton (2011) suggested a starting point is to identify the target behaviour, understand the psychological determinants of behaviour, with Kelly and Barker (2016) suggested simple education alone does not change habits. In the context of SH education, Halson (2019) stated that an understanding of the athletes' environment, economic circumstances and culture may help to support changes in sleep habits. This is suggestive of the need to take a holistic approach, with appreciation towards an individualised perspective, encompassing discussion around underpinning reasons behind current habits and potential barriers to initiating change.

Additionally, understanding an individuals' perspective on SH as well as gaining feedback throughout the process of attempting change should also be considered (Halson, 2019). These considerations could be suggestive of the need to further explore individualised approaches to SH education, an area which warrants further attention within the research body.

2.14. Summary

Sleep is a key recovery strategy for athletes. Athletes face a unique set of lifestyle circumstances which are often counterproductive to optimising sleep factors, and with female athletes commonly operating with greater constraints around training and competition due to funding and provision restrictions, these issues may be exacerbated. Female athletes are susceptible to short sleep durations and lower sleep quality, compared to male counterparts and non-athletic controls, and SH could be one method used to improve sleep habits. Yet despite these considerations, there is a distinct lack of research on female athletes' sleep, and further research is needed into potential strategies to investigate potential strategies of sleep improvement for female athletes. As well as potentially improving sleep, additional performance benefits may be observed via improved sleep indices. Despite growing interest around the topic of SH education, there is a lack of literature on the optimal means of delivering successful SH education. **Table 2.2** presents different methods of SH education in recent studies, where a range of methods of intervention can be observed. Yet with successful interventions evident across different practices (i.e., different durations of educational intervention, different methods of educational intervention) it is unclear what should be considered best practice within this remit and is suggestive of the need for further research in this area. With consideration to available literature, direction of future research, and identified gaps in the literature, the overall aims of this thesis were firstly to identify factors to inform the monitoring process of female athlete sleep, and secondly, to investigate the impact of different approaches to SH education methods, and whether improved sleep can affect physical performance variables.

3. GENERAL METHODS

This chapter describes the common methods used throughout the four studies of this PhD thesis. Where experimental chapters used additional methodologies, appropriate descriptions of procedure can be found detailed within the methods section of each study, furthermore, nuance around experimental procedure is also detailed within each study chapter.

3.1. Health and Safety

All experimental studies were conducted at the training ground of a professional football club, prior to which, the Club's health and safety operating procedures and risk assessments of the site were reviewed by the researcher. This was a requirement from the club, and all testing procedures were always conducted with consideration of these. Risk assessments for all internal training spaces to be used, were viewed by the researcher prior to commencing, to ensure clarity of operational procedures and awareness of best practice in terms of risk minimisation.

3.2. Ethics and Informed Consent

Each study was approved by the University of Brighton Ethics Committee in accordance with the principles of the revised Declaration of Helsinki 1964 (revised 2013). An ethical application was submitted for each study to the Brighton Research Ethics Application Manager (BREAM), which was then reviewed by the Life, Health, and Physical Sciences Cross-School Research Ethics Committee (CREC) at the University of Brighton. Participants were given information sheets detailing the study design, requirements, risks, and benefits, and were informed they could withdraw at any time without providing explanation, incurring any negative feedback or penalties. Written informed consent was given by each participant prior to study commencement, and additionally by parent or guardian in cases where participants were under the age of 18 (**Study 1**).

3.3. Data Protection and Confidentiality

All research was conducted in accordance with the Data Protection Act (2018). Data was collected and stored confidentially and anonymously under a numerical code for each participant, on a password-protected computer, on the University of Brighton OneDrive, which has dual authentication. All collected data will remain securely stored on a password protected computer, for a period of 10 years, upon which point they will be safely disposed of.

3.4. Participants

Volunteering participants were aged 14-34 years, with each study chapter detailing the recruited cohort who had met the specific inclusion/exclusion criteria for each study. As the information from this thesis is aiming to be used to further the understanding of female athletes' sleep, solely female athletes were recruited to take part in the study, with "female" being defined as biological sex. Participants were recruited from posters sent to the researchers' professional network, asking for expressions of interest to take part in research. Following initial expressions of interest, emails were sent to prospective participants providing a participant information sheet, which included researcher contact details and details of inclusion and exclusion criteria for taking part. Participants interested in volunteering were encouraged to contact the researcher should they require further clarification of any procedures or statements in the given literature. Participation was unfortunately declined if the participant did not give informed consent or answered yes to any of the exclusion criteria. Any athletes who were part of a squad, who chose not to take part, did not incur any penalties or negative consequences for choosing not to partake.

3.5. Inclusion and Exclusion criteria

All participants were female athletes, competing at a minimum of national level in their sport, and across all studies, were categorised as Tier 3, 4 and 5, according to the proposed framework from McKay et al. (2022) (Tier 3: National level, Tier 4: International level, Tier 5: World Class). Given that all participants were biologically female, considering menstrual cycle (MC) status was relevant in the interest of increasing internal validity and reducing inter-study variability by accurately describing the participant population. Inclusion criteria required participants to have a MC of 21-35 days, which categorised them as naturally menstruating women (without confirmed ovulation); this approach aimed to homogenise participants as much as possible and minimise MC-related physiological variance affecting results. The methodological considerations for working with female participants are vast, yet because of the complexity around the variance of each woman's MC, plus considering the changes that occur with age, there may never be a universal blueprint for the considerations required within female specific research (Elliot-Sale et al., 2021). Elliot-Sale et al. (2021) stated that if a study is not directly examining the effects of the MC/phase on an outcome, a description of the population is sufficient. Additionally, it was reported whether participants were taking oral contraceptives, complying with the methodological guidelines stated by Elliot-Sale et al. (2021) in accurate reporting of participant population. It was hoped that by reporting this factor, additional clarity would be gained by readers in respect of replicability and reducing inter-study variability. Sleep studies in non-athletic populations routinely report menstrual cycle phase, yet in a recent systematic review of 38 studies (Miles et al., 2022), only a single study (Schaal et al., 2015), reported for MC descriptors.

Furthermore, it has been reported that changes in sleep quality in the luteal phase are more pronounced in those with extreme premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD); two disorders in which social and behavioural dysfunction occurs due to physical or psychological symptoms during the luteal phase, with PMDD being characterised by additional severe psychiatric symptoms (Hamanishi et al., 2019). It is for this reason that clinical premenstrual syndromes were stated as an exclusion criterion for studies within this thesis. Indication of a pre-existing sleep disorder was an exclusion criterion for participants throughout all studies. For **Studies 2, 3 and 4**, this was assessed as part of routine medical screening from their football club. For **Study 1**, this was self-assessed. If participants felt unsure if they met this exclusion or not, this was indicated by asking a participant to complete a Pittsburgh Sleep Quality Index questionnaire, from which a score of >5 should be considered indicative of a sleep disorder (Buysse, 1989).

Any participant reporting a substantial injury (defined as "a moderate to severe reduction in performance or the inability to participate in any sport (Van Rosen, 2018)), were excluded due to the previously evidenced reciprocal connection between sleep and inflammation (Irwin, 2009). Participants were removed from the study if such as injury occurred during the testing period.

3.6. Researchers

For studies involving physical testing procedures (**Study 3**), two researchers were always present during the testing period, and a trained first aider was also on site. This study was conducted within the first team gym, at the training ground of a professional football club, which has its own risk assessment and health and safety protocols for this space.

3.7. Experimental Procedures

3.7.1. Qualitative measures

All studies within this thesis have utilised qualitative and quantitative research methods. The below information details the reliability, validity and general information on pre-existing questionnaires which were used across all studies.

3.7.2. Considerations for questionnaire data

The sensitivity of the questionnaire tool must be considered, specifically with regards to data interpretation from both the researcher and participant (de Jong et al., 2018). All questionnaires used within this thesis were administered to participants via Microsoft Forms, a GDPR compliant method of obtaining such data. Below highlights two key considerations for the interpretation of questionnaire data, which were observed within all studies.

3.7.3. Insufficient error responding

Insufficient Error Responding (IER) is defined as a situation where responses are provided by participants with low or little motivation to comply with survey instructions, interpret item contents or to provide accurate responses (Huang et al., 2012). Huang et al. (2012) highlighted the importance of looking at average response times in comparison to individual response times, and whilst undoubtedly individual time variations will occur, any response time which is vastly shorter and likely an outlier, should indicate the data from that participant should be removed as is highly indicative of IER. Huang et al. (2015) suggested IER can inflate the strength of observed relationships by increasing common method variance, thus increasing the risk of Type I error. Average and individual response times were directly reported for each questionnaire, via Microsoft Forms (individual response times available via data extraction to Excel).

3.7.4. Questionnaire duration

In general, the longer the questionnaire tool, the greater potential for participant disengagement and/or fatigue, resulting in IER or incomplete response (Braun et al., 2020). Braun et al. (2020) highlighted the importance of piloting questionnaire-based tools to ensure clarity, and useability of the tool if online. The ability to complete questionnaire-based data on any device is also key in maximising response rates (Braun et al., 2020). Nguyen (2017) suggesting long questionnaires negatively impact data quality and potentially decrease internal reliability and subsequently, suggested shorter questionnaires to be more favourable. All these points were considered in the selection of qualitative tools used across studies, with pre-existing validated questionnaires used, and where possible, reduced questionnaires (pre-validated) of the original design.

3.7.5. Reduced morningness:eveningness questionnaire (rMEQ)

The rMEQ (Adan and Almirall, 1991) adapted the original 19-point morningness: eveningness questionnaire (MEQ) (Horne and Ostberg, 1976, detailed in **Section 2.4**) down to 5 questions, utilising questions 1, 7, 10, 18 and 19 from the original scale, which had been criticised for both length and complexity (Natale et al., 2006). Total scores of the rMEQ range from 4-26, with the answer to each question given a numerical value which is then summed to provide a total score. The rMEQ classifications were indicated as follows (Adan and Almirall, 1991): 22-25 - definitely morning type; 18-21 - moderate morning type; 12-17 - neither type; 8-11 - moderate evening type; 4-7 definite evening type, with some studies choosing to group rMEQ scores into broader interpreted categories of morning type, neither type or evening type (Danielsson et al, 2018). Adan and Almirall (1991) originally validated this new reduced scale by comparing scoring categorisation and individual item scores from the rMEQ to the MEQ (n = 908, n =578 females, mean age 24.8 ± 6.37 years). The correlation between item scores using both questionnaires was reported as $r = 0.898$, $p<0.0001$, with sensitivity of categorisation reported as 78%. Using sub-analyses on sex, the authors reported rMEQ scores to be independent of sex. Since the original validation, supporting evidence concurs with the original validations, suggesting the rMEQ to have good correlation to the MEQ (0.87-0.90, Milia et al., 2013), excellent test-retest reliability ($r = 0.71$, Young, 2018) and good internal consistency (Cronbach's α =0.68) (Danielsson et al., 2018). The conciseness and psychometric properties of this scale mean it is widely used across sleep research, including within athletic populations (Danielsson et al., 2018; Hoshikawa et al., 2021).

3.7.6. Sleep Hygiene Index

The Sleep Hygiene Index (SHI) (Mastin et al., 2006), is a 13-item self-report measure used to assess the practice of sleep hygiene behaviours. Each item is rated on a five-point scale ranging from 0 (never) to 4 (always). Total scores range from 0 to 52, with a higher score representative of poorer sleep hygiene. In the development of the tool, Mastin et al. (2006) selected questionnaire items based on the diagnostic criteria by the International Classification of Sleep Disorders for poor sleep hygiene (American Sleep Disorders Association, 1990). The authors attempted to validate the SHI (n = 632, n = 404 females, mean age 22.7 (SD not reported)) via correlation to previously validated tools, namely the Epsworth Sleepiness Scale and Pittsburgh Sleep Quality Index. Results indicated a positive correlation with the Epsworth Sleepiness Scale ($r = 0.24$, $p < 0.01$) and the Pittsburgh Sleep Quality Index ($r = 0.48$, $p < 0.01$), whilst the SHI was also having good test-retest reliability ($r = 0.71$, Mastin et al., 2006). Mastin et al. (2006) noted the SHI to be a much shorter instrument for monitoring sleep factors than previously reported, a factor which was considered in the development of study methods within this thesis. Since the original validation of the tool, the SHI has been validated for use in athletic populations, with Knufinke et al. (2018) demonstrating positive correlations of SHI scores to sleep quality in athletes ($r=0.50$, $p < 0.001$), with the authors concluding this may be a useful tool to monitor sleep hygiene factors of athletes.

For questionnaire analysis, results from SHI can be grouped into 6 broad categories; regularity (questionnaire item 2, 3, 5), environment (items 10, 11) psychological strain (items 8, 13), active behaviours (items 4, 7, 9, 12), naps (item 1), and substance use (item 6) (Storfer-Issar et al., 2013, Knufinke et al., 2018). The SHI is widely used across the body of sleep research (Knufinke et al., 2018, Zagaria et al., 2021).

3.7.7. Athlete Sleep Behaviour Questionnaire (ASBQ)

Developed by Driller et al. (2018), the Athlete Sleep Behaviour Questionnaire (ASBQ) aimed to build on pre-existing questionnaires whilst expanding on the unique challenges faced by athletes around sleep practices. Whilst other questionnaires may be appropriate for general or clinical use, Driller et al. (2018) suggested previous tools may lack the specific questions tailored towards sleep challenges faced by athletes. The ASBQ asks participants to provide a Likert scale rating on how frequently they engage with specific behaviours (never - 1, rarely - 2, sometimes - 3, frequently - 4, always - 5), with scores summed to give a global ASBQ score. Higher scores are indicative of worse sleep habits and sleep hygiene. The authors suggested interpretation of global scores as follows: ≤ 36 should indicate good sleep behaviours; this would represent a mean response of "rarely" for most questions, whilst global scores ≥42 suggest poor sleep behaviours; with this necessitating one or more responses of "always", "frequently" or "sometimes".

Significant differences were observed between athletes and non-athletes in ASBQ global scores (43.5 and 40.6 respectively, $p<0.01$, $d=0.47$) (Driller et al., 2018), with the development of the tool utilising athletes and non-athlete participants (n=282 men, n=282 female) across 9 countries including England. The ASBQ has previously been validated against actigraphy, with a moderate relationship shown between total sleep time and sleep quality ($r = -0.42, -0.39$ respectively) (Driller et al., 2018); furthermore, the tool has acceptable reliability (ICC=0.87) (Driller et al., 2018). Internal consistency of the ASBQ was shown to be moderate (Cronbach's $\alpha = 0.63$) (Driller et al. 2018), with the authors acknowledging this is below the usually accepted threshold of 0.70. However, given this is a measure of internal consistency for the relationship between ASBQ items, this was not the aim of the practical tool being developed. Indeed, the ASBQ was intentionally designed to measure different aspects of sleep behaviour, and therefore, was not critical that all items on the questionnaire are related. No differences were observed between male/female responses (Driller et al., 2018). It was concluded this to be a useful tool for identifying maladaptive sleep practices among elite athletes and is widely used within sleep research (Biggins et al., 2019; Driller et al., 2022).

3.8. Quantitative measures

3.8.1. Actigraphy

Actigraphy is a method of determining sleep-wake cycles based on movement parameters. Although polysomnography (PSG) is considered the gold standard in sleep monitoring (Van de Water et al., 2011) as it detects sleep via brain wave activity rather than motion, the practicalities of using this lab-based method is challenging due to time, expense and enforced disturbance of usual sleep routines (Halson, 2013, Fekedulegn et al., 2020). Therefore, a more common method for the monitoring of athletes' sleep is to use actigraphy devices; small digital devices worn continuously on the wrist for a defined time period (usually days or weeks). One of the primary benefits of actigraphy-based sleep monitoring is that data can be collected over multiple nights in the participants' usual sleep environment, which has been demonstrated to provide more reliable estimates of sleep compared to one of two nights in a sleep laboratory (Blackwell et al., 2008; Rupp and Balkin, 2011), as well as giving the data high ecological validity. Actigraphy has been validated against PSG in multiple populations (Sadeh et al., 1994; de Souza et al., 2003; Meltzer et al., 2012) including athletes (Sargent et al., 2016).

Work within this thesis used two different actigraphy devices, GeneActiv and Actigraph GT9X, due to device availability. GeneActiv devices have previously been validated against PSG (Plekhanova et al., 2022), demonstrating good agreement for a variety of sleep indices, including duration, efficiency and latency. Plekhanova et al. (2022) used GeneActiv devices simultaneous to PSG monitoring in a healthy, adult population (n= 31, 63% female, mean age 31.5 ± 7.2 years); sensitivity to sleep detection (% of sleep epochs correctly detected by the actigraph device) for the GeneActiv devices relative to PSG was reported to be 92%, leading the authors to conclude the GeneActiv devices were appropriate for field-based measurement of sleep. Weaver et al. (2023) attempted to validate the use of Actigraph GT9X via the comparison to PSG monitoring. The authors demonstrated the devices had an accuracy (% of all PSG sleep and wake epochs correctly detected by actigraphy) of 85.5%, sensitivity of 87.4% and specificity (% of PSG wake epochs correctly identified by activity monitors) of 76.8%, leading to the conclusion that these devices were considered appropriate for field-based sleep measurement. However, it should be noted that this validation was conducted with youth participants, and a limitation of the use of these devices within this thesis may be the lack of validation specifically within an athletic population. However, although sleep metrics differ in youth to adult populations, it was deemed that the above study still provided appropriate justification for use, given the commonalities of device settings and methodological approach.

Sargent et al. (2016) used low (>20 activity counts = wake), medium (>40 activity counts = wake), and high (>80 activity counts = wake) threshold settings on Actical monitors (Philips Respironics, USA) and analysed epoch to epoch comparisons to PSG. A total of 122 nights of sleep were recorded with both techniques simultaneously, and agreement (% of all PSG sleep and wake epochs correctly detected by actigraphy), sensitivity (% of PSG sleep epochs correctly detected by activity monitors) and specificity (% of PSG wake epochs correctly identified by activity monitors) were calculated. Additionally, Cohen's Kappa was used to quantify "better than chance" agreement between the two techniques. Agreement was reported between 80.9-89.5%, with high thresholds indicating better agreement (89.5%, Cohens Kappa 0.5, moderate). Sensitivity ranged from 80.6-91.9%, with high thresholds producing higher sensitivity (91.5%, Cohens Kappa 0.5, moderate). Specificity ranged from 67.0-82.3% across all thresholds, with low thresholds indicative of greater specificity to PSG (82.3%, Cohens Kappa 0.38, fair). The authors concluded actigraphy was a valid alternative to PSG for monitoring the sleep of athletes and suggested that the use of high threshold settings produced the optimal combination of agreement, sensitivity, and specificity. There is currently no standardised protocol on the use of different threshold settings for research practitioners (Fuller et al., 2018), with many studies not reporting device settings, which may impact the replicability potential of study methods.

In contrast to some of the findings from Sargent et al. (2016), Kosmadopoulos et al. (2014) stated medium threshold produced the best sleep-wake agreement with PSG (87.7%) compared to other thresholds yet agreed with the overall conclusions from Sargent et al. (2016) in that actigraphy is a valid tool for sleep monitoring. The differences in findings for these studies may be accounted for by the different devices used and different participant groups; indeed, Sargent et al. (2016) hypothesised that the heavy training load of the participants in their study may have contributed to more movements whilst sleeping, due to muscle soreness. The consideration of the use of high thresholds must be balanced against the length of time required for monitoring, given that battery life of many actigraph devices diminishes rapidly with increased threshold monitoring.

There is currently no standardised protocol on the use of different threshold settings across research (Fuller et al., 2018) yet previous studies have used medium sleep-wake (~40Hz) thresholds, most likely due to the fact this is set as standard on the software of most devices (Lastella et al., 2015). Reporting the sampling frequency in study methods is of value in the interest of replicability, given evident differences in device outputs following manipulation of this factor (Sargent et al., 2016). Sargent et al. (2016) suggested high thresholds (~80Hz) to be most useful, whereas Fuller et al. (2018) reported medium thresholds produced the smallest mean bias compared with PSG for sleep duration, efficiency and wakes after sleep onset. The differences in findings for these studies may be partially accounted for by the different participant groups and study conditions; indeed, Sargent et al. (2016) hypothesised that the heavy training load of the subjects in their study may have contributed to more movements whilst sleeping, due to muscle soreness, thus the use of a higher activity count in determining a sleep period was of value. In the absence of clear methodological guidelines, it may be logical to adopt previously advocated approaches from studies with similar participant groups – all experimental studies within this thesis uses athlete participants, and as such, the conclusions from Sargent et al. (2016) were used as guidance, with the aim to use devices at high thresholds (80Hz).

For conversion of raw accelerometery data, device specific software was used. For GeneActiv, device specific software was used to convert raw data to BIN files, which were then run through R-Studio scripts to convert to readable outputs. For Actigraph GT9X, data were downloaded directly into device-specific software for analysis. To review data for outliers, raw data was converted to Z-scores within Excel, with scores greater than +2 or less than -2 considered as outliers (Fields, 2003). Driller et al. (2017) concluded there were no significant differences in device output (across multiple parameters) when actigraphs were worn on the dominant or non-dominant wrist. Therefore, participants across all studies were allowed individual choice for which wrist to wear the device.

3.8.2. Time of experiments

Across the research base, very few studies state the timing of data collection within the methods, with Harada et al. (2016), the only study to provide this information to the authors' knowledge. Given the potential for seasonal adjustment of sleep habits and chronotype (Allebrandt et al., 2014), the month of data collection was stated in all studies for the purposes of clarity, replication, and wider application of findings. When presenting descriptive statistics around normative values for sleep indices, this is of value in providing contextual reference to this data.

3.8.3. Pilot testing

Due to device availability, two different devices were used within this thesis, with ActiGraph GT9X (Florida, USA) used in **Study 2** and GeneActiv (Activinsights, Cambridge UK) used in **Studies 3 and 4**. Based on comparable studies in athletic cohorts, each sleep monitoring period in all studies was set at 7 days; with previous research spanning monitoring periods of 3 days (Vitale et al., 2019) to 10 days (Caia et al., 2018). Furthermore, longer testing periods were refused by technical coaches in some instances, due to player scheduling constraints. Pilot testing of actigraph devices was conducted to determine the maximum threshold setting which could be used whilst maintaining battery life of the device for the required duration of test - both devices used within this thesis ranged from 30-100Hz in sampling rate. Based on information presented in **Section 3.8.1**, higher thresholds were tested (80Hz) yet battery life within the devices did not last for the full week of testing in some of the available devices. Despite Driller et al. (2016) suggesting inter-device reliability of actigraph devices to be very high (ICC > 90), consideration of participant routine, adherence and preference of coaching staff was such that it was determined that monitoring across a continual week at a slightly lower sleep-wake threshold was preferable to switching devices mid-monitoring period. For context, comparable literature has reported using settings of 16Hz (Driller et al., 2016) up to 80Hz (Fuller et al., 2017). Actigraph GT9X devices were found to last for required testing durations if set at 60Hz; this was the highest threshold setting achievable for 7 days usage without having to change devices. Similarly, GeneActiv devices were set to 50Hz for the same rationale.

3.8.4. Baseline measures

Prior to all experimental studies, participants completed one week of baseline sleep testing to determine habitual norms. The establishment of usual sleep habits is key in the interpretation of meaningful change in response to any intervention. Comparable literature presents baseline periods as 3 days (Knufinke et al., 2018), 1 week (O'Donnell and Driller, 2017) and 2 weeks

(Caia et al., 2018). Given the time constraints presented by the football club from which participants were contracted to, and in line with previous research, all experimental studies used a baseline monitoring period of 1 week.

3.8.5. Hypothesis generation

Experimental hypotheses for each study were generated via evaluation of similar lines of research or descriptive research, as well as via the review of the overall research consensus relevant to the similar remit of each study. When a hypothesis is not stated prior to data collection and analysis, the potential for a Type I error can increase via the potential for the manipulation of statistical tests to look for any statistical significance (Bernards et al., 2017). Furthermore, Bernards et al. (2017) encouraged authors to review the practicalities of findings rather than focusing solely on statistical significance. Experimental hypotheses cannot be accepted using statistical analysis but rather statistical significance suggests support towards the experimental hypothesis (Fields, 2003). A summary of supported/unsupported hypotheses for each experimental chapter is presented within **Chapter 8, General Discussion**.

3.9. Statistical Analyses

A variety of statistical analyses were used within each study; details of which can be found within each experimental chapter. Data were analysed using a statistical package (IBM SPSS Statistics version 29) and R (R Core Team, 2022) and reported as mean ± standard deviation (SD).

3.9.1. Type I and II errors

Type I error can be considered a “false positive”, meaning the null hypothesis may be incorrectly rejected. In contrast, Type II error can be considered a “false negative”, which means the null hypothesis could be accepted incorrectly (Turner, 2022). In the context of research within this remit, this could be manifest in incorrect interventions for athletes, risking not only sub-optimal practice, but negatively affecting performance outcomes.

3.9.2. Power Analysis

Before initiating investigations, *a priori* power analysis was conducted using G*Power software (version 3.1) to establish a lower boundary sample estimate for each study. The size of the effect (mean (group 1) - mean (group 2)/SD) reported in comparable studies with a similar experimental design were used to perform the calculation for each study. This minimises the chance of Type II errors by ensuring studies are not underpowered (Lu et al., 2016). The subsequent number of participants required was based upon alpha (α=0.05) and beta (β=0.80) levels to ensure sufficient power.

3.9.3. Central tendency and variation of data

Central tendency of data is expressed as the mean (Vincent, 1994), which is calculated from the sum of the data, divided by the number of data points. It is expressed in the unit of the measure.

$$\text{Mean} = (\Sigma\ xi) / n$$

(xi is the data and n the number of data points within the analysis).

Standard deviation (SD) is used to describe the variation of each data set. One SD is provided alongside the mean to describe 68.2% of the normal distribution of the data set. SD is calculated from the square root of variance.

$$SD = \sqrt{[\Sigma\ (xi - X)\ 2 / (n - 1)]}$$

(xi is each individual data point, X is the mean of the data set, and n is the number of data points).

3.9.4. Normality and data sphericity tests

Data were tested for normality using the Shapiro-Wilk test prior to further analysis to determine the effective modelling of a normal distribution and the probability of random error preventing normal distribution (Field, 2013).

3.9.5. Skewness Kurtosis

Skewness and kurtosis were used to measure the asymmetry and "tailedness", respectively, of the probability distribution of a real-valued random variable about its mean (Vincent, 1994). Limits deemed acceptable were set to a range of ± 2.

Calculation of skewness = Σ Z3 / n

Calculation of kurtosis = (Σ Z4 / n) - 3.0

Where Σ = the sum, Z = z score of the data, n = number of data points.

3.9.6. Mauchly's test of sphericity

Mauchly's test of sphericity is used to validate the use of repeated measures ANOVA, with the assumption of sphericity indicated at values $p>0.05$. A significant test of sphericity ($p<0.05$) would indicate Greenhouse-Geisser or Huynh-Feldt correction, with Girden (1992) suggesting when sphericity is >0.75, Huynh-Feldt correction should be used, and when <0.75, Greenhouse-Geisser correction should be used.

3.9.7. Statistical significance

A significance level of 0.05 (5%) was set, providing 95% confidence that p is determined correctly and not by chance, whilst controlling for Type I error (Vincent, 1994).

3.9.8. Intraclass correlation coefficients

Intraclass correlation coefficients (ICC) were used to assess the absolute agreement between multiple measures. Koo and Li (2016) described an ICC of > 0.90 as an excellent correlation, 0.75-0.85 as good, 0.5-0.75 as moderate and below 0.50 as poor. As opposed to Pearson product moment correlation, ICC is unbiased for any sample size and conceptually similar to r^2 found in regression (Field, 2003).

ICC = (between-subject SD^2 – within-subject SD^2) / between-subject SD^2.

3.9.9. Typical Error of Measurement

The typical error of measurement (TEM) is a measure of reliability representing the variability in a value from measurement to measurement (Hopkins, 2000). Measurement variation when repeated (TEM) can be influenced by factors such as equipment or environmental conditions (Buck and Lambert, 2022). The TEM relates to the technical error and is commonly displayed in absolute and relative forms. Absolute TEM can be calculated as follows:

Absolute TEM = SD of the mean difference $/\sqrt{2}$

Relative TEM is expressed as a mean coefficient of variation (CV%) (Hopkins, 2000). The coefficient of variation % measures the variability of difference, allowing for comparisons to be made across different studies or different measurement tools (Atkinson and Nevill, 1998). The following criteria was used in the interpretation of CV%: good <5%, moderate 5-10%, poor >10% (Hopkins, 2000). All data was normally distributed which justified the use of CV%, and it should be noted the degree of the agreement between tests depends on the magnitude of the measure (Atkinson and Nevill, 1998).

Relative TEM (CV%) = (SD / mean difference) x 100

3.9.10. Analysis of Variance (ANOVA)

ANOVA is a collection of statistical models which are used to analyse differences between group means and the variation within- and between-groups (Field, 2003). Data used during ANOVA was checked if it met the criteria for distribution, normality, and sphericity. The calculated F statistic (F) for each comparison was related to the degrees of freedom and probability level ($p < 0.05$). The F statistic is a ratio of the variability of two sets of data, accounting for the variability of each group mean from the overall mean and also the variance within each group from the group mean. For multiple comparisons, in the prevention of familywise error, Bonferroni correction was implemented (ie, the adjustment of significance level to reduce the risk of Type I error, which increases with the number of comparisons made) using the below formula.

Significance level (α) / number of tests

3.9.11. T Test

A T test is an inferential statistic used to determine if there is a statistically significant difference between the means of two groups. T test determines if the mean of a group is significantly different to the mean of another group. The T ratio signifies the relationship between the differences in means to the variability in the sample size and data (Field, 2003).

3.9.12. Cohen's *d* effect size

Cohen's *d* effect size states either the size of association between two variables or the size of differences between two group means (Lakens, 2013). A *d* of 1 indicates a difference of 1 standard deviation. Cohen (1988) suggested the following interpretation of *d,* and these classifications are widely used within literature: small effect size 0.2, moderate effect size 0.5, large effect size 0.8.

Cohen's *d* can be calculated as follows:

$d = (\bar{X}_1 - \bar{X}_2) / SD$

Where: $\bar{X}_1$ is the mean of data set 1 and $\bar{X}2$ is the mean of data set 2.

Cohens *d* effect sizes translate approximately into 0.20, 0.60, 1.20, 2.0 and 4.0 for standardised differences in means (the mean difference divided by the between-subject SD) (Hopkins, 2009).

3.9.13. Partial eta squared

Partial eta squared (η_p^2) can also be used as a measure of effect size. Eta squared is the proportional variance in a dependent variable defined by an independent variable (Richardson, 2011), whereas partial eta squared is a similar measure, but the effects of other independent variables and interactions are factored into the analysis (Richardson, 2011). Partial eta squared expresses the sum of squares of the effect in relation to the sum of squares of the error associated with the effect (Lakens, 2013). Calculation of η_p^2 can be performed as follows:

$n_p^2 = SS_{effect} / (SS_{effect} + SS_{error})$

Where SS effect is the sum of squares of the effect and SS_{error} is the sum of the squares of the error, both of which are calculated during an ANOVA. Partial eta squared was reported to give an indication of effect size, with values of 0.01, 0.06 and 0.14 considered as small, medium, and large effect sizes respectively (Girard et al., 2013).

3.9.14. Limits of Agreement

Limits of Agreement plots (plotting the mean against the difference of the measures) were used to estimate the range within which differences between the measurements lie; Bland and Altman (2007) suggested this to be the most appropriate method for determining agreement between methods with multiple observations, whilst maintaining within subject variation. Heteroscedasticity (differences in the data in relation to the magnitude of the mean) is assessed by calculating the correlation coefficient between the absolute differences and individual means. If heteroscedasticity is not present, then the following equation is applied to obtain 95% random error, with upper and lower confidence intervals (Bland and Altman, 1986). Bland-Altman plots indicate systematic bias and random error when the direction and magnitude of the scatter is examined. Calculation of 95% LoA and CI:

95% LoA = SD of the mean difference *1.96

Upper CI = mean difference + LoA, Lower CI = mean difference – LoA

In the absence of significant systematic bias (identified by a paired t-test), LoA is expressed as, ± value (lower, upper CI), which can provide total error (bias and random) (Atkinson and Nevill, 1998).

4. STUDY 1: SLEEP HYGIENE AND CHRONOTYPE ACROSS A FEMALE ATHLETE POPULATION

4.1. ABSTRACT

Female athletes are at a greater risk of sleep issues than male counterparts, therefore providing accurate educational interventions aiming to improve sleep are of value in this cohort. Previous evidence suggests individuals with an evening chronotype may be associated with lower sleep duration and quality (Nunez et al., 2019), yet there is a lack of evidence to determine whether this may be underpinned by a worse sleep hygiene (SH) status. The purpose of this study was to firstly determine whether chronotype affected SH factors, and secondly, investigate which areas of SH were most problematic for female athletes, whilst also considering difference between sport types and age. Female athletes competing at a minimum of national level in various sports (n=144) completed the Reduced Morningness:Eveningess questionnaire (rMEQ), Sleep Hygiene Index (SHI), and Athlete Sleep Behaviour Questionnaire (ASBQ). Linear regression analysis determined whether chronotype predicts for SH scores and frequency analysis determined the lowest scoring categories of SH. Scores of ASBQ and SHI between individual and team sport athletes were compared via t-tests. The level of statistical significance was set at $p \leq 0.05$. Being classified as a morning chronotype predicted a reduction in SH scores (indicating more favourable SH) ($t = -8.19$; $p = 0.001$) while an evening chronotype predicted a significant increase in SH scores ($t = 2.96$; $p = 0.004$), indicating a worse SH status. Team sport athletes demonstrated a significantly worse SH status than athletes from individual sports with regularity, psychological factors and active behaviours identified as the most problematic areas of SH issues across all participants. Education around SH for female athletes should focus on the areas of regularity, psychological factors and active behaviours. Use of rMEQ for female athletes is of value in identifying eveningness chronotypes who are likely to have a worse SH status, therefore this may be used as a method of prioritising athletes for SH education in a team sport setting.

4.2. INTRODUCTION

Sleep, regulated by circadian rhythm and homeostatic sleep drive, can be defined as a reversible behavioural state during which the individual is unresponsive to the external environment (Bachar et al., 2022). It has been recognised as an essential component within the training schedules of athletes' (Halson, 2014), with deep sleep providing crucial recovery and regeneration of musculoskeletal tissues, as well as being shown to enhance sports performance (Mah et al., 2019). Sleep issues for athletes may be attributed to unfavourable training schedules, excessive psychological arousal, competition timings, supplement use, poor evening routines, stress and physiological demands (Halson, 2013, Halson, 2014, Juliff et al., 2015, Walsh et al., 2021). With increasing awareness around optimal sleep for athletes, there has been a notable rise in research investigating sleep data of athletes (Halson et al., 2022), yet there is a lack of studies investigating the sleep of female athletes.

Walsh et al. (2021) identified female athletes as having a greater risk for sleep issues than male counterparts. The discrepancy between male and female sleep may be partly explained by female monthly hormone fluctuations (Buysse et al., 2008), inducing temperature-related changes and affecting self-reported comfort (Maijala et al., 2019, Steward and Raja, 2020; Koikawa et al., 2020), and lifestyle factors, such as stress (Chang et al., 2014). Chronic partial sleep deprivation, defined as not fully meeting sleep needs for a sustained period, is a common problem within an athletic population and has far reaching consequences in terms of physical, physiological, and psychological impairments (Halson, 2013), including slower decision making, decreased muscle recovery and decreased sports performance (Jarraya et al., 2013; Barnes et al., 2015; Halson, 2014). Thus, identifying current sleep habits of athletes and implementing targeted educational components is of value in the management and prevention of these issues. Fullagar et al. (2015) previously suggested team sport athletes to be at particular risk of poor sleep, demonstrating reductions in sleep quality and duration compared to those from individual sports.

Sleep hygiene (SH) can be defined as practising habits that facilitate sleep and avoiding behaviours that inhibit sleep (Mastin et al., 2006). Improving the SH of athletes can result in increased sleep duration, quality, and latency (Caia et al., 2018), therefore, the use of SH education within an athlete population is becoming recognised as an important part of an overall training programme. Miles et al. (2019) surveyed 86 Australian sport coaches and sports science staff, all of whom worked in a high-performance environment, and found only 43% had promoted SH to their athletes. The 57% of coaches who had never used sleep education with their athletes stated this was due to lack of knowledge and a lack of resources. This serves to highlight the potential gap in the working knowledge and practices of sport coaches, and the need for educational resources around sleep to be easily available to coaches (Miles et al., 2019). Bonnar et al. (2018) stated identifying and addressing poor sleep habits amongst athletes is a key clinical and research concern, with potential impacts on athlete performance, recovery, and long-term wellbeing. Gaining better understanding of athletes' sleep habits may offer coaches an avenue to optimise sleep indices, and thus offers a potential performance benefit (Miles et al., 2019). Time demands in elite sport are high, thus identifying targeted areas of sleep education is of value in the efficient promotion of healthy sleep habits.

Chronotype can be defined as an individual's predisposition towards morning or evening preference (Vitale et al., 2017). Data examining chronotype of female athletes is limited yet has relevance in sporting success, both directly, given those working in contrast to chronotype preference have commonly been shown to report higher RPE during exercise (Lastella et al., 2021), and less skill accuracy (Schmidt et al., 2015), and indirectly, given the potential negative effects on sleep habits when working in contrast to chronotype preference (Yadav et al., 2016). Athletes with an evening chronotype have been shown to demonstrate reduced sleep durations and lower sleep quality compared to those with morning preferences (Vitale et al., 2015), yet there is a lack of evidence to ascertain whether chronotype affects SH status. Nunez et al. (2019) concluded those with an evening chronotype had lower sleep quality than morning chronotypes, whilst similarly, Roepke et al. (2010) reported evening chronotypes to have a greater sleep debt. Investigating whether these factors are underpinned by SH differences is of value in proactive interventions for such issues.

The primary aim of this investigation was to determine whether chronotype affects SH status; to the authors knowledge, no prior publications have investigated the association between the two in female athletes. Secondary aims were to identify commonalities across SH factors for female athletes with a view to informing future educational interventions, whilst also considering whether sport type or age impacted SH factors. Based on previous literature suggesting evening chronotypes to have worse objective sleep indices, it was hypothesised that athletes with an evening chronotype would have a worst SH status, and that team sport athletes would have worse SH than those from individual sports.

4.3. METHODS

4.3.1. Participants

The size of the effect reported in a comparable study (Miles et al., 2019) was used to establish a lower boundary sample estimate for the present investigation. *A priori* power analysis (G*Power, 3.1), based on alpha (α: 0.05) and beta (β: 0.80) was used to calculate a minimum required sample size of n=138 for the present investigation; this was based on published mean, SD, and effect size data from similar studies (Sargent et al., 2021, Bachar and Douer, 2022). A sample of n=144 female athletes (mean age 26.8 ± 7.2, n=4 <18 years), competing at a minimum of national level (Tier 3, 4 and 5 athletes according to McKay et al., 2022), were recruited from various sports (**Table 4.1**), with inclusion criteria as follows: training in their chosen sport a minimum of 10 hours per week and actively competing within their sport at a minimum of national level. No participants met any exclusion criteria detailed in **Chapter 3, General Methods.** Institutional ethical approval was issued in accordance with the Declaration of Helsinki 1964 (revised 2013) (approval number 2022-9608).

Table 4.1: Participant sport

Sport	Number of participants	Mean age ± SD
Football	36	23.2 ± 4.3
Athletics	35	24.5 ± 5.8
Taekwondo	18	26.1 ± 4.0
Rugby	15	25.5 ± 4.3
Volleyball	12	19.1 ± 0.6
Basketball	10	23.4 ± 2.0
Hockey	9	27.6 ± 3.3
Tennis	9	19.0 ± 3.8

Additional covariates of MC phase, weekly training volume and competition phase were considered within the analysis, but were not deemed directly relevant to the study aims. Further research may be directed towards sub-analyses on these categories, which may provide the potential for greater generalisability of the findings.

Participants were informed of potential benefits and risks and provided informed consent. Where participants were under the age of 18 (n=4), additional parental/guardian consent was taken prior to data collection. Across all participants, n=68 participants reported taking hormonal contraceptives (type unspecified).

4.3.2. Experimental design

The study adopted an observational, mixed methods approach (McGannon and Schweinbenz, 2011). Participants completed three previously validated questionnaires - a) Reduced Morningness:Eveningness Questionnaire (rMEQ) (Adan and Almirall, 1991), b) Sleep Hygiene Index (SHI) (Mastin et al., 2006), c) Athlete sleep behaviour questionnaire (ASBQ) (Driller et al., 2018), amalgamated into one Microsoft Forms questionnaire for participant ease. Details on each questionnaire can be found in **Chapter 3, General Methods**. Participants were instructed to complete all questions upon waking. Responses were anonymised and collated into a spreadsheet for data analysis, with scores for each questionnaire summed according to original publications (Adan and Almirall, 1991, Mastin, 2006, Driller et al., 2018). Responses from the SHI were grouped into categories for analysis as described in **Chapter 3, General Methods**, with response frequency collated and expressed as a percentage against response options. Given the potential for seasonal adjustment of chronotype and variation in sleep habits (Allebrandt et al., 2014), it should be noted that data collection of this study was carried out in the month of January.

4.3.3. Statistical Analyses

All statistical analyses were conducted on SPSS software (version 23; SPSS Inc, Chicago, IL). Descriptive statistics were run to check data distribution; skewness kurtosis and visual assessment of P-P plot regression were carried out. Mean ± SD global scores were calculated for each questionnaire individually. Multiple linear regression was carried out to assess whether chronotype predicted average sleep hygiene scores. "Morningness" and "Eveningness" chronotypes were entered into the model using dummy coded variables. The intercept of the model therefore reflected the average sleep hygiene score for individuals who could not be classified within either the morningness or eveningness chronotype (i.e., neither). Comparisons between ASBQ and SHI scores from "team sport" and "individual sport" athletes were performed using independent samples t-tests, with Cohens *d* used as a measure of effect size (boundaries consistent with those reported within **Chapter 3, General Methods**). The effect of age on SH scores were reviewed via the grouping of data into four quartiles (Q1 mean age 31.1, Q2 mean age 26.8, Q3 23.0, Q4 18.3); differences in mean SHI and ASBQ scores between age group quartiles were investigated using one-way ANOVA, with partial eta squared used to report effect size (boundaries consistent with those reported within **Chapter 3, General Methods**). Level of significance was set at $p \leq 0.05$.

4.4. RESULTS

Mean time for questionnaire completion was 4 minutes 10 seconds. No indication of insufficient error reporting (IER) was observed within individual responses.

4.4.1. Chronotype and sleep hygiene

Chronotype distribution across the group was as follows: Morning type 54%, neither type 23%, evening type 23%. Analysis of model fit indicated that incorporation of chronotype (morningness and eveningness) could account for 54.3% of the variance in the average sleep hygiene scores (r^2 =0.543). Both morningness and eveningness chronotypes significantly predicted SHI scores after controlling for the effect of the other variable. Beta coefficients of the multiple regression are presented in **Table 4.2**. Being classified as a morningness chronotype predicted a reduction in SHI score ($t = -8.19$; $p = 0.001$) while, conversely, an eveningness chronotype predicted a significant increase in SHI score ($t = 2.96$; $p = 0.004$).

Table 4.2: Multiple linear regression analysis for the effect of chronotype on sleep hygiene scores.

	Coefficients	SE	95% Confidence Intervals	
			Lower Bound	Upper Bound
Intercept	34.27	0.83	32.62	35.91
Morningness	-8.34	1.02	-10.35	-6.32
Eveningness	1.09	0.37	0.37	1.82

4.4.2. Sleep Hygiene Index

Mean SHI score across all participants was 31.6 ± 8.6. The effects of age on SHI scores were not significant, with no significant differences observed between quartiles ($p=0.08$, $\eta_p^2 = 0.38$). Frequency analysis on SHI scores demonstrated three groups where athletes commonly scored highest in, indicating a worse sleep status: regularity, psychological factors, and active behaviours. The SH categories athletes scored lowest in (indicating better sleep habits) were naps, substances, and environment. **Figure 4.1** below presents the response percentages for questions within each category of sleep hygiene, with the scoring as follows: 1=never, 2=rarely, 3=sometimes, 4=often, 5=always. Lower scores are indicative of more favourable sleep hygiene practices.

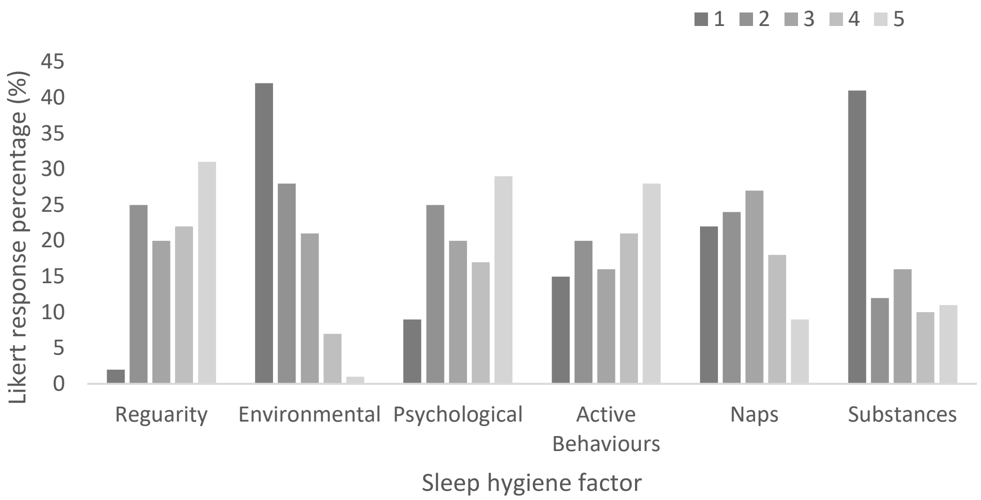

Figure 4.1: Frequency analysis of response percentages for each category of sleep hygiene, derived from the scores from sleep hygiene index.

4.4.3. Athlete Sleep Behaviour Questionnaire

Mean ASBQ score across all participants was 42.3 ± 10.2. The effect of age on ASBQ scores was not significant, with no significant difference observed between the quartiles (p=0.97, η_p^2 = 0.11).

4.4.4. Sport Type

Table 4.3 presents mean scores ± SD for ASBQ and SHI for each sport type. Mean differences between individual and team sport athletes were significant for both SHI scores (p=0.02, *d*=0.39) and ASBQ scores (p=0.004, *d*=0.55).

Table 4.3: Mean scores ± SD for ASBQ and SHI for each sport type.

Sport type	SHI score	ASBQ score
Individual	29.7 ± 5.2	40.6 ± 6.1
Team	33.6 ± 7.4	44.0 ± 5.4

4.5. DISCUSSION

This observational study aimed to present the SH factors and chronotype of female athletes from both individual and team sports. Female athletes with an evening chronotype are more likely to present a worse SH status, whereas those with a morning chronotype are more likely to have a better SH status. The areas of SH most problematic across all participants were reported as regularity, psychological factors, and active behaviours. To the authors knowledge, both these findings add novel information specific for female athletes. Team sport athletes had worse SHI and ASBQ scores, compared to those from individual sports, suggesting team sport athletes are operating with worse sleep habits than those from individual sports.

4.5.1. Chronotype

Results of the present study showed athletes with an eveningness chronotype are likely to have a worse SH status, therefore identifying athletes chronotype is of value in determining individuals who may have a greater risk of sleep issues, providing proactive monitoring and subsequently, earlier interventions. Previous evidence has presented those with an evening chronotype as likely to have worse sleep quality and lower sleep duration (Vitale et al., 2015). The present study adds the knowledge that evening chronotype may also indicate worse SH status. From a practical perspective, this is perhaps logical, given the aforementioned associations between chronotype, sleep quality and duration, yet encouraging, as the present data would suggest these factors may be modifiable via sleep hygiene adjustments.

In the present study, 54% of athletes were classified as morning preference, and 23% as evening preference, with 23% as neither type. In contrast to the general population, for whom chronotype distribution amongst non-athletes generally presents a bell-shaped curve of chronotype distribution, with the majority of individuals operating between the two extremes of morning or evening preference (Ashkenazi et al., 1997, Liu et al., 2020), it would seem female athletes in this cohort have a greater tendency towards a morning preference. Previous studies focusing specifically on the chronotype of athletes, partially concur with the results of the present study, in that athletes seem more likely to present morning chronotype than non-athletes: Biggins et al. (2019) demonstrated 19% of athletes to have a morning chronotype with only 7% evening, and Lastella et al. (2016) reported 22% of athletes reporting morning chronotype and 10% evening. Of note, is the fact both the aforementioned studies used a mixed sex sample, with Biggins et al. (2019) reporting n=24 female participants (41% of sample) and Lastella et al. (2016) reporting n=26 female participants (22% of sample), and neither study presented sub-analyses on sex. To the authors knowledge, this present study is novel in presenting chronotype data specific for female athletes, which seemingly has evident differences to mixed or male-derived data.

Perhaps the most obvious difference in the data of the present study, is the large number of female athletes with morning chronotype, relative to other chronotype preferences. In non-athlete populations, it has previously been noted that females are more likely to present as morning chronotype, compared to males (Randler and Engelke, 2019), a notion which has been attributed to hormonal differences (Randler and Engelke, 2019), genetic predisposition (Fabbian et al., 2016) and lifestyle factors (Fabbian et al., 2016). Thus, it would seem in the absence of sub-analyses of sex in previously published literature, the overview and perception of chronotype distribution amongst athletes is perhaps misleading for female athletes. Another difference in chronotype data of the present study compared to previous studies, is the greater number of athletes at each end of the chronotype spectrum, with a lower proportion operating in the middle of the extremes. Whilst it was beyond the scope of the study to investigate underlying physiological reasoning, it could be postulated that differences in sport type and training schedules may be contributory. Previous research has shown chronotype shift to occur in response to differing training times, with intermediate types being particularly susceptible to chronotype shift (Chtourou et al., 2014, Thomas et al., 2020). Therefore, it could be feasible that those with an intermediate chronotype, have phase shifted in response to regular training interventions.

4.5.2. Sleep hygiene factors

Global SHI scores (mean 31.6 ± 8.6) were comparable to previously published data from athlete populations; Driller et al., (2018) reported mean SHI of 32.3 ± 8.6 from a mixed-sex participant group. Similarly, mean ASBQ scores (42.3 ± 10.2) presented in the current study are comparable to Driller et al. (2018) reporting mean global ASBQ scores of 43.5 ± 5.8 in a mixed-sex participant group. Teese et al. (2023) compared male vs female athletes ASBQ scores and reported mean global ASBQ for female athletes as 46.5 ± 6.5, compared with 43.9 ± 5.3 for males, leading the authors to suggest female athletes indicate worse sleep habits than male counterparts. Despite results of the present study aligning more closely with previous scores demonstrated by male athletes in the work by Teese et al. (2023), global ASBQ scores for female athletes within the present study are still considered as poor, using original classifications from Driller et al., (2018).

The areas of SH which were reported as most problematic for female athletes in the present study were regularity, active behaviours and psychological factors; Knufinke et al. (2018) sampled 98 athletes (n= 56 female) and demonstrated the same three categories as being the lowest scoring areas, however within the aforementioned study, sub-analyses to understand any potential differences between the sexes were not carried out therefore conclusions could not be attributed specifically to female athletes. Therefore, this study builds on the work of Knufinke et al. (2018), providing novel female-specific data that concludes the areas of regularity, active behaviours and psychological factors are indeed the most problematic areas of SH for female athletes. Furthermore, this is suggestive of the fact there may similarities between males and female athletes in this area, although further research is needed to strengthen this observation.

Sleep hygiene education has been shown to improve sleep duration, quality, latency, and efficiency (Caia et al., 2018; O'Donnell and Driller, 2017). This study adds to the potential efficacy of SH interventions, allowing for a more targeted approach to SH education delivery. As such, the authors recommend that SH education for female athletes should focus on the areas of regularity (the similarity of sleep patterns between consecutive 24-hour periods, Halson et al., 2022), active behaviours (pre-bedtime behaviours, such as exercise or studying Storfer-Issar et al., 2013), and psychological factors (feelings, emotions or mental state which may impact sleep indices, Storfer-Issar et al., 2013). With Fullagar et al. (2016) stating generic SH education efforts may be illogical and that education tailored to specific needs is more appropriate, this study provides information allowing for a more targeted approach to sleep hygiene to be possible within this demographic. Given the vast degree of intra-individual differences in lifestyle and sleep habits, whilst this study provides key focus areas for coaches to consider, nuance between interventions for each individual athlete will likely be relevant, specifically the means of behaviour modification necessary to support sleep habits for each individual.

It is likely the specifics of active behaviours and psychological factors vary between sports and individuals, with each different sport presenting unique sleep challenges, for example, the timings of training and competition schedules (Walsh et al., 2021). Similarly, an individuals' lifestyle management will have significant impact on both these categories (Walsh et al., 2021). It has previously been demonstrated that athletes who reported greater levels of anxiety and worry, also had worse sleep quality, latency, and lower sleep durations than those without these issues (Akerstedt et al., 2007; Ehrlenspiel et al., 2018). The potential for daytime stressors to impact on sleep markers demonstrates the need for holistic lifestyle management within an athletes' programme.

Sleep regularity, defined as the similarity of sleep patterns between consecutive 24-hour periods, has been stated to be a key factor in meeting required sleep duration, with irregular sleep patterns potentially leading to delayed onset of melatonin secretion, subsequent delayed sleep timings, and increased daytime sleepiness (Phillips et al., 2017). Sleep variability commonly increases in response to insufficient sleep duration; the resultant failure to meet self-perceived recovery demands enforces subsequent adjustments, such as having long lie-ins on days where schedules allow (Sargent et al., 2014). Therefore, it is likely that the observed poor scoring in this area of the SHI indicates athletes in the present study are operating with sub-optimal sleep durations, although this was not objectively measured. Additionally, Halson et al. (2022) indicated athletes with poor sleep regularity have worse sleep efficiency than regular sleepers, giving support to the need to address this issue for athletes. With data on SH factors of female athletes lacking, the present study provides much-needed direction on potential focus areas of for SH education for female athletes.

Interestingly, no significant differences were observed between age group quartiles for SHI or ASBQ. Given the physiological and psychological variation which occurs across different life stages, this is perhaps surprising to observe. Despite all female athletes in the present study being a minimum of national standard in their chosen sport, lack of professionalisation of some of the sports sampled in this study may account for similar SH scores across all ages, with some older athletes potentially still operating with sub-optimal training times, and needed to work alongside sporting commitments, akin to younger athletes who have to balance school alongside training commitments. Despite no significance differences in global SHI or ASBQ scores across age sectors, it should be noted that different causal factors to global scores may warrant the use of individualised discussion to identify priority action points, where differences may be evident.

4.5.3. The influence of sport type

Results of the present study indicate that team sport athletes had a worse SH status than those from individual sports, which could be alluded to the need for uniformity within scheduling across a team, thus affecting individual choice towards sleep habits. Whilst group scheduling cannot necessarily be mitigated, this information should direct coaches within a team sport setting to be mindful of the potential for educational components to be of value and take an individualised approach to sleep management within a team setting where possible. These results support Driller et al. (2022) who demonstrated team sport athletes to have significantly worse sleep habits, indicated by global ASBQ score, as well as lower total sleep time compared to individual sport athletes (7h: 40min and 7h: 57min respectively). Suppiah et al. (2021) observed improved sleep habits from youth athletes partaking in individual sports compared to team sports, with team sport athletes reporting significantly higher scores in PSQI, indicating worse sleep quality. In contrast, results of the present study contradict previous work by Erlacher et al. (2011), who observed worse sleep habits in those partaking in individual sports compared to team sport athletes. However, Erlacher et al. (2011) conducted their study pre-competition, with the authors alluding to the potential for individual athletes to be more susceptible to higher stress, potentially due to the irregular nature of competition for many individual sports, compared to many team sports which generally operate weekly competition.

Similar to Erlack et al. (2011), Lastella et al. (2015) also concluded those from individual sports had worse sleep habits than team sport athletes. However, the cohort of individual sport athletes studied by Lastella et al. (2015) were predominantly endurance-based sports (triathlon, swimming, race walking), which traditionally include high training volumes and early morning scheduling, in contrast to the individual sports investigated within the present study (athletics, tennis, taekwondo) which do not follow the same pattern of training. The inconsistencies in athlete sleep characteristics by sport type between studies highlights that contextual between-sport differences may exist. These potential between-sport differences in athlete sleep characteristics warrant further investigation and highlight the possibility that instead of comparing individual and team sport athletes, perhaps a more appropriate comparison may be between physical categorisation of sports, i.e., endurance-based vs. strength and power-based athletes.

4.5.4. Study limitations and future research directions

The primary limitation of this study is that no objective sleep measures were taken, and the data relies solely on subjective reporting. Whilst pre-validated, self-report questionnaires have been consistently found to be valid and reliable whilst also having the benefit of being cost effective (Saw et al., 2015), objective sleep monitoring may have added to the validity of the results. This study was designed to give a broad overview of the status of female athletes' SH, habits and chronotype, therefore did not monitor for training or competition phase which would have been different for athletes from each sport. As such, assumptions regarding the impact of psychological factors on sleep cannot be made specific to competition anxiety but are made of general psychological state, and similarly, active behaviours do not reflect training phase. Future research should aim to present sleep characteristics specific to the training and competition phase to provide baseline measures for each stage of a periodised year across a range of sports. Menstrual cycle phase was not monitored in this study, but future research may be directed towards presenting female athlete sleep characteristics specific to menstrual cycle phase with the intention of optimising sleep factors at different points in a monthly cycle.

4.6. CONCLUSIONS

Athletes with an evening chronotype are more likely to have a worse SH status, thus the implementation of a rMEQ may be of value in determining athletes with an evening chronotype, in order to provide bespoke monitoring and potentially prioritised SH education. The areas of sleep regularity, active behaviours, and psychological factors should be prioritised in the development of SH education for female athletes; to the authors knowledge, this is the first study to present this information for this demographic, building on previous work that presented this information across a mixed cohort. Team sport athletes demonstrate worse scores in SHI and ASBQ than individual sport athletes, thus it should be considered how scheduling and education could potentially be manipulated to address this. No significant differences across age quartiles were evident in measured variables, however the authors postulate that different causal factors to global scores may warrant the use of individualised discussion to identify priority action points.

5. STUDY 2: DOES SELF-REPORTED SLEEP DURATION AND SLEEP QUALITY REFLECT ACTIGRAPHY REPORTED SLEEP DURATION AND SLEEP QUALITY IN FEMALE FOOTBALL PLAYERS?

5.1. ABSTRACT

Sleep is often compromised in athletes. The monitoring of athletes' sleep is an important preventative and educational tool. With many athletes using daily questionnaires and wellness check ins to estimate sleep duration and sleep quality, there is a need to understand whether these are being reported accurately, and thus whether self-report data is useful in this context. This study aimed to be the first to examine agreement between self-reported and actigraph reported sleep duration and quality in female athletes. Twenty-two female footballers provided a daily self-report across 7 days, whilst also wearing an actigraph across the same testing period. Self-reported sleep quality was compared to actigraph reported sleep efficiency, number of wakings and sleep fragmentation index to determine which factors predicted for the self-reported score. For sleep duration, agreement between self-reported duration and actigraph reported duration was analysed. Analysis of the self-report vs actigraphy reported sleep duration demonstrated a mean bias of −0.54 h (95% CI − 0.66 to − 0.43) meaning there was a tendency for participants to overestimate their self-reported sleep duration by 32 min. With the limits of agreement ranging from +24 min to −90 min, true differences between objective and self-reported measurements for 95% of pairs of future sleep observations are expected to be as high as 2 h. For sleep quality, actigraph reported number of wakings, sleep fragmentation index and sleep efficiency only accounted for 27.5% of variance in self-reported score, with only number of wakings being a significant predictor ($p=0.000$). Findings suggest self-reported measurements of sleep duration should be interpreted with caution in a female athlete cohort, and objective monitoring is advised to assess this factor. When asking for self-reported sleep quality, coaches should infer this score may be referring to the number of wakings an athlete experiences, which may inform intervention and SH advice.

5.2. INTRODUCTION

Success in sport is underpinned by optimal preparation and recovery (Juliff et al. 2015). With sleep being highlighted by Halson (2013) as the single most important recovery strategy available to an athlete, the accurate monitoring of sleep is crucial to optimise recovery status, and thus, performance. Short sleep has been shown to negatively affect sports specific skills, coordination, mood, rating of perceived exertion and injury risk (Mah et al. 2019; Walsh et al. 2021; Costa et al. 2022); therefore, identifying athletes experiencing regular sleep debt is of paramount importance for both sports performance and athlete wellbeing, and thus, sleep must be monitored. Sleep is often compromised in athletes due to enforced training times, competition scheduling, travel, stress or physiological arousal in the evening (Nédélec et al. 2012; Halson 2014), with female athletes being at particular risk of sleep issues (Walsh et al. 2021). Athletes are particularly susceptible to short sleep durations, with a recent systematic review finding the mean sleep duration of over 1860 athletes, was 7.2 ± 1.1 h per night (Vlaihoyannis et al. 2021); a duration lower than recommendations from recent studies, which suggest athletes need 7.9 h (Morita and Sasai-Sakuma 2021) and 8.3 h (Sargent et al. 2021) in order to report satisfaction with their sleep. Both sleep duration and quality are factors which contribute to the perception of 'a good nights' sleep' (Ogeil et al. 2021). With as many as 50–78% of elite athletes reporting sleep disturbance and 22–26% of athletes suffering highly disturbed sleep (Samuels 2008; Swinbourne et al. 2016; Gupta et al. 2017), the accurate reporting of athlete sleep data is paramount to ensure early intervention and prevention of performance degradation.

Early work by Reilly and Piercy (1994) demonstrated a significant reduction in maximal bench press and deadlift following sleep deprivation (3 h per night sleep allowance). Sleep deprivation in athletes has been shown to result in reductions in the following parameters: sprint times (Skein et al. 2011), countermovement jump performance (Skein et al. 2013), grip strength (Souissi et al. 2013), cognitive performance (Fullagar et al. 2015) and sports performance (Reyner and Horne 2013; Sinnerton and Reilly 2013). Findings from a systematic review of 69 publications on the effects of sleep loss on physical performance (Craven et al. 2022) suggested a negative impact of sleep loss on exercise performance, highlighted the need for robust monitoring of athletes' sleep. Across a sample of 207 male athletes and 215 female athletes, Kawasaki et al. (2020) found females were more likely to have poor sleep, which could be attributed to lifestyle factors and hormonal changes throughout the menstrual cycle. Research around how sleep factors are affected by the MC are inconclusive – most likely due to the level of intra and interindividual variation of the MC (Elliott-Sale et al. 2021). Whilst the importance of sleep to recovery and performance seems clear (Fullagar et al. 2015), the best practice to monitor sleep within an athletic population is more controversial. There is currently no 'standardised' practice in sleep monitoring of athletes (Halson 2019) and the monitoring of choice is often largely determined by the practitioners' interpretation of best practice.

Polysomnography (PSG) is considered the gold standard method for monitoring sleep (Van De Water et al. 2011), a measure which detects sleep via brain-wave activity rather than motion. However, PSG is an expensive, lab-based measure, also potentially impractical and disruptive for sleep tracking purposes (Caia et al. 2018; Halson 2019). Therefore, a common method for the monitoring of athletes' sleep is to use actigraphy devices. One of the primary benefits of actigraphy-based sleep monitoring is that data can be collected over multiple nights in the participants' usual sleep environment, which has been demonstrated to provide more reliable estimates of sleep compared to one or two nights in a sleep laboratory (Blackwell et al. 2008; Rupp and Balkin 2011), as well as giving the data high ecological validity. Actigraphy has been compared against PSG in multiple populations (Sadeh et al. 1994; de Souza et al. 2003; Meltzer et al. 2012), including athletes (Sargent et al. 2016). Concordance between

PSG and actigraphy appears good, with previous work yielding agreement in the range of 78–95% (Kushida et al. 2001).

Self-reporting can be defined as an individual's own report of their perspectives, behaviours or beliefs (Stone et al. 1999) and self-reporting of sleep is commonly used within an athletic population. Both the use of validated questionnaires (Buyssee et al. 1989) and simple questions, often utilising Likert scales (Sargent et al. 2021), are commonplace for the monitoring of athletes' sleep (Halson 2019). Recent research has employed the use of short questions to provide self-report measures (Caia et al. 2018, Sargent et al. 2021), likely due to the lesser time commitment from the athlete, and the fact that many athletes within elite sport settings are habitually answering these types of questions daily as a requirement for daily wellness monitoring. In some circumstances, access to objective measures may be limited by funding or availability, therefore it must be established whether self-reported measures can provide accurate and reliable estimates of sleep factors.

Self-reported measures are significantly less expensive to administer and are potentially less time-consuming in the process of data analysis, compared to other measures (Saw et al. 2016). In a systematic review of 56 studies comparing self-report and objective reporting of athlete recovery status, Saw et al. (2016) summarised that subjective self-reported measures provided superior sensitivity and consistency compared to objective measures. They concluded self-reported measures, used on a regular basis, are useful to reflect changes in athlete well-being and that coaches should employ self-report measures with confidence. However, the use of self-report questionnaires may be affected by response bias, with data interpretation potentially affected by the lack of standardised data for athletes (Zhang et al. 2022). Despite these potential issues, self-report measures are widely used for monitoring athletes in high-performance sport (Taylor et al. 2012), with many daily wellness questionnaires incorporating questions regarding sleep factors (Brown et al. 2021).

Kölling et al. (2016) compared actigraphy reporting and self-reporting of sleep duration for 72 physical education students (32 females); they demonstrated good agreement between the two measures for sleep duration (ICC = 0.90 to 0.92). Sub-analyses were not done to understand any potential differences in reporting between the sexes, demonstrating a gap in understanding of the reporting of female athlete sleep. There is a paucity of information on the validity and reliability of self-reported sleep measures compared to objective sleep measures in female athletes, as well as a lack of research on the constructs of self-reported sleep quality and this study would endeavour to be the first to address these gaps. The primary aim of this study was to compare the agreement between self-reporting and actigraphy reporting of sleep duration in female football players, thus informing best practice for athlete monitoring. Based on comparable reports in a male athlete population, it was hypothesised that there would be good agreement between the two methods for both sleep durations. A secondary aim was to determine which actigraph reported sleep parameters contribute to self-reported sleep quality, with a view to further understanding the interpretation of this factor amongst female football players. Due to previous evidence supporting self-reported measures, it was hypothesised that there would be good agreement between self-reported and actigraph reported sleep durations. Claudino et al. (2019) previously suggested sleep efficiency was a significant contributor to sleep quality, it was also hypothesised that sleep efficiency would predict for self-reported sleep quality score.

5.3. METHODS

5.3.1. Participants

With **Study 1** demonstrating team sport athletes to have report worse sleep habits than those from individual sports, team sport athletes were identified as a priority demographic for this study, given the importance of effective monitoring within this cohort. Twenty-two female football players volunteered to take part. All participants (mean age 19.5 ± 1.3 years) were part of the U21 squad at their football clubs and played regularly in the Women's Super League (WSL) Academy League. Prior to the commencement of the study, all participants were informed of study requirements and gave informed consent. Participants met the inclusion criteria and did not fulfil any exclusion criteria detailed in **Chapter 3**, **General Methods.** Across all participants, n=14 reported taking hormonal contraceptives (type unspecified). Institutional ethical approval was issued (protocol number 2022–10035) in accordance with the Declaration of Helsinki 1964 (revised 2013). Prior to the testing period, participants were asked to wear an actigraphy device for 7 days to collect baseline sleep data; no outliers were identified during this familiarisation period. Throughout the whole data collection period, participants were advised to maintain their normal sleep routines, and slept in their usual, home-based environment. During the 7 days of data collection, participants completed their usual on-pitch training (mean 10.7 ± 1.5 h) and gym-based training (mean 3.0 ± 0.9 h). Sixteen players took part in one match, whilst six players did not take part in any matches during this period.

5.3.2. Experimental design

A mixed methods observational experimental design with repeated measures was used across 7 days to assess the agreement between self-reporting and actigraphy reporting of sleep duration and sleep quality parameters.

5.3.3. Actigraphy sleep assessment

Baseline sleep data was collected for 7 days, which served an additional purpose of familiarisation. Following baseline data collection, participants were asked to wear an actigraphy device (ActiGraph GT9X, Florida, USA) for a duration of a further seven nights. Devices were set to collect data in 1-min epochs, at a sampling rate of 60Hz, and participants were instructed to only remove devices for matches throughout the testing period.

5.3.4. Subjective sleep assessment

Across the same monitoring period, participants were asked to give a self-reported sleep duration and sleep quality on Microsoft Forms (as described in **Chapter 3, General Methods**), first thing upon waking, as demonstrated by Caia et al. (2018):

1. Please give an estimate of your sleep duration (how long you slept for (hh:mm)
2. How would you rate the quality of your sleep last night (1-5 Likert scale response, where 1= very poor, 5 = excellent).

Participants were sent a reminder to complete this via a group text message from coaches, as such, the completion rate was 100%. All participants were familiar with this question and were habitually completing this daily as a requirement from their clubs. At the end of the monitoring period, self-report for each night was compared with actigraph data of the same night for each participant.

5.3.5. Statistical Analyses

Descriptive statistics (mean ± SD) were calculated daily for each method, with % CV used to present dispersion around the mean. Estimates of reliability and agreement between objective and subjective measures of sleep were computed. All of the above were calculated using the 'SimplyAgree' package (Caldwell, 2022; https://doi.org/10.21105/joss.04148) in R (R core team, 2020). Limits of Agreement plots (plotting the mean against the difference of the measures) were used to estimate the range within which differences between the measurements lie; Bland and Altman (2007) suggested this to be the most appropriate method for determining agreement between methods with multiple observations, thus maintaining within subject variation. Repeated assessments were taken into account in the estimation of limits of agreement by incorporating within-subject variation to reduce the risk of producing limits of agreement that are too narrow and therefore estimating higher agreement between measures than is true (Bland and Altman, 2007). Repeats of objective and subjective sleep measurement were assumed to vary within participants across days (Bland and Altman 2007; Zou, 2013), with limits of agreement estimated based on methods accounting for such nested, 'non-constant' contexts using the 'agree_nest' function (Bland and Altman, 2007; Caldwell, 2022). Assumptions relating to the normal distribution of residuals, heteroscedasticity and proportional bias were checked and verified through visual inspection of the plots produced using the 'check' function within the 'SimplyAgree' package (Caldwell, 2022). The agreement between the two methods was subsequently visually represented.

If measurements with the two methods are similar, the differences between them will be small, with an average near zero, they will be consistent over the range of measurement values, and the limits of agreement will be narrow (Abu-Arafeh et al., 2016). There is a paucity of research presenting either acceptable limits of agreement within this cohort, or minimal clinically important differences, however in line with available evidence in other populations (Werner et al. 2008; Meltzer et al., 2012), *a priori* limits of agreement of <30 min were considered acceptable. Reporting of the Bland-Altman analysis has been aligned with considerations listed by Abu-Arafeh et al. (2016). To investigate sleep quality, multiple regression analysis was conducted using the following actigraphy derived parameters - number of wakings, sleep fragmentation index (SFI) and sleep efficiency (SE) to assess which had the greatest impact on self-reported sleep quality. Cook's distance was reviewed to identify any potential outliers, with scores of over 1 suggestive of an influential value requiring further investigation.

5.4. RESULTS

A total of 308 observations were collected from n = 22 participants (154 actigraph, 154 self-report) across a 7-day period.

5.4.1. Sleep duration

The mean sleep duration across the investigated days using actigraphy was 6.63 ± 0.87 h. Computed coefficient of variation (CV) indicated that duration of sleep as measured through actigraphy varied by 10.9% across the investigated period. The subjective assessment of sleep duration yielded a mean of 7.18 ± 0.84 h, with a CV of 9.64% across the studied duration, on average, for each participant (**Table 5.1**).

Table 5.1. Sleep durations (hours) recorded using actigraphy and self-report.

	Day						
	1	2	3	4	5	6	7
Actigraphy	6.71 ± 1.11	6.72 ± 1.00	6.83 ± 0.63	6.63 ± 1.14	6.36 ± 0.89	6.67 ± 0.58	6.53 ± 0.55
Self-report	7.43 ± 1.16	7.30 ± 0.85	7.45 ± 0.58	7.04 ± 1.08	6.80 ± 0.70	7.18 ± 0.72	7.05 ± 0.46

A limits of agreement plot was generated (**Figure 5.1**) and demonstrated that 95% of the actigraph scores were between 1.49 lower and 0.40 greater than self-report.

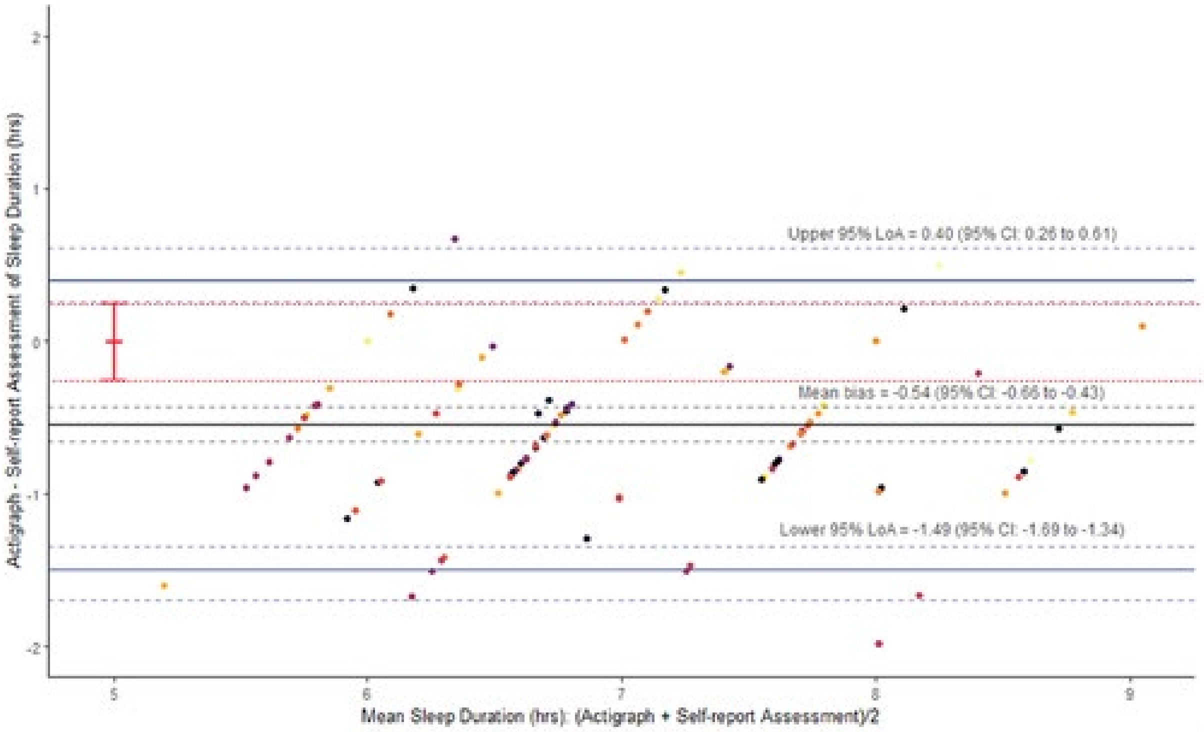

Figure 5.1. Limits of agreement plot comparing actigraph reported sleep duration and self-reported sleep duration. Red-dashed line and error bar represents the pre-defined acceptable range of agreement (−15 min to +15 min).

Analysis of the self-report vs actigraphy reported sleep duration demonstrated a mean bias of −0.54 h (95% CI − 0.66 to − 0.43) meaning there was a tendency for participants to overestimate their self-reported sleep duration by 32 min. With the limits of agreement ranging from +24 min to −90 min, true differences between objective and self-reported measurements for 95% of pairs of future sleep observations are expected to be as high as 2 h. Accordingly, our findings suggest self-reported measurements of sleep may lack justification as interchangeable to actigraphy-based tracking.

5.4.2. Sleep quality

Mean self-report score of 3.78 ± 0.78 on a 5-point Likert scale was reported across the 7 nights. Multiple regression analysis using the actigraph derived parameters sleep efficiency, number of waking and sleep fragmentation index (**Table 5.2**) showed $r^2 = 0.275$, meaning the incorporation of SE, number of wakings and SFI could only account for 27.5% of variance in self-reported sleep quality scores (Standard error 0.671, t = 5.679). Only the number of wakings was a significant predictor for sleep quality (p=0.000); the coefficient states that for every 1 increase in wakings, there is a reduction of 0.049 in self-reported sleep quality on the Likert scale. Sleep efficiency and SFI were not significant predictors of self-reported sleep quality.

Table 5.2: Multiple regression analysis for the effect of actigraph-derived parameters on self-reported sleep quality scores.

					95% Confidence intervals	
	B Coefficients	Standard error	t test	Sig.	Lower	Upper
(Constant)	3.808	0.671	5.679	0	2.483	5.133
Wakings	-0.049	0.007	-6.631	0.000	-0.064	-0.035
SFI	0.016	0.011	1.441	0.152	-0.006	0.037
Efficiency	0.011	0.007	1.697	0.092	-0.002	0.024

5.5. DISCUSSION

5.5.1. Sleep duration

The primary aim of this study was to assess measurement agreement between self-reported and actigraphy reported sleep duration for sleep tracking in female footballers, with the intention to determine whether a self-report of this factor could be considered valid and useful. Bland-Altman analysis demonstrated clear disagreement between the two methods, with a mean bias of −0.54 (32 min), and the width of the limits of agreement spanning almost more than 2 h. Therefore, the two measures did not meet earlier defined acceptable limits of agreement of <30 min. de Zambotti et al. (2015) suggested even if data comply with defined acceptable limits, the determination of clinical usefulness should also take into account the dispersion of discrepancies (upper and lower limits of agreement) rather than solely the average of the discrepancies. Given the large agreement range within the present study, considering the suggestion by de Zambotti et al. (2015), it is evident the measures in the current study present in disagreement, suggesting that self-reported sleep durations for female athletes may not be providing useful or meaningful data. Determining athletes' sleep duration is a key component of athlete monitoring; an inaccurate answer could mean that adjustments to subsequent training routines could be unnecessary or illogical, whilst equivocally, in the absence of accurate data, necessary adjustments may be missed.

Previous research on non-athletic cohorts has demonstrated poor agreement between self-reported and actigraphy reported sleep duration (Billings et al. 2022). Similarly, Jackowska et al. (2016) reported weak association between self-reported and actigraphy reported sleep durations amongst women (non-athletes), mean age 26 ± 4.9 years. However, previous research comparing self-reported and actigraphy reported sleep parameters on athletic cohorts are sparse. Caia et al., (2018) investigated this research question with male rugby players reporting a large, positive correlation ($r = 0.85$) between self-reported and actigraphy reported sleep duration. However, statistical issues limit the interpretation and comparison to the present study, as statistical correlation does not necessarily indicate good agreement between methods, simply the shared variance between measures (Giavarina et al., 2015); additionally, the authors of the aforementioned study have used between-subjects correlations, despite examining repeated measures data. The present study is novel in its experimental and statistical approach, addressing previous methodological errors in prior research, by using the more appropriate Bland-Altman analysis for repeated measures, as well as providing novel insights into the usefulness of self-reported sleep duration for female athletes.

Results showed a tendency for players to overestimate their sleep duration with a mean bias of +32 min. One reason for such overestimation could perhaps be attributed to conscious bias, with athletes potentially keen to report more favourable responses (Saw et al., 2015; Halson, 2019). Considering the mean bias and the large disagreement range within this female athlete cohort, relying on a self-reported sleep duration to provide meaningful monitoring of female athletes may be considered as problematic, potentially leading to a lack of appreciation for the athlete operating with repeated short sleep, or in a state of partial sleep deprivation. Physiologically, neural changes can be observed when operating in a state of partial sleep deprivation, with reductions in functional MRI signal in the dorsolateral prefrontal cortex and intraparietal sulcus evident whilst performing attentional tasks (Krause et al., 2017). Previous research has demonstrated the behavioural manifestations of such neural changes with athletes incurring reduced reaction time, focus, psychomotor performance, determination, and vigilance (Davenne, 2009; Edwards and Waterhouse, 2009; Underwood et al., 2010) in response to lack of sleep. Early identification of sleep loss or mounting sleep debt is of paramount importance in the prevention of negative performance and health impacts, thus this study highlights the need for methods beyond solely self-reporting of sleep durations to be employed, where possible, for female footballers, to accurately determine sleep status, prevent potential performance degradation and in the proactive prevention of habitually poor sleep.

5.5.2. Sleep quality

A secondary aim was to determine which objective sleep parameters contributed to self-reported sleep quality, with a view to enhancing interpretation of this factor into practical adjustment. The notion of sleep quality is often poorly understood (Claudino et al., 2019). Results demonstrated that the incorporation of SE, SFI and number of wakings only accounted for 27.5% of variance in self-reported sleep quality, with only the number of wakings being a significant predictor of self-reported score ($p=0.000$). It would seem that self-reported sleep quality represents a number of characteristics (Libman et al., 2016) with results of the present study furthering the understanding of sleep quality as a multifactorial construct, providing the novel finding that self-reported sleep quality, in this cohort, may be indicative of the number of wakings an athlete has experience that night.

Caia et al. (2018) investigated the correlation between subjective sleep quality (1-5 Likert scale) and sleep efficiency in male rugby players and found a small positive relationship ($r = 0.22$; ±0.06, $p = 0.73$). The authors concluded that sleep quality encompasses many factors, including sleep efficiency. This present study adds to those findings by demonstrating the number of wakings is a significant predictor for self-reported sleep quality in female athletes. With night wakings commonly attributed to environmental factors (heat, noise) or poor sleep regularity (Phillips et al., 2017), repeated reports of low sleep quality may be suggestive of the need for sleep hygiene interventions. Indeed, Edinborough et al. (2023) found a sleep hygiene intervention to be effective in reducing number of wakings per night, and number of wakings per hour. It is suggested that when interpreting self-reported sleep quality, further discussion with the athlete on an individual basis is prudent, to investigate the causative issues and guide restorative intervention.

5.5.3. Study limitations and future research

In this investigation, menstrual cycle was monitored for cycle length within inclusion criteria. However, a potential limitation of this study was the fact that the menstrual cycle phase was not controlled for during the testing period, and many participants may have been at different phases of their cycles. Menstrual cycle phases may affect sleep variables (Baker and Driver, 2007) and thus potentially, both the subjective interpretation of sleep factors and the actigraph report. Elliott-Sale et al., 2021) states when a study is not examining direct effects on the menstrual cycle on an outcome, a description of the population is solely relevant. However, not controlling for cycle phase may also be viewed as a strength of the study, as the results are representative of females at varying points of their cycle thus indicative of a wider representation of the data. During the process of data collection, it is feasible that participants felt a pressure to perform due to perceived club or squad expectations, which could have affected the self-reported data. Additionally, Kuosmanen et al. (2022) noted the potential for sleep monitoring and wearing sleep tracking devices to provide an additional stress, which may have skewed results. The use of collecting baseline data in this instance, not only served as establishing sleep norms for each participant but also could have had the additional benefit of familiarisation and mitigation of the aforementioned factors. Although the testing period in this study was comparable with previous research, which ranged from 3 days (Kölling et al. 2016) to 10 days (Caia et al. 2018), further prevention of these issues could be done via a longer testing period.

Although many studies have compared actigraphy with concurrent polysomnography reporting high correlations, this study did not include internal validation of the actigraphs used, which could be a potential limitation regarding the validity of the data. This study chose not to control for menstrual cycle phase to give a broad application of data for female athletes across various cycle phases, however further research may be directed towards the comparison of self-reported and actigraphy reported sleep data during different phases of the menstrual cycle, with a view to understanding potential variance of the accuracy of self-reporting at differing points of the monthly cycle. Finally, the sample size used may not have been adequate (Lu et al. 2016) yet was limited due to players' availability and level of athletes, potentially limiting the application of the findings to a wider cohort. As such, the study would benefit from being repeated with a larger sample size.

5.6. CONCLUSIONS

This study demonstrates clear disagreement between self-reported and actigraphy reported sleep durations and is the first study to present this information for a female athlete population. Coaches using a self-report of sleep duration as part of daily athlete monitoring should be interpreting the results with caution. With issues in the accuracy of self-reported sleep durations in this cohort, coaches should be aware of the potential misinformation they may be receiving regarding athletes' sleep status, the subsequent risk of implementing potentially misinformed programme adjustments based on these data, or missing key information which could affect their athletes' health and performance. As such, coaches should consider other methods of sleep monitoring, rather than solely relying on a self-report, to ensure they are operating with optimal practice within situational constraints. Additionally, it can be concluded that sleep quality is a multifactorial construct, as shown by the incorporation of SE, SFI and number of wakings only accounted for 27.5% variance in self-reported sleep quality, with number of wakings the only significant predictor of self-reported score. These findings discourage the use of self-reported sleep durations for future studies, due to the potential inaccuracies of the measure. In relation to future studies within this thesis, objective measures of sleep duration are advised, as opposed to relying on self-report. When using a self-report of sleep quality, within this population, it should be inferred that this may relate to the number of wakings, which may guide intervention and education around behaviour modification to address this issue.

6. STUDY 3: CAN SLEEP HYGIENE INTERVENTIONS AFFECT STRENGTH AND POWER OUTCOMES FOR FEMALE ATHLETES?

6.1. ABSTRACT

Improved sleep can enhance sprint, endurance, and sports-specific skills; however, it is yet to be investigated whether improved sleep indices could enhance strength and power performance. Sleep hygiene (SH) is growing in popularity as a tool to enhance sleep indices amongst athletic cohorts, yet the optimal delivery strategy of sleep hygiene education is yet to be determined. Using a randomised, controlled design with repeated measures, this study recruited 34 female footballers playing in Women's Super League (WSL) or WSL academy league. Participants were randomly split into 3 groups: one receiving both group-based and individualised sleep hygiene education, one receiving only group-based SH education and a control group receiving no education. Monitoring of sleep (actigraphy, diaries) and physical performance (countermovement jump, isometric mid-thigh pull) was carried out at week 1, week 4 and week 7. Split-plot ANOVAs were used to assess for differences between groups x weeks, and groups x time. Those receiving individualised sleep hygiene education resulted in significantly improved sleep duration ($p = 0.005$), latency ($p = 0.006$) and efficiency ($p = 0.004$) at week 7 compared to controls, whilst also resulting in significantly improved countermovement jump scores ($p = 0.001$) compared to controls. Results of this study suggest that jump performance may be affected by sleep factors, and that the addition of individualised SH education may be superior to solely group-based SH, providing information to coaches regarding training optimisation and the efficacy of SH education methods.

6.2. INTRODUCTION

Sleep and exercise influence each other in a bidirectional relationship, via multiple physiological and psychological pathways (Chennaoui et al., 2015). Alongside physical conditioning, nutrition and psychology, sleep is now considered a key influential variable for physical performance (Bonnar et al., 2018; Halson, 2019), with effects being modulated by factors including age, sex, and current training levels. Maximising sleep factors can be one way to enhance physical performance, with improvement in sleep coinciding with improvements in sports specific skills (basketball free throw percentage improved by 9%, Mah et al., 2011; improved accuracy of tennis serve, 35.7% vs. 41.8% pre-post, Schwartz and Simon, 2015). Conversely, short sleep has been shown to negatively affect jump performance, joint coordination, mood, rating of perceived exertion and injury risk (Mah et al., 2019; Walsh et al., 2021; Costa et al., 2022). With Sargent et al. (2021) reporting only 3% of athletes are meeting their self-assessed sleep needs, and 71% falling short of adequate sleep duration by an hour or more, it is evident many athletes are operating in a sleep debt, which could be affecting physical performance.

Sleep hygiene (SH) can be defined as practising habits that facilitate sleep, and avoiding behaviours that inhibit sleep (Mastin et al., 2006) - it is a simple, non-invasive, low-cost strategy which can be used to enhance many sleep indices (Caia et al., 2018; Vitale et al., 2019), and as such, may be a useful tool to enhance athletes' sleep and minimise negative effects on sports performance. Many previous studies have implemented group-based SH delivery: O'Donnell and Driller (2017) used a single group design to determine whether group-based SH education was effective in improving sleep indices for elite netballers. Results showed a single SH education session significantly improved total sleep time, wake variance, and wake episode duration. Despite the vast inter and intra individual variation of sleep, very few studies have utilised an individualised SH education approach within athletic populations, an approach which tailors SH education to the individual based on previous sleep data, current habits, and individual lifestyle. The few studies that have taken an individualised approach have demonstrated positive results - Driller et al. (2019) provided 30-minute individualised SH education for 9 male cricketers, with participants showing post-education improvement in sleep latency, and sleep efficiency. In a case study of a male academy footballer, Edinborough et al. (2023) found an individualised SH education intervention, to be effective in improving wakings per night and wakings per hour, coinciding with an improvement in the athletes' self-report of Pittsburgh Sleep Quality Index (Buysse et al., 1989). Interestingly, Dunican et al. (2020) utilised both group-based education (~2 hours) and individualised SH education (~20 min) but found this combination did not result in a significant increase to total sleep time for female basketball players. The authors hypothesised that this non-significant result may be since many players were already sleeping >8 hours at baseline, thus potentially already fulfilling their sleep needs and demonstrating a ceiling effect for that parameter. Additionally, the intervention contact time may play a role in the aforementioned insignificant findings, with a single individualised SH session of 20 minutes perhaps of an insufficient duration to promote meaningful change.

Gaps in the literature investigating the interaction between sleep and strength and power performance have already been identified (Watson, 2017; Walsh et al., 2021). Due to the potential impact on physical performance, there is a need to understand the interaction between sleep and physical performances focusing on strength and power. Strength performance, defined as the ability to exert force on an external object or resistance (Suchomel et al., 2016), is determined by many factors, including musculotendinous stiffness, motor unit recruitment and synchronisation, rate coding (the rate at which action potentials are discharged), intra and intermuscular coordination and neural drive (Beattie et al., 2014; Maestroni et al., 2017), whilst power can be defined as force x velocity. It has previously been noted that any physical performance requiring motor control can be impaired by insufficient sleep (Reilly and Waterhouse, 2009), with previous studies reporting sleep restriction to decrease vertical jump height (Takeuchi, 1985; Mah et al., 2019) and negatively affect maximal strength performance (Reilly and Piercey, 1994).

It is evident that more research is needed with regards to sleep interventions for female athletes and despite female gender being described as a risk factor for poor sleep (Walsh et al., 2021), there is limited research investigating individualised SH education for female athletes. In a recent systematic review, Craven et al. (2022) evaluated 77 studies to assess the effects of acute sleep loss on physical performance; within that review, 89% of participants were male, demonstrating the gender gap across this area of research. Similarly, Gwyther et al. (2022) conducted a systematic review examining sleep interventions for performance and also noted underrepresentation of female athletes, with representation of male athletes four times as high. Female athletes commonly have a worse sleep status than male counterparts, reporting a variety of negatively impacted sleep indices compared to males (Silva et al., 2019), with findings from **Study 2** suggesting sleep factors should be objectively monitored. Kawasaki et al. (2020) found female athletes were more likely to report subjectively poor sleep quality (48.8% females; 31.4% males) than male athletes. The reason for such male-female discrepancy in sleep indices could be attributed to hormonal changes across the menstrual cycle (MC), yet research conclusions are mixed regarding the impact of MC phases on sleep factors, likely due to the high intra- and inter-individual variation of the MC (Hrozanova et al., 2021).

Walsh et al. (2021) highlighted the fact there is a lack of research regarding the role of sleep as a tool to enhance strength and power variables, thus this study would endeavour to provide novel insights into this, by investigating the efficacy of two SH education methods, one solely group-based, and utilising individualised education, alongside two common tests for lower body power and strength. The aims of this study were to investigate whether sleep hygiene interventions affect strength and power outcomes, with a secondary aim to assess whether there are any differences between individualised and group-based SH education on sleep indices in female athletes. Due to the existing knowledge regarding the effectiveness of SH on sleep and physiological pathways of performance, it was hypothesised that sleep hygiene education would be a useful tool to enhance strength and power performance, via improve sleep indices. Due to the high degree of individual variation regarding factors affecting sleep, it was hypothesised individualised SH would be more effective in improving sleep indices than group-based education.

6.3. METHODS

6.3.1. Participants

A priori power analysis (G*power, version 3.1) was used to establish a minimum sample size (n=30) for the present investigation. Sample size calculations were based on a medium effect size of 0.5 and a type I (α) error rate of 5%. A convenience sample of 36 female football players volunteered to take part; one participant withdrew following baseline data collection and was removed from the study. One further participant withdrew from the study in Week 3; meaning n=34 completed the study. All participants gave informed consent prior to data collection. All participants (participant demographics detailed in **Table 6.1**) were part of the U21 or First Team squad at their football clubs in the United Kingdom, and all were categorised as Tier 3 and 4 participants according to McKay et al. (2022). All participants and had played regularly in the Women's Super League (WSL) or the WSL Academy League in the previous season. Throughout the study, participants slept in their usual, home-based environment.

Table 6.1: Participant demographics

Participant demographics		
	Mean	SD
Age (years)	20.3	1.4
Height (cm)	164.2	11
Mass (kg)	62.1	10.8
Weekly training hours (football)	10.4	4.1
Weekly training hours (gym based)	4.6	0.9

Across all participants, 15 reported regularly taking hormonal contraceptives (type unspecified). Prior to the commencement of the study, all participants were informed of study requirements and gave informed consent. No participants met any exclusion criteria detailed in **Chapter 3, General Methods**. Institutional ethical approval was issued (approval number 2023-12534) in accordance with the Declaration of Helsinki 1964 (revised 2013).

6.3.2. Experimental design

A randomised, controlled trial with repeated measures was used to assess whether sleep hygiene interventions could affect strength and power performance, and whether the method of SH delivery (individualised education vs. group) has any effect on sleep indices and performance. Given the potential for seasonal adjustment of sleep patterns (Allebrandt et al., 2014) and the potential variability of sleep patterns throughout a football season, it should be noted that data was collected during pre-season in July and August.

A random number generator (www.randomizer.org) was used to allocate participants into one of three groups: Control, Group SH, Individualised SH with n=12 initially in each (two participants withdrew during the course of the study, **Figure 6.1**). A schematic of the study protocol is detailed below in **Figure 6.1**.

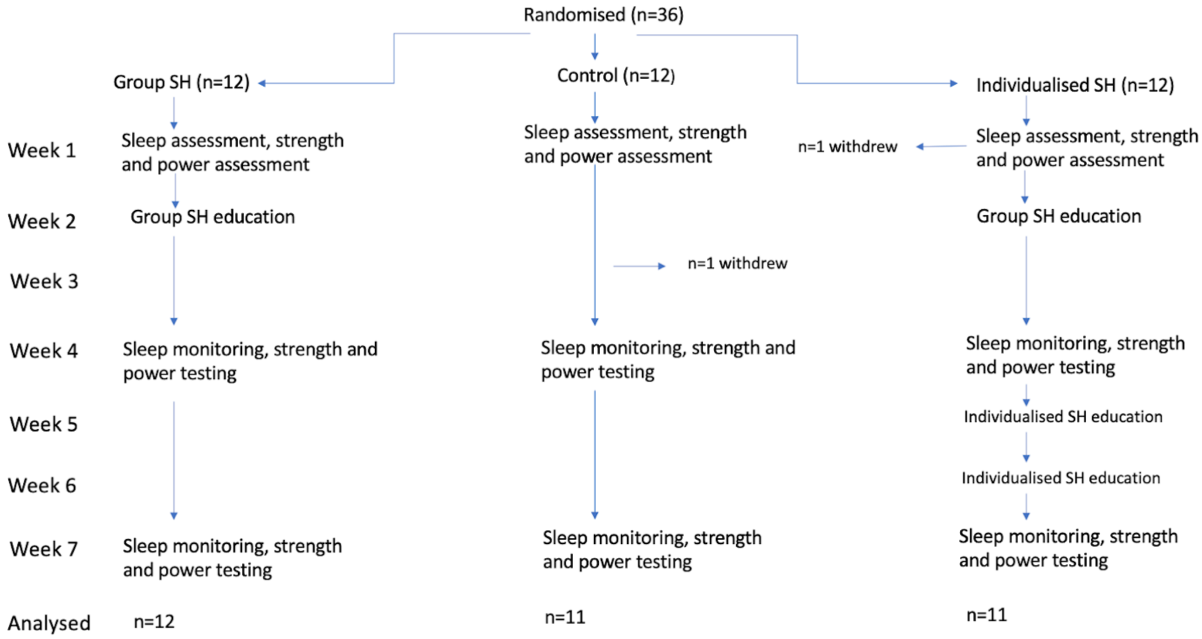

Figure 6.1: Participant flow diagram

6.3.3. Sleep monitoring – Weeks 1, 4 and 7

All participants completed the Athlete Sleep Behaviour Questionnaire (ASBQ) (Driller et al., 2018) and Reduced Morningness Eveningness Questionnaire (rMEQ) (detailed in **Chapter 3, General Methods)** with global scores summed according to original author classifications presented in **Chapter 3, General Methods.** All participants were allocated an actigraph (GeneActiv Original, Activinsights, Cambridge UK) which they were instructed to wear continuously during monitoring weeks, only removing them for pre-season matches. Every morning during sleep monitoring, participants were asked to provide a self-report (Likert scale 1-5) of sleep quality, which was reported directly to coaches via the club's daily wellness check ins, and then sent to the researcher via an Excel file.

6.3.4. Strength and power assessment – Weeks 1, 4 and 7

In Weeks 1, 4 and 7 of the study, all participants completed testing of countermovement jump (CMJ), and isometric mid-thigh pull (IMTP). The chosen testing battery was limited to only two tests at the request of the participants football club. All athletes had prior experience of both tests as part of physical testing requirements from their club and had completed the test regularly throughout the previous season. Week 1 was considered as baseline data. Participants followed a standard 15-minute warm up following a RAMP protocol (Jeffreys, 2006) led by a strength and conditioning coach, after which warm up repetitions of each test were carried out (detailed below). Strength and power tests were conducted by the same tester throughout the study. Given the potential for circadian influence on performance (Drust et al., 2005), performance testing was carried out at the same time of the day throughout the study (2pm ± ~30 min).

6.3.5. Countermovement jump (CMJ)

The CMJ test was conducted prior to the isometric mid-thigh pull and was performed on VALD ForceDecks (Force Decks, VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. Participants were instructed to keep their hands on their hips to eliminate arm swing and perform a fast downward motion to around 90° knee flexion, followed by an immediate upward vertical jump as high as possible, all in one sequence (Slinde et al., 2008). Prior to the test attempts, participants performed 2 jumps at 75% maximal effort, each separated by 2 minutes; this was designed to act as an extended warm up, additional familiarisation, and reinforce test technique (Carroll et al., 2019). For the test attempts, participants were instructed to deliver a maximal attempt and performed the test 3 times, each attempt separated by 2 minutes. Jump height (cm) was calculated from impulse momentum (Frick, 1991; Linthorne, 2001) computed by the VALD ForceDecks software (VALD Performance, FD4000, Queensland, Australia). Software detected the initiation of movement as a 30 N deviation from the initial body weight calculation, eccentric to concentric phase moment as the lowest centre of mass displacement, and take-off as the moment the vertical forces fell 30 N below body mass (Merrigan et al., 2021). Perez-Castilla et al. (2021) stated the importance of defining and using a consistent threshold to identify take off and the importance of using a consistent threshold to enable comparisons between trials and testing sessions. The best of the 3 trials was used for analysis.

6.3.6. Isometric mid-thigh pull (IMTP)

Methodological guidelines from Comfort et al. (2019) were followed in the administration of this test, with testing carried out on VALD ForceDecks (VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. Participants were initially asked to self-select a start position that reflected the start of the second pull of a clean (clean mid-thigh pull, see Comfort et al., 2022); this allows for athletes' individual anthropometrics to be considered in the adoption of an optimal pulling position (Comfort et al., 2019). Knee and hip angles were then checked with a hand-held goniometer to ensure knee angles were within the range of 125-145º and hip angles were within the range of 140-150º (Comfort et al., 2019) and straps were used by all athletes to mitigate the risk of grip strength becoming a limiting factor (Comfort et al., 2019). Prior to testing, single reps were performed at 50% maximal effort for 5 seconds, and 75% maximal effort for 5 seconds, each separated by 60 seconds rest, with the purpose of serving as further warm up, additional familiarisation and reinforcing test technique (D'os Santos et al., 2017). For the beginning of the maximal attempts, the tester gave the athlete a countdown of 3,2,1 before the initiation of the test. Participants were instructed to "push their feet into the ground as hard and fast as possible", maintaining the tension for a period of 5 seconds timed by the tester. This verbal cue has been previously shown to result in greater peak force than focusing on internal cues (Halperin et al., 2019). Each trial was separated by 2 minutes rest. The highest force generated was reported as the absolute peak force (PF) with relative PF then calculated by dividing this by the body mass of each participant (Haff et al., 2015). The best of the 3 trials was used for analysis.

6.3.7. Group sleep hygiene education – Week 2

A 40-minute group sleep hygiene education was delivered to both SH group and Individualised SH group in Week 2 of the study; the session was led by the lead researcher (myself). O'Donnell and Driller (2017) had previously shown a single group session of SH education was sufficient to improve sleep for female athletes. The session took place in a private room within the athletes' training ground, with two technical coaches also present. The focus of the session was to provide athletes with general information regarding SH and provide practical tips on the following areas – maintaining a regular bedtime and wake time (Phillips et al., 2017), maintaining a cool and dark bedroom (Dautovich et al., 2022), avoidance of light-emitting screens before bed (Driller et al., 2019), and implementation of relaxation techniques before bed (McCloughan et al., 2014). The session was delivered in a way that focused on positive reinforcement and potential performance benefits, rather than negative impacts of bad habits. The session concluded with participants writing down 2-3 practical changes to their sleep habits which they would aim to implement following the session.

6.3.8. Individual sleep hygiene education – Week 5 and 6

In addition to the group-based education session in Week 2, participants within the Individualised SH group were each given one one-on-one session per week, delivered via Microsoft Teams, where they were provided with individualised advice on their sleep hygiene, based on week 1 sleep data and self-reported perception of areas they needed to improve. Any areas reported above a "3 = sometimes" on the ASBQ was discussed as an area for improvement with each participant. Discussions aimed to establish and prioritise practical changes participants could implement daily and to overcome any concerns regarding changes. Participants were encouraged to ask questions and to focus on their own specific requirements, and each session concluded with the participant writing down 2-3 key areas of focus for their sleep habits which they would aim to implement. The initial individualised session for each participant lasted 30 minutes, with the second session lasting 20 minutes, to include a review of the success of previous action points, discussions of any concerns, and if necessary, amendments of any practical advice based on individual circumstances.

6.3.9 Statistical analyses

Descriptive statistics (mean ± SD) were calculated for all variables. Data was checked for normality using Shapiro-Wilk tests, and inspection of skewness-kurtosis. Between and within session reliability was assessed using two-way mixed intraclass correlation coefficients (ICC) and %CV for all performance outcome variables. ICC values were deemed as poor if ICC < 0.50; moderate 0.50–0.74; good if 0.75–0.90; and excellent if ICC > 0.90 (Koo and Li, 2016); %CV was considered acceptable <10% (Cormack et al., 2008). Split-plot ANOVA were used to examine the effects of SH education on strength and power outcomes, by using a 3 (group: Individual SH, group SH, control) by 3 (time: week 1, week 4, week 7) design. Sphericity was verified by Mauchly's test, as described in **Chapter 3, General Methods**. For each variable, the main effects for group x week were examined, as well as the group x time interaction. To protect for familywise error, statistical significance was set at $p < 0.008$ via Bonferroni correction (Armstrong, 2014). Partial eta squared was reported to give an indication of effect size, with values of 0.01, 0.06 and 0.14 considered as small, medium and large effect sizes respectively (Girard et al., 2013). For chronotype, data was analysed from raw rMEQ scores rather than classifications. Statistical analyses were performed on SPSS (version 29.0, SPSS, Chicago, Illinois) and Microsoft Excel (Microsoft Office 365, Microsoft Corporation, USA).

6.4. RESULTS

Intraclass correlation coefficients (ICC) reliability measures ranged from good to excellent (Koo and Li, 2016) across measured performance variables, and %CV also met pre-defined acceptable thresholds for reliability (**Table 6.2**).

Table 6.2: ICC and %CV for performance measures.

	Week 1		Week 4		Week 7	
	ICC	%CV	ICC	%CV	ICC	%CV
CMJ						
Jump height (cm)	0.89	7.3	0.86	8.0	0.85	7.6
IMTP						
Absolute PF (N)	0.97	7.1	0.93	7.2	0.94	8.9
Relative PF (N/kg)	0.96	7.5	0.92	8.7	0.92	9.8

6.4.1. Sleep measures

Pairwise comparisons of sleep duration indicated a significant difference between Ind SH and control at week 7 (F (2, 235) = 6.53, *p=0.005, η_p^2 = 0.29) (**Figure 6.2**).

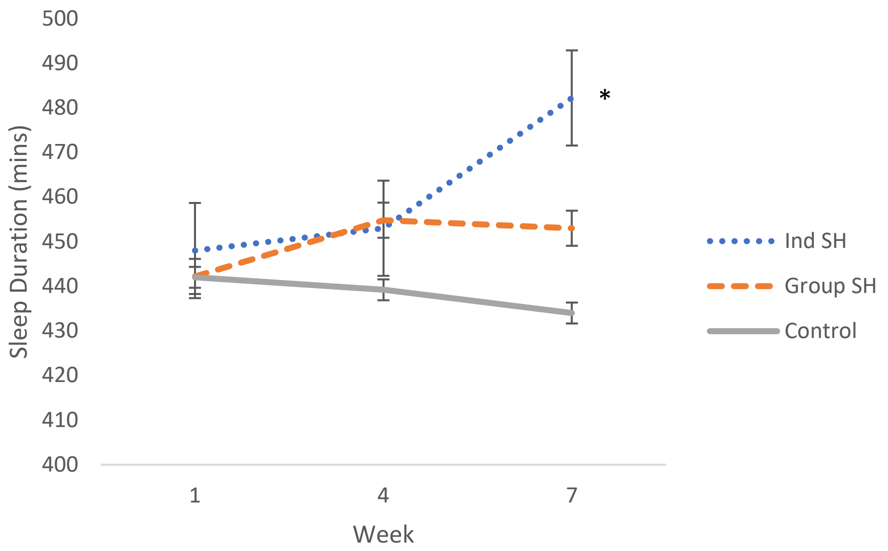

Figure 6.2: Changes in mean actigraphy-derived sleep duration across weeks 1-7, with error bars depicting SD.

Pairwise comparisons for sleep efficiency indicated significant differences were identified between Ind SH and control at week 7 (F (2, 235) = 8.85, *p=0.004, η_p^2 = 0.246) (**Figure 6.3**).

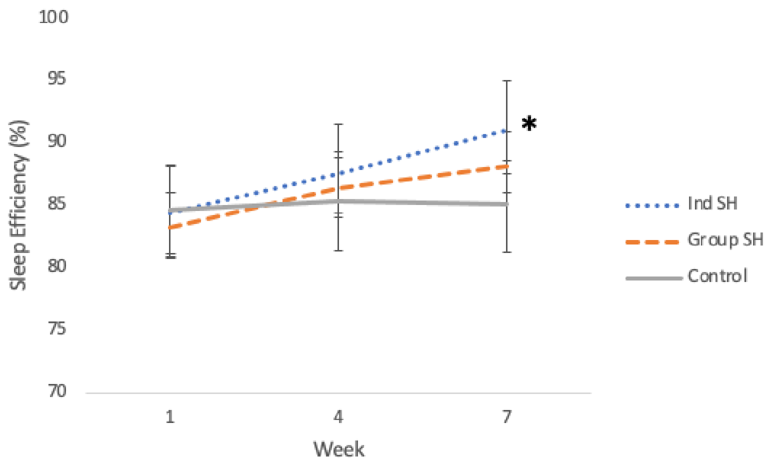

Figure 6.3: Changes in mean actigraphy-derived sleep efficiency across measured week 1-7, with error bars depicting SD.

Pairwise comparisons for sleep latency indicated a significant difference between Ind SH and control (F (2, 235) = 10.65, *p=0.006, η_p^2 = 0.081) at week 7. Group x time interactions demonstrated a significant difference from week 1 to week 7 within the Individual SH group (-3.29 min, p=0.001) (**Figure 6.4**).

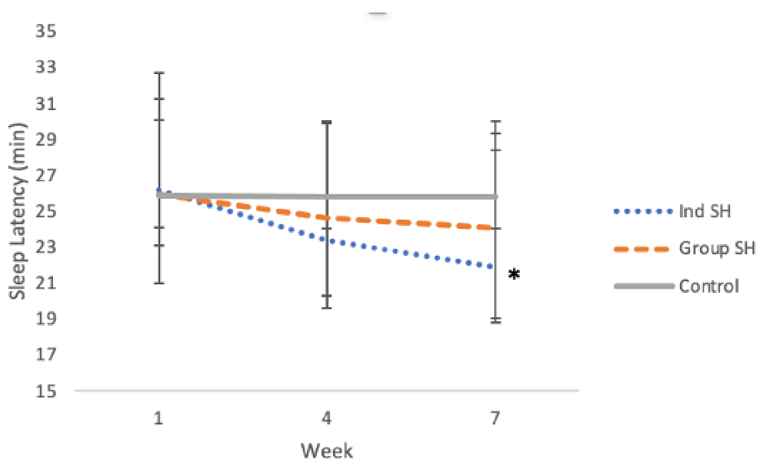

Figure 6.4: Changes in mean actigraphy-derived sleep latency across weeks 1-7, with error bars depicting SD.

Group x week comparisons indicated changes in self-reported ASBQ score were significant between Ind SH and control group (F (2, 31) = 14.35, *p=0.002), and group SH and control (**p=0.004), η_p^2 = 0.085 at week 7 (**Figure 6.5**).

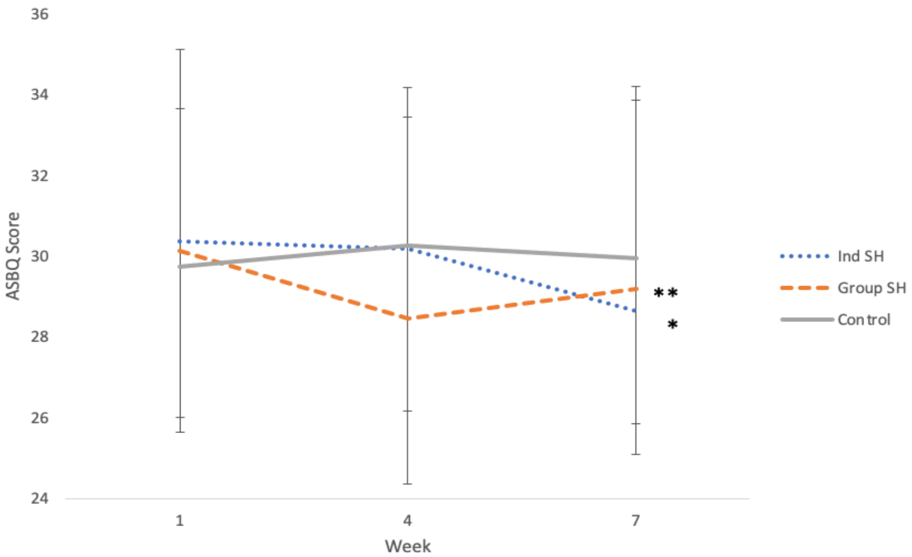

Figure 6.5: Changes in mean self-reported ASBQ score, with error bars depicting SD.

Group x week comparisons for sleep quality indicated significant differences between Individual SH and control (F (2, 235) = 6.22, *p=0.001) and Individual SH and group SH at week 7 (*p=0.003), η_p^2 = 0.35 (**Figure 6.6**).

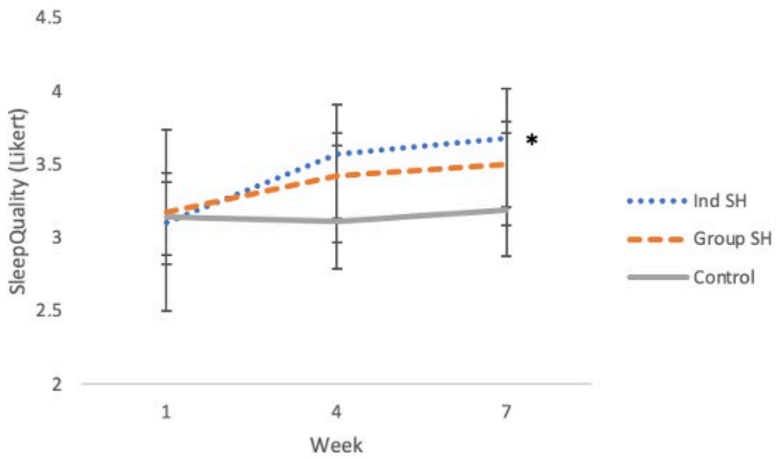

Figure 6.6: Changes in self-reported sleep quality across weeks 1-7, with error bars depicting SD.

6.4.2. Individual vs group sleep hygiene delivery

Changes over time between Individual SH and group SH demonstrate no significant differences at week 1 or week 4 between the two groups across any sleep parameters. At week 7, significant differences were observed between Individual SH and group SH in sleep quality (p=0.003) but no other sleep parameters were significantly different, despite Individual SH presenting better mean values at week 7 for all sleep parameters. At week 7, both Individual SH and group SH significantly improved ASBQ scores compared to control group. At week 7, group SH showed a decay in improvements for sleep duration (-2 min compared to week 4) and ASBQ (+ 0.74 compared to week 4, indicating a worse sleep status).

6.4.3. Chronotype

No significant differences in raw rMEQ scores of self-reported chronotype were identified group x week or group x time (**Figure 6.7**). Chronotype distribution was as follows across all participants: morning type 23%, intermediate/neither type, 53%, evening type 24%.

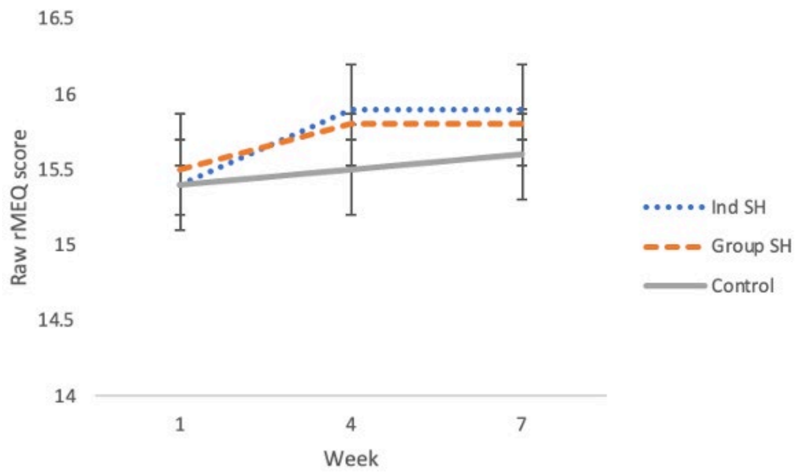

Figure 6.7: Change in mean self-reported rMEQ score across weeks 1-7.

6.4.4. Performance measures

For countermovement jump, there was a significant interaction effect for group x week (F (2, 31) = 3.84, p=0.001; η_p^2 =0.31) Pairwise comparisons indicated significant differences across weeks for Ind SH group compared to control (*p=0.001). Group x time interactions were significant from week 1 to week 7 for Ind SH (p = 0.001) (**Figure 6.8**).

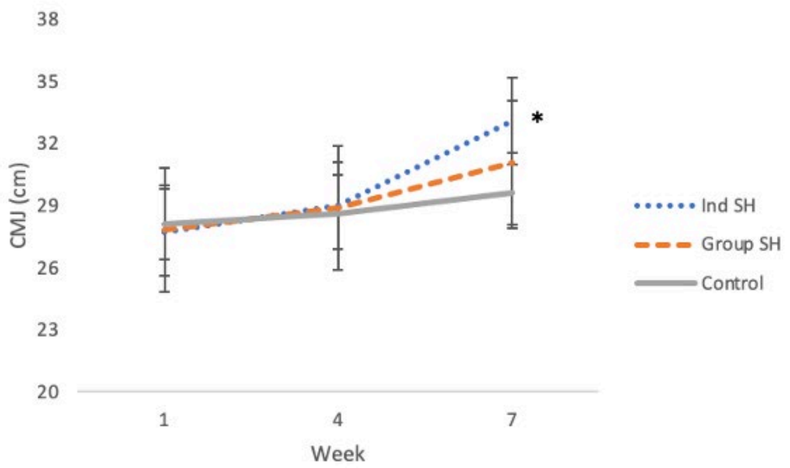

Figure 6.8: Changes in CMJ height across weeks 1-7.

For isometric mid-thigh pull, no significant differences were observed in absolute peak force for groups x week or group x time interactions (**Figure 6.9**).

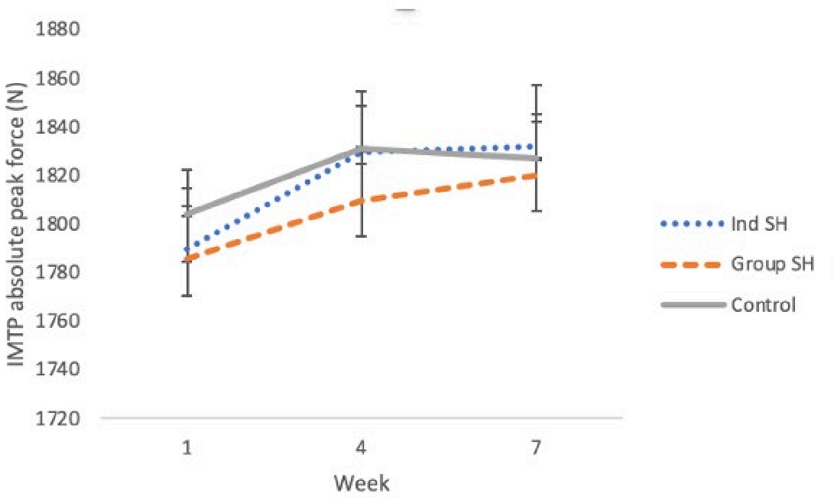

Figure 6.9: Changes in IMTP absolute peak force across weeks 1-7.

Changes in IMTP relative peak force was not significant for any group x week or group x time interactions (**Figure 6.10**).

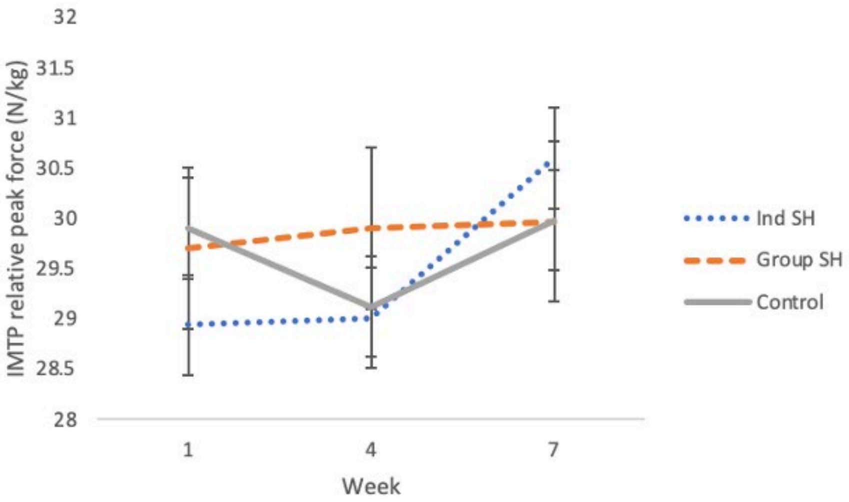

Figure 6.10: Changes in IMTP relative peak force across weeks 1-7.

6.5. DISCUSSION

The aim of this investigation was to determine whether SH interventions could positively affect strength and power outcomes for female athletes, via improved sleep indices, and whether the addition of individualised SH education (alongside group-based education) would provide greater benefit to sleep factors, above a single group-based session. Individualised SH education resulted in significant improvements to all measured sleep indices compared to a control group, and significantly improved sleep quality compared to group-based SH. Results suggest that the implementation of SH education could be beneficial to jump performance, with athletes receiving individualised SH demonstrating significantly improved jump performance compared to those exposed to solely group-based education or none. Findings also demonstrate that maximal strength performance was not significantly affect by sleep indices.

6.5.1. Sleep effects on strength and power performance

Participants receiving individualised SH demonstrated significantly improved CMJ performance concurrent to significantly improved sleep indices across weeks, suggesting improved sleep to be beneficial in enhancing jump performance. Whilst there is limited comparable previous research, some findings of this study are in agreement with the available literature regarding improved physical performance following sleep extension. Sleep extension studies on athletic populations have previously demonstrated improved reaction times (Waterhouse et al., 2007), sprint times (Mah et al., 2011), tennis serving accuracy (Schwartz et al., 2015) and endurance performance (Roberts et al., 2019), thus this study adds to the research body by demonstrating improved jump performance with improved sleep factors. This supports conclusions from earlier work, demonstrating the opposite effect with sleep restriction, where decreases in vertical jump height were evident (Cullen et al., 2019; Takaeuchi, 1985), thus it would appear that jump performance is indeed affected by sleep variables. Although it was beyond the scope of this study to investigate underlying physiological mechanisms, it could be postulated that the observed sleep improvements increased intra and inter-muscular coordination, as well as neural drive, two key variables for successful jump performance. Insufficient sleep has been associated with increased adenosine, a neuromodulator that has a general inhibitory effect on neural activity (Boonstra et al., 2007), inhibiting neural drive. Furthermore, a lack of sleep has been shown to reduce joint coordination (Mah et al., 2019), which may negatively affect jumping biomechanics. By improving sleep indices, it is feasible jump performance may have been enhanced via the optimisation of neural factors and increased joint coordination.

Results from the present study demonstrated improved sleep factors to have no significant effect on strength performance. Previous literature regarding the effects of sleep on strength performance are mixed; Reilly and Piercey (1994) showed decreased performance of deadlift, leg press and bench press following sleep restriction, whilst other studies have demonstrated strength performance to be maintained during periods of sleep deprivation (Cullen et al., 2019). Differences in previous findings could be attributed to methodological differences, with Reilly and Piercey (1994) utilising strength movements requiring a greater degree of technical ability (deadlift, bench press, leg press) and therefore neurological processing, than maximal tests requiring less technical aspects and less coordinated movements, such as handgrip (Cullen et al., 2019) or IMTP, as used in the present study. Additionally, external motivation has been cited as being an important factor in modulating the effects of sleep variability on performance (Taheri and Arabameri, 2012), with differences in verbal motivation potentially contributing to prior conflicting results. In the absence of comparable studies investigating sleep improvements on strength performance, the present study supports the work of Cullen et al. (2019) suggesting maximal strength performance may be unaffected by sleep status.

6.5.2. Methods of delivery of SH education

Results suggest the addition of individualised SH delivery to be superior to solely group-based SH delivery for improving sleep indices. Given the high intra and inter variability of sleep factors, it seems logical that the inclusion of individualised SH would demonstrate greater improvements, and thus results provide key information for coaches when considering optimal strategies to improve athletes' sleep. Strengths of the present study are the ecological validity, and the relatively short education sessions that were used. Previous research has implemented longer group-based SH education sessions (~2 hours, Dunican et al., 2020, 50 minutes, O'Donnell and Driller, 2017), whilst the present study implemented a single group-based session of 40 minutes and individualised sessions of 30 minutes and 20 minutes on consecutive weeks. With time pressures in elite sport high, this study presents a promising, time-efficient method of sleep education to improve both sleep and jump performance. In this study, football performance was not measured, but previous research has demonstrated vertical jump performance may be a strong predictor of football performance (Sawyer et al., 2002), with the authors highlighting even small increases in jump performance may make for a significant benefit to aspects of football performance (Sawyer et al., 2002). Therefore, improving sleep factors via SH may be one such way to gain additional performance benefits without any additional physical load.

The present study is novel in its approach, implementing improvement to a variety of sleep variables via sleep hygiene education, rather than focusing on solely extending sleep via napping (Waterhouse et al., 2007) or instructions to simply stay in bed longer (Mah et al., 2011). Athlete engagement in recovery strategies has been shown to be an important construct in the success of the intervention, whilst furthermore, the notion of engaging the athlete in education around their own sleep may have the added benefit of providing longevity to sleep improvements. Athlete education on recovery parameters has previously been advised (Crowther et al., 2017). Saunders et al. (2020) stated active learning, i.e., the direct engagement with learning materials via discussion or debate, to be a key condition for success of the educational intervention, thereby providing further rationale towards the use of individualised, sleep education for athletes, involving discussion and mutual collaboration. The athletes' perception of sleep interventions is likely to be critical to outcome success: specifically, if an athlete believes in the strategy being administered, they are more likely to fully engage with the process. Crowther et al. (2017) suggested athletes perception of the effectiveness of different recovery is likely to be individual, but a common theme for successful "buy in" to recovery strategies include highlighting the importance of the strategy to physical performance outcomes.

From week 4-7, there is evidence of a small decay effect within those exposed to solely group-based SH for sleep duration and ASBQ score. Previous studies have demonstrated the transient nature of the benefits related to SH education (Caia et al., 2018), and it would appear the present sample follows a similar pattern, although both aforementioned sleep factors remain enhanced from baseline level and the level of change non-significant. The implementation of individualised SH education is likely to have served as a “top up” to the group-based session, providing individuals with the chance to tailor generic advice to fit with their own lifestyle and habits, plus also reinforcing previous information. Whilst it is unclear whether the improved sleep indices within the Individual SH group were the result of cumulative effects of experiencing both group and individualised sleep education, results highlight the importance of some level of individualised SH education to be included within sleep education for athletes.

Due to imposed limitations on the study design, those receiving individualised SH education also received group-based education prior to this input, thus raising the question of whether dose is also a key consideration with the success of the intervention. O’Donnell and Driller (2017) showed a single group session of SH to be effective in improving sleep for female athletes, therefore previous evidence suggested a single educational input may be sufficient for improving sleep. As information from the group session was not repeated in the individualised sessions, this suggests the individual-specific topics covered were the primary drivers of success, rather than repeated exposure. Furthermore, if the additional (individualised) SH session was of equal value, it may be expected to see a steadier improvement across weeks, rather than a sharp increase from week 4-7 within that group.

The fact that this study was conducted with both naturally menstruating females and those on hormonal contraception may be viewed as another strength of the study, as results are representative of females at varying points of their cycle and throughout various hormonal changes, thus indicative of a wide representation of data. Loureiro et al. (2011) concluded MC phase to have no significant effect on strength performance. Similarly, García-Pinillos et al. (2021) found no significant differences in CMJ or sprint performance across different phases of the MC, although interestingly, despite lacking objective verification, self-perception of strength and power performance has been demonstrated to be lower around the time of menstruation (Carmichael et al., 2021). Participants within this study were not asked for self-perceptions of performance alongside objective testing but future research may look to employ this strategy to gain a deeper understanding into the complexities of optimising physical performance.

6.5.3. Study limitations and future research

Future research could be directed towards the incorporation of hormonal testing alongside sleep interventions to objectively determine MC phase. Factoring this into the analysis could then determine whether certain cycle phases affect sleep variables or impact the efficacy of the educational component. This was not feasible in the current study due to off-season timings, availability of players and total player numbers. Although the sample size met the *a priori* sample size requirements, each comparison group had a maximum of 12 participants in each. As such, the study may benefit from being repeated with a larger sample size to allow greater generalisability. However, with squad sizes in professional female football clubs usually much smaller than male squads, as detailed in **Chapter 1, Introduction**, the recruitment of larger sample sizes becomes challenging, and the use of squads from different clubs brings the additional challenge of reducing homogeneity across participants, particularly in regard to training hours and player availability, which is likely to affect the standardisation of interventions.

This study was conducted in pre-season; therefore, results may not be generalisable at different timepoints of a competitive season. Further research is required to establish if the application of individualised SH could translate into season-long sleep improvements, particularly given that previous research into SH education has commonly shown effects to be transient, with improvements to sleep indices diminishing over time (Caia et al., 2018; Vitale et al., 2019). Future research is also directed towards assessing individualised vs group-based SH education with identical dose responses, and a matched pairs design may be appropriate in this remit. Assessing SH interventions across the course of a season could then also translate into determining the optimal duration and frequency of sessions.

6.6. CONCLUSIONS

In conclusion, results suggest that the implementation of SH education can be useful to improve sleep indices and jump performance, with athletes receiving additional individualised SH demonstrating superior benefits to those exposed to solely group-based education or none. This could provide a novel way of performance enhancement for athletes. Furthermore, results should be interpreted with practical application towards providing coaches with guidance on the optimal delivery method of SH education, with the implementation of additional individualised input offering superior benefits to that of solely group-based delivery.

7. STUDY 4: THE USE OF INDIVIDUALISED, MEDIA-BASED SLEEP HYGIENE EDUCATION FOR PROFRESSIONAL FEMALE ATHLETES

7.1. ASBTRACT

Poor sleep hygiene (SH) is common amongst elite athletes and improving SH can be one way to enhance sleep. Given the large inter-individual variability of sleep, there is a need for further investigation into individualised SH for elite female athletes, with consideration for the practical application of the method. Using a self-controlled time series design with repeated measures, n=16 professional female footballers completed a 9-week study during mid-season. Monitoring of sleep (actigraphy, self-report) occurred at week 1, 4, 7 and 9 - a control period occurred at week 2 and 3, and an subsequent intervention period occurred at weeks 5 and 6. Based on baseline sleep monitoring, media-based messages were designed with the purpose of giving a singular SH message; all participants received these individualised messages daily across the 2-week intervention period at a standardised time of 8.00pm, with the intention of them actioning the SH point. One-way ANOVA with repeated measures were conducted to assess the differences between control period, intervention period and follow up for each measured variable. Significant differences were observed post- intervention for sleep efficiency ($P<0.001$), sleep latency ($P<0.001$), whilst Athlete Sleep Behaviour Questionnaire score significantly improved in the follow up period (week 9) post intervention ($p=0.039$). This is the first study to present this novel method of individualised SH education for elite female athletes and is also the first study to demonstrate the use of SH interventions to improve sleep factors for female athletes' mid-season. This demonstrates a promising, time-efficient approach to SH education, with a potentially wide scope of application, as well as demonstrating there is indeed potential for elite female athletes to gain sleep improvements mid-season.

7.2. INTRODUCTION

Sleep hygiene (SH) can be defined as practising habits that facilitate sleep, and avoiding behaviours that inhibit sleep (Mastin et al., 2006) - it is a simple, non-invasive, low-cost strategy which can be used to enhance both sleep quality and sleep duration. Poor SH is common amongst athletes, for a variety of reasons such as scheduling constraints, and lifestyle factors (Halson, 2019), with Sargent et al. (2021) reporting only 3% of athletes report satisfaction with their sleep. Many aspects of physical performance, such as sport-specific skills and speed, are positively affected by sleep (Walsh et al., 2021, Mah et al., 2011, Schwartz and Simon, 2015). Costa et al. (2022) stated the importance of sleep for emotional regulation and maintaining overall mental health in athletes, as well as reducing potential illness and injury risk. Despite this knowledge, more than 70% of athletes are regularly operating in a sleep debt (Sargent et al., 2021), therefore strategies for sleep enhancement must be considered a priority by coaches. Sleep hygiene education is one such method that has previously been demonstrated to be an effective tool to enhance athletes' sleep (Caia et al., 2018).

O'Donnell and Driller (2017) found SH education resulted in significantly improved total sleep time (mean improvement 22.3 ± 39.9 min), wake variance and wake episode duration for elite netballers. These findings are supported by Caia et al. (2018) and Driller et al. (2019) who both demonstrated SH education sessions to be effective for improving sleep factors for elite male rugby players and elite male cricketers respectively. Despite the vast inter and intra individual variation of sleep (Costa et al., 2019), only very few studies have utilised an individualised SH education approach within athletic populations, yet as demonstrated in **Study 3**, the use of individualised SH education would appear to be important. Driller et al. (2019) provided 30-minute individualised SH education for 9 male cricketers, during which athletes were given feedback on their baseline sleep measurements, as well as practical tips to resolve any self-reported issues. In terms of the measured sleep variables pre-to- post, there were significant improvements in sleep efficiency % (5%, d = 1.38, very large), latency (−29 min, d = −0.85, large) and sleep onset variance (−28 min, d= −0.88, large) following the intervention. In a case study of a male academy footballer, Edinborough et al. (2023) found an individualised SH education intervention, based on participant discussion around self-reported issues, as well as general SH advice, to be effective in improving wakings per night (Pre: 7.9 ± 3, Post: 4.5 ± 1.9, −43%) and wakings per hour (Pre: 1.2 ± 0.5, Post: 0.6 ± 0.2, −50%), coinciding with an improvement in the athletes' self-report of Pittsburgh Sleep Quality Index.

Studies have also reported more prominent intra-individual variation in sleep efficiency and sleep latency in professional footballers, as well as wider athletic populations (Leeder et al., 2012) compared to age-matched non-athletic controls (Whitworth-Turner et al., 2018). Given the amount of individual variation within sleep and lifestyle factors, an individualised approach would seem logical where possible, yet this approach is not commonly used, perhaps due to the potential lack of resources, or increasing time-burdens on coaches within sporting environments (Low et al., 2023). The cause of such individual variation is likely multifactorial yet commonly overlooked. Indeed, Fullagar et al. (2016) suggested habitual tendencies render the prescription of generic sleep recommendations illogical.

With time pressures on coaches within elite sport high, there is a need to investigate novel, time-efficient methods of SH delivery which can also be individualised. Recent research has shown a move towards more novel methods of SH education; Hassanin et al. (2023) used SH videos (2.44 – 3.27 min long) with 5th and 6th grade children (n=49), with the cartoon videos designed to educate on the importance of sleep and practical tips. The authors observed a positive change in Pittsburgh Sleep Quality Index score, 13.6% improvement in sleep duration, 10.9% improvement in sleep disturbance and 22% improvement in sleep latency. Similarly, in a pre-intervention study, Putri (2023) described the initial trials of SH videos (3-6 min long) for the elderly, with all videos delivered via WhatsApp for the reasons of cost and time efficiency. To the authors knowledge, no research exists on the development and use of media-based SH delivery to athletes, and importantly female athletes, yet this could provide a practical, time efficient method of SH education with a broad scope of use. Walsh et al. (2021) highlighted that SH education should be delivered multiple times throughout a season, a notion further supported by the evident transient effects of singular bouts of SH education in athletes (Caia et al., 2018; Vitale et al., 2019). Therefore, given lack of time and / or resources was the most cited barrier to sleep monitoring from a range of practitioners working within elite sport (Hough et al., 2021) and that approx. 70% of athletes use their electronic device in the evening (Knufinke et al, 2018), the development of media-based SH education that facilitates repeated exposure to SH education with minimal additional coach workload, warrants investigation. Liang et al. (2024) noted gamification and technology-based interventions may increase engagement with SH strategies. Therefore, the aim of this study was to ascertain the efficacy of delivering visual media-based SH education (using both animated Graphics Interchange Format (GIF) and single sentence messaging), and whether this could positively affect athletes' sleep indices. Given previously evidenced success in differing cohorts, it was hypothesised that media-based SH interventions would improve sleep indices for professional female athletes.

7.3. METHODS

7.3.1. Participants

Sixteen professional female footballers (mean age 24.4 ± 2.6 yrs) gave written informed consent and volunteered to take part in the study (**Figure 7.1**). According to the classification by McKay et al. (2022), participants were classed as Tier 4 and 5.

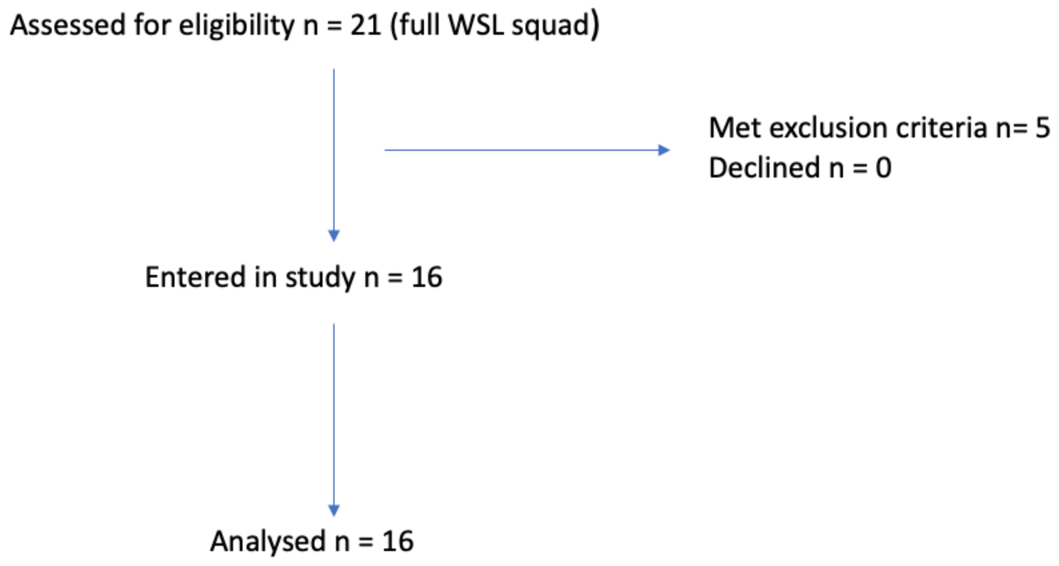

Figure 7.1: Recruitment process for the study.

All participants were currently playing regularly in Women's Super League (WSL), which is the highest level of women's football in the United Kingdom; n=6 were established international players for their respective countries. Full demographics are detailed below in **Table 7.1**.

Table 7.1: Participant demographics

Participant demographics		
	Mean	SD
Age (years)	24.4	2.6
Height (cm)	168.3	9.1
Mass (kg)	64.6	10.1
Weekly training hours (football)	10.1	3.9
Weekly training hours (gym based)	3.1	0.6

During the study, a total of 8 WSL matches were played, with mean playing time 68.7 ± 35.9 min. Across all participants, n=8 reported regularly taking hormonal contraceptives (type unspecified), whilst n=8 were classified as naturally menstruating women, (according to the definition by Elliot-Sale (2021). Prior to the commencement of the study, all participants were informed of study requirements and gave informed consent. Participants met inclusion criteria and did not meet any exclusion criteria detailed within **Chapter 3, General Methods.** Institutional ethical approval was issued (approval number 2023-12896) in accordance with the principles of the Declaration of Helsinki 1964 (revised 2013).

7.3.2. Experimental procedures

A self-controlled time series design, with repeated measures, was used; each participant completed a control period and an intervention period, meaning each participant could act as their own control across the study duration. This approach was taken due to the relatively small sample size available, to maximise statistical power (Peterson et al., 2016) and is well suited for preliminary testing of novel interventions where a strong evidence-base does not yet exist (Brown et al., 2020). A schematic of the study method is presented below in **Figure 7.2**.

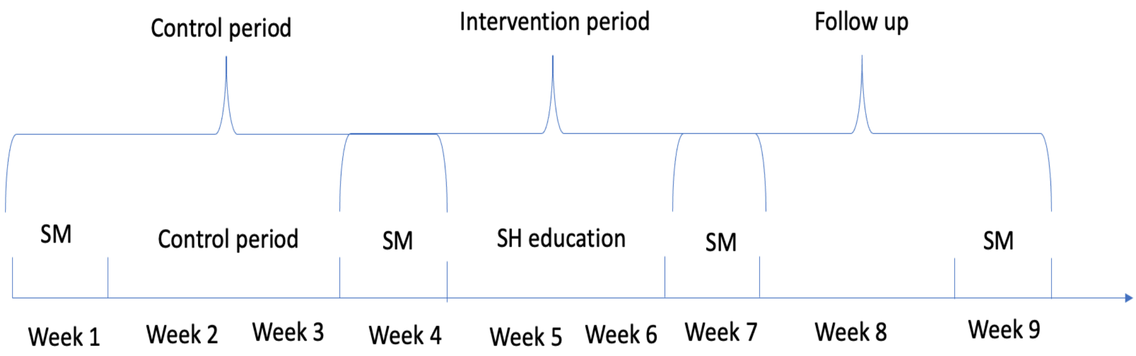

Figure 7.2: Schematic of study method detailing the week-by-week approach (SM: Sleep monitoring, SH: sleep hygiene).

7.3.3. Sleep monitoring weeks 1, 4, 7 and 9

All participants were allocated an actigraph (GeneActiv Original, Activinsights, Cambridge UK) which they were instructed to wear continuously during monitoring weeks, only removing for matches. Every morning during sleep monitoring, participants were asked to provide a self-report (Likert scale 1-5) of sleep quality, which was reported directly to coaches via the club's daily wellness check ins, and then sent to the researcher via an Excel file. All participants completed the Athlete Sleep Behaviour Questionnaire (ASBQ) (Driller et al., 2018) and rMEQ (Adan and Almirall, 1991).

7.3.4. Control period weeks 2 and 3

Participants were instructed to carry on with daily routines as normal. No information was given to participants regarding their baseline sleep data recorded from week 1.

7.3.5. SH education weeks 5 and 6

Baseline sleep data for all participants was reviewed by the lead researcher (myself). Any item scored above a "3 = sometimes" on the ASBQ was identified as an area for improvement and was reviewed in conjunction with actigraph data to determine the optimal approach for improvement. These identified areas were viewed holistically (i.e., with consideration for other aspects outside the remit of sleep), as suggested by Mastin et al. (2006). Following this, I held brief discussions (10 min) with each participant with the aim of allowing SH factors to be viewed in the context of each individuals' lifestyle, so I could then consider optimising individual daily routines and habits.

7.3.6. Development of media-based SH education tool

For each participant, target areas of SH were identified from the data, from which a GIF was developed from Adobe Stock Library videos. A suitable video was chosen, which was then converted into a GIF for the purpose of giving a concise, simple message. The message was accompanied by purposely short text, to facilitate a high engagement rate (Hassanin et al., 2023). Where participants had multiple areas for improvement, priority was selected in conjunction with knowledge around participants' daily routines and individual discussion. Prior to the start of the intervention period, a 10-minute group briefing session informed participants that they would be receiving a daily message via WhatsApp for the next two weeks, from which they should try and initiate the action point within the message, that evening. Interpretation of baseline sleep data alongside individual participant discussions presented the following areas for SH improvement across all participants, from which media-based messages were developed with the aim of targeting improvement within that remit (**Table 7.2**).

Table 7.2: Summary of individualised media-based advice provided to players within the intervention period.

Issue and observation method	**Strategy**	**Content of recommendation (Gif image and wording)**	**Rationale**	**Number of participants for which this was used**
Technology use before bed (ASBQ)	Screens away 30min before bed	 Screens away 30 min before bed.	Limiting phone use 30 min before lights improved sleep duration (Fullagar et al., 2016), reduces sleep latency and improved sleep quality (He et al.,2020). Social media use before bed has a negative effect on sleep quality (Watkins et al., 2022).	15
Poor sleep regularity (ASBQ, actigraph)	Maintain regular bedtimes		Consistency in sleep timing is key for improving sleep	12

		Choose a bedtime and stick to it daily.	efficiency in athletes (Halson et al., 2022). Sleep regularity shown to have positive effects on sleep duration (Phillips et al., 2017).	
Evening stress, worrying about sports performance (ASBQ, discussion)	Evening stretching routine	 Go through recovery stretches this evening before bed*	Stretching in the evening can reduce sleep latency and promote onset of sleep (D'Aurea et al., 2019; Bender et al., 2024). Short stretching beneficial for reducing anxiety (Montero-Marin et al., 2015).	10
Poor evening routine and long sleep latency (ASBQ,	Reading in bed before sleep onset	 Make reading your final activity before sleeping.	Reading in bed increases melatonin concentration compared to tablet use (Jones et al.	4

actigraph, discussion)			2018) and may improve sleep quality (Finucane et al., 2021).	
Bedroom environment (ASBQ, discussion)	Maintain a cool, dark, and quiet bedroom	 Ensure your bedroom cool, dark and quiet.	Bedroom environment should be cool (17-23degrees) (Caddick et al., 2018, Pan et al., 2011) dark (complete blackness) (Caddick et al., 2018) and quiet (<35dB) (Caddick et al., 2018) to optimise sleep quality (Brown et al.,2002).	3
Evening light exposure (ASBQ, Discussion)	Use lamps in the evening	 Turn off the main light! Use lamps this evening.	Bright evening light can suppress melatonin secretion, negatively impacting sleep latency and sleep quality	2

			(Bender et al., 2024)	
Evening caffeinated drinks** (ASBQ, discussion)	Replace with non-caffeinated herbal tea or water	 Replace evening caffeine with herbal tea or water.	Caffeine consumption <6 hours before bed has disruptive effects on sleep (Drake et al., 2013).	2

*Participants were familiar with a recovery stretching routine aimed at relaxation which was used within their usual training environment as part of recovery protocol.

**No evening matches were scheduled during the intervention period; therefore, evening caffeine use in this context refers to the habitual consumption of caffeinated drinks as a lifestyle choice rather than a performance-enhancement effort.

7.3.7. SH Message delivery

Each participant was allocated 3 messages; only one was sent per day, which was texted directly to the participant's phone. Another message from their allocation would then be sent the following night. When all their allocation had been used, the first one was sent again in a rotation for the duration of the intervention period. The timing of the messages aimed to optimise the impact, with all messages sent in the early evening (8.00pm), giving 2.3 ± 0.65 hours between timings of messages and bedtimes. This aimed to give enough time for the participants to action the point and consider the point as part of their evening routine. Technical coaches had informal conversations with participants during the intervention period (during regular scheduled training sessions) to discuss any potential issues and ensure messages were being received - no participants raised any concerns. Coaches continued to verbally encourage adherence throughout the intervention period. Adherence to the intervention was monitored via a subjective report the following morning. Specifically, participants were asked to provide a simple “yes” or “no” as to whether they implemented the suggested action and provide a subjective value of how difficult it was for them to implement the SH suggestion the previous night (0= very difficult, to 10 = very easy), as demonstrated by Vitale et al. (2019). This was reported via Microsoft Forms.

7.3.8. Statistical analyses

Descriptive statistics (mean ± SD) were calculated for all variables. Data was checked for normality using Shapiro-Wilk tests, and inspection of skewness-kurtosis. Once data met assumptions for parametric statistical analyses, one-way ANOVA with repeated measures was conducted to assess the differences between control period, intervention period and follow up for each measured variable. Tukey’s Post Hoc tests were used to determine where any potential significance lay between the weeks. Partial Eta squared was reported for ANOVA analysis to give an indication of effect size, with values of 0.01, 0.06 and 0.14 considered as small, medium and large effect sizes respectively (Lakens., 2013). The data was median split for each measured variable, with percentage change presented to demonstrate differences between pre and post data for each group plus effect sizes to show magnitude of change. Threshold effect sizes for percentage changes were considered as follows, based on Hopkins (2009): trivial ≤0.2, small >0.2, >0.6 moderate, >1.2, ≥2.0 very large.

7.4. RESULTS

A total of 448 observations were taken from 16 participants across a 9-week period (4 different testing weeks). Week 1 chronotype distribution of participants was as follows: evening type 25% (n=4), neither type 44% (n=7), morning type 31% (n=5). No significant differences were observed between weeks 1-4 for any monitored variable (control period).

7.4.1 Adherence and ease of implementation

Total adherence to the intervention was 97% across all participants. Participants graded the ease of following all recommendations 7.00 ± 2.19 on the 10-point scale (0 being very difficult, 10 being very easy). **Table 7.3** below presents the mean ease of implementation score for each SH suggestion.

Table 7.3: Mean ± SD participants subjective rating for ease of implementation of each suggestion on the 10-point scale.

Sleep hygiene intervention	Mean ease of implementation score	Standard deviation
Screens away 30 min before bed	5.17	0.65
Maintain regular bedtimes	4.06	1.11
Evening stretching routine	8.64	0.61
Reading in bed before sleep onset	8.52	0.79
Maintain a cool, dark, quiet bedroom	5.11	0.58
Use lamps in the evening	9.29	0.86
Replace evening caffeine with alternatives	8.35	0.86

7.4.2. Sleep indices

Individual and mean data for each measured variable are presented below in **Figure 7.3**.

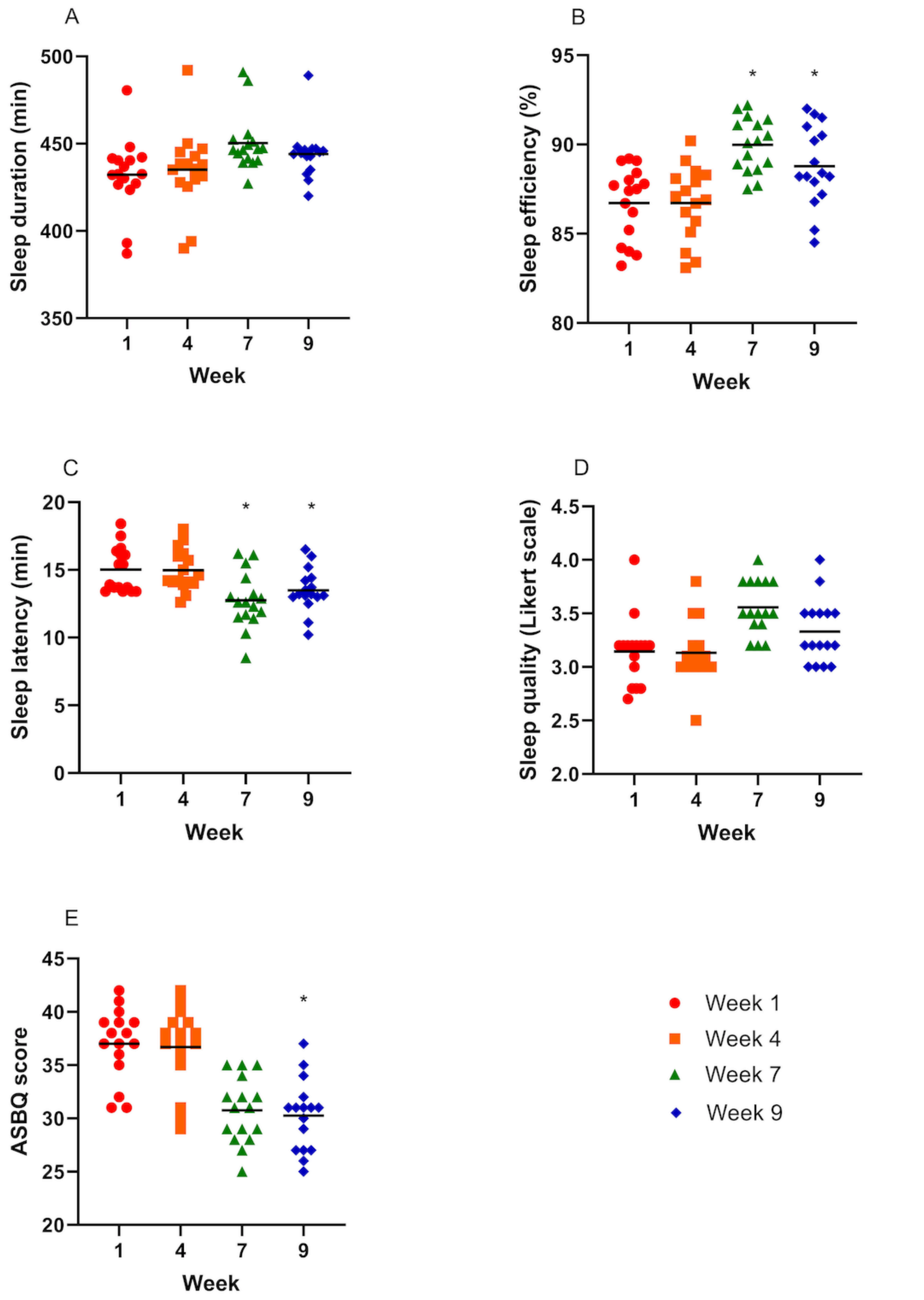

Figure 7.3A-E: Scatter plots indicating the spread of data and means (indicated by black line)

for each measured variable. * $p<0.05$ for inter-week differences from control period to post-intervention. Plot C and E, a decrease in mean value indicates an improvement that the indices.

Sleep efficiency

Sleep efficiency significantly increased between week 4 and week 7 ($F (3, 444) = 10.2$, $P<0.001$, $\eta p^{2} = 0.12$) and between week 4 and week 9 ($p<0.001$).

Sleep latency

Sleep latency significantly decreased (indicating a more favourable sleep latency) between weeks 4 and 7 ($F (3, 444) = 13.6$, $p<0.001$, $\eta p^{2} = 0.08$), and between week 4 and week 9 ($p<0.001$).

ASBQ

Self-reported ASBQ scores significantly decreased (indicating more favourable sleep behaviours) between week 4 and week 9 ($F (3, 60) = 5.69$, $p=0.039$, $\eta p^{2} = 0.22$).

Median split of data for each measured variable demonstrated those starting with lower baseline scores across all variables, showed a greater percentage change following the intervention period (**Figure 7.4** and **Table 7.4**).

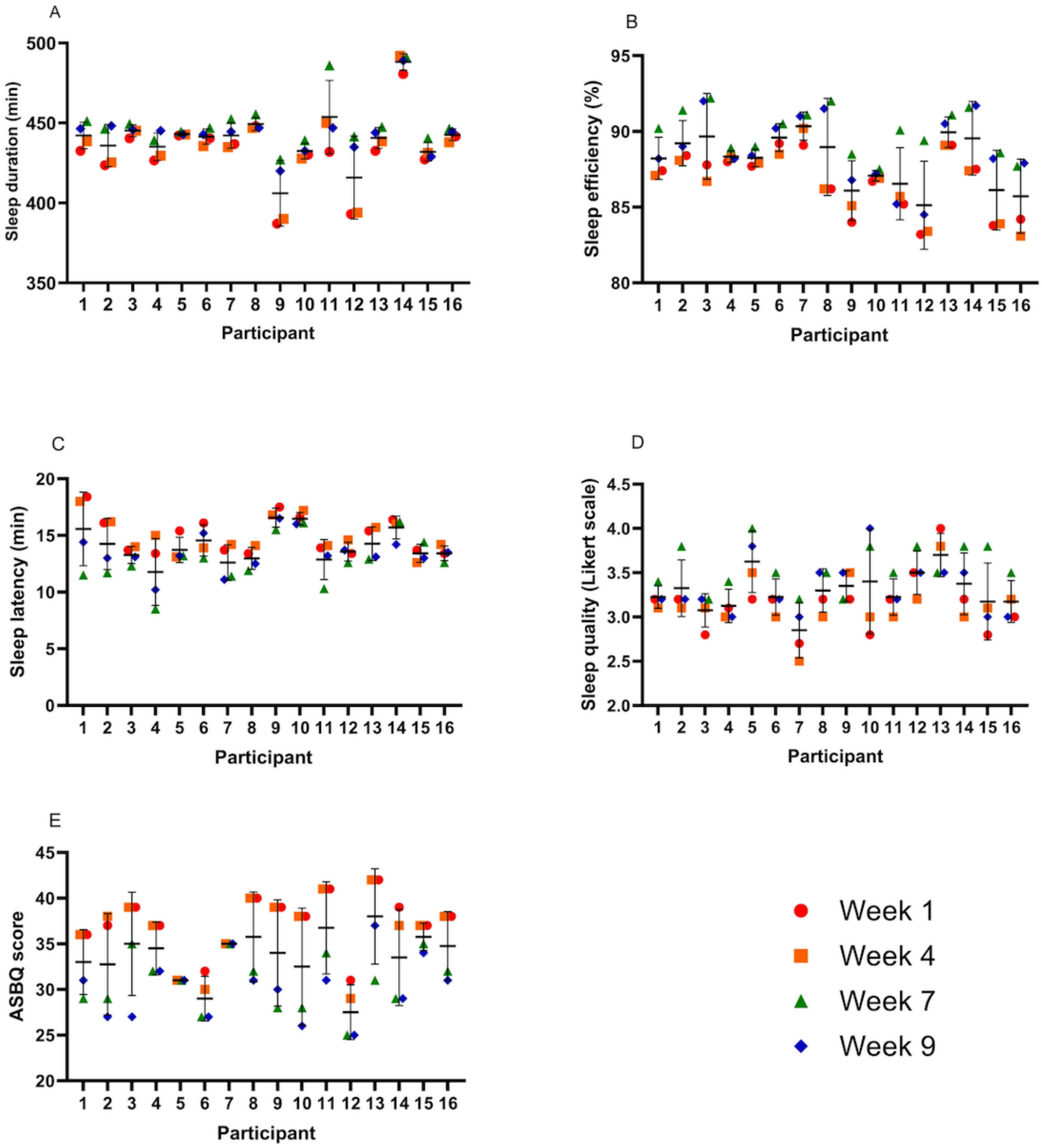

Figure 7.4: Individual data plots for each measured variable.

Table 7.4: Median split data percentage changes for the upper and lower halves of the data across all variables following the intervention period and follow up period.

	Median group	Week 4-7 (%)	Effect size	Week 7-9 (%)	Effect size
Sleep duration	Upper	5	1.0, moderate	-0.1	0.2, trivial
	Lower	12	1.4, large	-1.3	0.6, small
Sleep efficiency	Upper	2	0.5, small	-0.9	0.1, trivial
	Lower	16.3	3.1, very large	-1.6	0.6, moderate
Sleep latency	Upper	16.8	1.6, large	-11	0.9, moderate
	Lower	19.7	1.8, large	-2.9	2.4, very large
Sleep quality	Upper	3.1	0.3, small	-0.3	0.1, trivial
	Lower	2.1	0.2, small	-0.9	0.1, trivial
ASBQ	Upper	3.1	0.4, small	1.9	0.3, small
	Lower	20.9	5.3, very large	5.4	0.6, moderate

For all variables across the intervention period apart from sleep quality, the lower split of participants demonstrated greater percentage improvements than the upper split.

7.5. DISCUSSION

The aim of this study was to ascertain the efficacy of delivering media-based SH education (using both animated Graphics Interchange Format (GIF) and single sentence messaging), and whether this could positively affect female athletes' sleep indices. The main findings were that using media-based SH education across a two-week period had significant positive effects on sleep efficiency, latency and ASBQ scores. Therefore, initial evidence highlights a promising strategy for a remote, individualised SH education intervention, demonstrating a time efficient method of improving the sleep of professional female footballers during mid-season. Furthermore, this strategy provides the potential for athletes to access specialist advice in sleep, without the constraint of location for both parties.

Visual media to portray an educational message has several advantages, namely that the message conveyed is packaged attractively so that it will be easily remembered by the audience, is not limited by distance or time, and can be repeated (Maramis, 2020). Tuong et al. (2014) showed that media interventions were variably effective in modifying health behaviours depending on the target behaviours to be influenced - results of the present study suggest sleep behaviours may indeed be modifiable by visual media interventions, with female athletes in the present study demonstrating improvements in SE (week 4-7 improvement +2.9%), SL (week 4-7 improvement -3.6min) and ASBQ score (week 4-9 improvement -4.2 reduction on ASBQ score). This concurs with Asih et al. (2024), who concluded SH education, delivered via an animation video as a first-line strategy, to be beneficial in improving SH practices, although it should be noted Asih et al. (2024) investigated a different population (pregnant women, n=108). Similarly, Nisa et al. (2021) advocated the use of WhatsApp messaging to increase knowledge and attitudes around sleep amongst adolescents (n=82, 40 intervention, 42 control). To the authors knowledge, this study is the first to apply this novel method of SH education to an athlete population.

Adherence to the strategy was high, with 97% adherence throughout the intervention period. Previous ease of implementation to SH interventions has been reported as 6.35 ± 2.7 on the 10-point scale by Vitale et al. (2019). In comparison, the present study reports a subjective grading of 7.00 ± 2.19, suggesting the messages used in the present study may be easier to implement than the combination of in-person education and leaflet used by Vitale et al. (2019).

Adherence and ease of implementation are not commonly reported in SH studies, with Harada et al. (2016) the only other study to present similar information, reporting an intervention index to SH education, which correlated to improvements in football performance ($r = 0.42$, $p=0.0003$).

Jenkins et al. (2021) concluded the delivery of generalised, group-based SH education mid-season had no effect on sleep parameters for professional rugby players. The authors alluded that SH education may only be useful during times in the season with lower stressors, such as pre-season, a notion supported by the fact that comparable studies demonstrating positive results of SH interventions were conducted pre-season (O'Donnell and Driller, 2017, Driller et al., 2019). To the authors knowledge, Caia et al. (2018) is the only study demonstrating positive effects of SH delivery in mid-season for professional athletes (rugby), although this was a male cohort. However, the approach used by Caia et al. (2018) was median split, meaning those who slept less and had worse sleep habits, received SH education, while those who slept more, received no SH education (control group). Whilst this approach is logical from a practical perspective (as individuals with a worse sleep status may benefit more from improvement), the absence of a balanced control group means this may not give an accurate representation of the effectiveness of SH education mid-season. The present study adds to the knowledge around the potential usefulness of SH education mid-season for professional athletes, demonstrating an alternative, effective method for mid-season sleep improvements, and is the first study to present this information for professional female athletes.

Electronic device use in the evening may serve as a distraction before sleep, potentially resulting in the device being used into usual bedtimes (Jones et al., 2021), and this factor should be considered around the timing of media-based sleep reminders to remove the risk of the intervention becoming counterproductive in compounding a common issue for problematic sleep. Indeed, Monma et al. (2023) reported 77% of judo athletes (mean age 22.9

± 3.1) used their phones in bed after lights out, with a prevalence of poor sleep 40.7%. In the present study, messages were sent at a standardised time of 8.00pm, which aimed to allow time for actioning the message, whilst also being cognisant of the potential for negative effects of phone use closer to bedtime. In a larger cohort, time of messaging could be individualised further to be more impactful, with the potential for automated messaging to be set up for each athlete from a centralised system, ensuring this remains a simple and viable method for coaches of larger groups.

When looking at the data median split, it is interesting to note that participants within the lower scoring group across all variables apart from self-reported sleep quality, had the greater magnitude of improvement compared to those in the upper group (**Table 7.4**). Dunican et al. (2023) delivered SH education to recreational swimmers (n=11 male, n=13 female) and found no significant differences in sleep pre-post. The authors alluded to a potential ceiling effect for SH education, given that the pre-test data showed sleep factors that were close to optimal recommendations. This may explain the difference in magnitude of improvements in the present study, with those starting from a lower baseline having greater potential for improvement than those who were already close to recommendations. These results support the previous postulation from Vitale et al. (2019), who suggested SH interventions may be of greater benefit for athletes reporting worse sleep behaviours. From a practical perspective, this information may be of value in the potential prioritisation of intervention within a professional sport setup.

During the follow up period (week 9), results showed a decrease in sleep duration (5 min decrease), efficiency (1% decrease), latency (6 min increase) and quality (-0.2 reduction in Likert rating) compared to week 7, although sleep duration, efficiency and latency were still improved from baselines. SH interventions have commonly been shown to have transient improvements; Caia et al. (2018) found sleep indices were comparable to baselines one-month post SH education for professional male rugby players. This notion is further demonstrated by Vitale et al. (2019) who implemented a 45 min group-based SH session prior to an evening football match, with sleep factors monitoring 1- and 2-nights post-intervention. The authors demonstrated comparable sleep factors to baseline 2 days post SH intervention. Results of the present study suggest a slower decay effect than Vitale et al. (2019), likely due to methodological differences, with Vitale et al. (2019) implementing a singular bout of SH education. This could infer the use of repeating SH messages to be of greater benefit for maintaining sleep improvements than singular inputs.

7.5.1. Study limitations and future directions

The novel method presented in this study demonstrated proof of concept of a media-based approach to SH education. However, it should be noted that long term adherence may be problematic, particularly once the novelty of messaging wears off for a participant. The SH strategy used within the present study is conducive to intervention "top ups" and thus a longitudinal study over greater duration (i.e., over a season) may be relevant in determining an intervention period followed by a "maintenance period" approach, with potential consideration for stimulus change via different imaging or wording to maintain interest.

Sample size was limited in this study due to athlete availability and overall squad size, and the study would benefit from being repeated with a larger participant group to increase statistical power. The method of SH education used in this study means success of the intervention cannot be attributed to a single change in athlete behaviour, therefore further research is suggested to determine the level of impact each message may have. This would allow for a more targeted, and potentially more efficient and effective, approach to be implemented. Additionally, future research should aim to determine a minimal dose response, and whether there is a dose effect threshold. Investigating athletes from different sports and within different environments would be beneficial to understand the efficacy of this strategy amongst different cohorts, whilst a longer intervention and follow up period may be of interest to determine whether effects can be sustained throughout a season. Further research should look to conduct the study with a sample size suitable to determine whether chronotype preferences affect responsiveness to the intervention - this study did not meet minimum sample size requirements to run multiple regression analysis to determine this (Jenkins and Quintana, 2020).

7.6. CONCLUSIONS

This study presents a novel, media-based method of SH education for professional female athletes, which has shown to have significant positive effects on sleep efficiency, latency and ASBQ scores across a two-week intervention period during mid-season. This suggests the use of media-based SH interventions may be a promising, time-efficient approach to SH education for professional female athletes, with a potentially wide scope of application. Future hypotheses for further investigation may be the suggestion that media-based SH delivery to professional athletes is more effective on improving a variety of sleep factors than in-person delivery due to the repeated nature and the timing of the delivery. Further research in this remit is suggested.

8. GENERAL DISCUSSION

8.1 Introduction

This chapter presents an overview of key findings of all experimental chapters within this thesis, followed by a critical interrogation of data across all studies, with application of context to other publications across the research base. Practical applications of this research are then presented. Sleep is considered vitally important for athletes, both as a recovery strategy and to optimise physical performance (Halson et al., 2024; Cunha et al., 2023), with studies examining sleep interventions for athletes growing exponentially over recent years (Lastella et al., 2020, **Figure 8.1).**

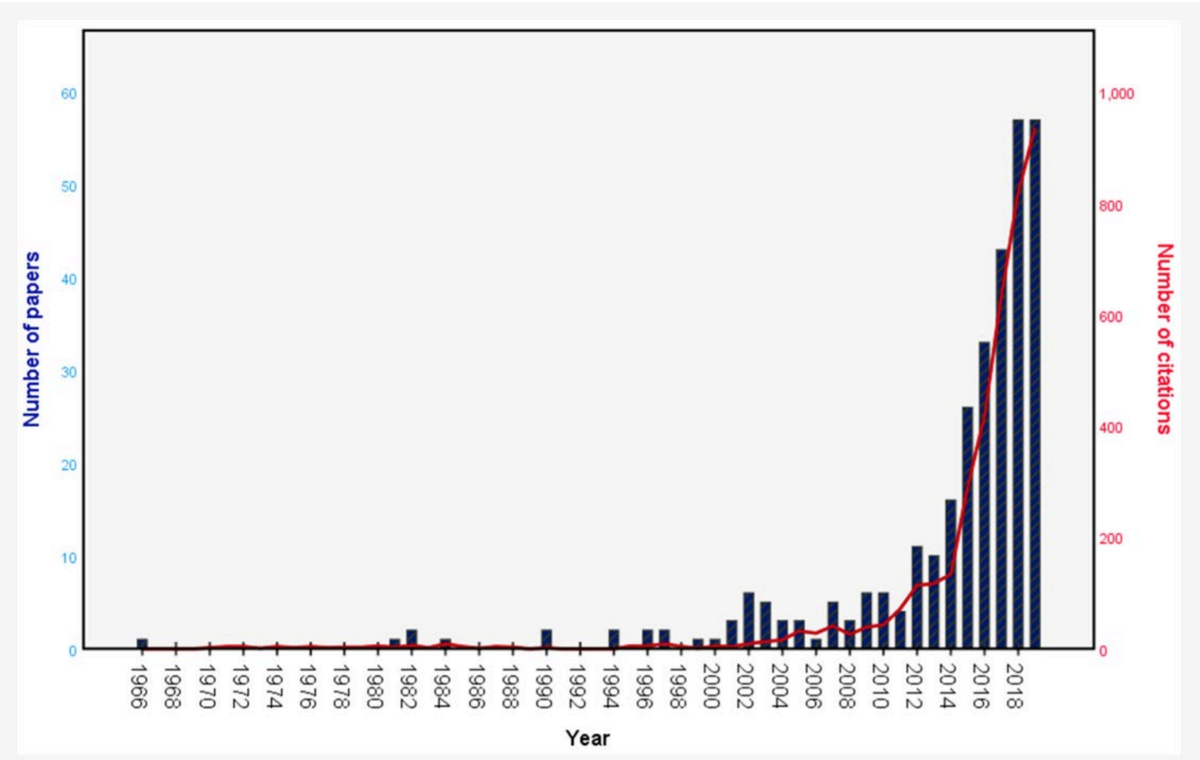

Figure 8.1: The trend of growth for sleep research outputs (Lastella et al., 2020). From 2011, there is a dramatic increase in both publications and citations, suggesting a growth of interest in this topic area.

The observed growth in interest around this topic is justified, given athletes commonly report a worse sleep status than non-athletic controls (Leeder et al., 2012; Walsh et al., 2021), yet have greater recovery needs (Halson et al., 2014). Whilst the increased body of research around this area is positive in terms of building knowledge around best practice, there remained a lack of data regarding sleep habits and potential methods of sleep improvement for female athletes, particularly with a view to understanding how this may affect sports performance. Identified gaps in the literature base were considered to develop the studies within this thesis, along with limitations of previous studies driving the methodological approaches. As such, this thesis offers novelty in methodological approach, participant demographic, research findings and potential reach to practitioners and athletes. The overall aim of this thesis was to gain an understanding of current sleep practices and sleep hygiene of female athletes, with a view to providing evidence-based recommendations for sleep improvements via SH interventions, considering optimisation of both recovery and sports performance.

8.2 Principal findings

8.2.1. Study 1

The aim of **Study 1** was to determine whether chronotype affected SH status, with secondary aims to identify commonalities across SH factors for female athletes to inform future educational interventions, whilst also considering sport type. To the authors knowledge, this study was novel in its approach, in being the first to present association between chronotype and SH, information which adds value in the process of athlete screening and monitoring. Data describing the chronotype of female athletes was lacking, with prior publications on athlete chronotype commonly conducted with a mixed-sex cohort (Biggins et al., 2019, Lastella et al., 2016), yet in the aforementioned studies, no sub-analyses were done based on sex. Given that the sample used within Biggins et al. (2019) was 41% female, and Lastella et al. (2016) was only 22% female participants, any inferences to professional practice for female athletes, made from conclusions from these studies, are highly likely to be skewed from the presence of male data. Furthermore, there remained a lack of evidence detailing SH factors for female athletes. Knufinke et al. (2018) aimed to identify SH aspects of elite athletes (n=98) with a view to informing SH education, yet this sample contained male data (n=56 females), and again, as sub-analyses were not done on sex, conclusions regarding directions for SH education for female athletes, is unclear. Therefore, it was important to understand the current SH practices of female athletes firstly, to direct methodology for later studies, and secondly from a practical viewpoint, to inform athlete monitoring and SH education.

Results showed reporting an evening chronotype preference predicted for a worse SH status, whilst conversely, those reporting a morning chronotype had a more favourable SH status. This information could be useful in determining athletes who may be more susceptible to poor sleep habits, in order to prioritise intervention, and is suggestive of the need for chronotype screening as part of athlete monitoring. Team sport athletes were shown to have a worse SH status than those from individual sports. Although the investigation of underlying reasons was beyond the scope of the study, it was postulated that this may be due to the lack of control over scheduling decisions (training and competition), and the increased regularity of competition athletes from individual sports usually face. This key finding provided rationale towards conducting subsequent experimental studies on team sport athletes. Across all participants, frequency analysis demonstrated the worst scoring areas of SH to be those of sleep regularity, active behaviours, and psychological factors, which provided guidance to allow for bespoke interventions in Study 3 and Study 4. With time pressures in elite sport being high, having the ability to prioritise focus areas of SH may increase efficiency and efficacy of educational interventions.

Within this study, 144 female athletes, all of whom were competing at a minimum of national level in their respective sports, volunteered to take part. This sample included 4 participants who were under the age of 18, yet findings showed no significant differences in global SHI or ASBQ scores between age group quartiles. Whilst this is an interesting finding, and at surface level, may suggest there are no significant differences between athletes of different ages in terms of sleep hygiene factors, considerations around the limitations of using global questionnaire scores must be appreciated. Whilst global scores given an indication of overall status, and can be useful from a practical perspective, this fails to delve into the specifics underpinning why that global score has been achieved. For example, instances occurred where the summed questionnaires between the two participants reported identical global scores, yet the areas of poor scoring were different between individuals. Furthermore, even when individuals report the same scores, underpinning reasons may differ, and intervention should be considered in relation to the individual preferences of that participant, thus further research into differences in sleep factors between athletes of different ages is warranted.

8.2.2. Study 2

With the increase in the use of subjective sleep monitoring in a variety of sports settings, there was a need to determine whether sleep factors were being reported accurately and therefore if the data was practically useful. If subjective reporting of sleep durations were shown to be useful, the reduction in financial and time constraints would likely increase the ease of monitoring this parameter. Therefore, **Study 2** compared self-reported sleep duration and actigraph reported sleep duration, to determine levels of agreement between the two methods, aiming to inform working practice and guide methodology for subsequent experimental studies, both within this thesis and within the research body. Given that sleep quality is a poorly understood construct (Claudino et al., 2019), secondary aims were to determine which objective sleep parameters contributed to self-reported sleep quality, with a view to considering practical interpretation of this factor.

Previously, Caia et al. (2018) compared self-reported and actigraph reported sleep durations in male rugby players and suggested strong agreement between the two, based primarily from the interpretation of r=0.85. However, whilst the observed positive correlation suggests shared variance between the two measures (Giavarina et al., 2015), it does not necessarily infer good agreement. Furthermore, although Caia et al. (2018) did include Bland-Altman analysis, the authors did not follow the methodological suggestions from Abu-Arafeh et al. (2016), nor used results of that analysis to inform primary conclusions, limiting interpretation of the analysis. Therefore, **Study 2** was undertaken not only to examine the relationship between self-reported and actigraph reported sleep durations in female athletes, which to the authors knowledge, had not been presented before, but also to address prior methodological errors in the literature. Caia et al. (2018) also noted that self-reported sleep quality was not directly indicative of sleep efficiency in male athletes, yet this had not been investigated in female athletes. Thus, a secondary aim was developed, to build on the work of Caia et al. (2018) and consider which other objectively reported sleep parameters may predict for self-reported sleep quality scores, information which may then direct intervention.

This study was the first to investigate agreement between self-reported and actigraphy reported sleep parameters within a female athlete population, which is perhaps surprising given the prevalence of which self-reported sleep measures are used amongst this cohort in professional practice. Results showed there was a tendency for participants to overestimate sleep duration, with a mean bias of 32 min. The disagreement range spanned ~2 hours (+24 min to -90min), suggesting self-reported sleep durations may not be of value in accurately determining an athlete's sleep duration. This was considered in the methodology of all subsequent studies within this thesis, with actigraph monitoring used for all sleep durations.

For sleep quality, the incorporation of actigraph-reported sleep efficiency, number of wakings and sleep fragmentation index only accounted for 27.5% variance in self-reported sleep quality, with only number of wakings being a significant predictor for self-reported score ($p=0.000$). It has been suggested that the notion of sleep quality may encompass sleep efficiency (<85% SE suggestive of poor sleep quality, Troynikov et al., 2019), sleep latency (>30 min SL suggestive of poor sleep quality, Troynikov et al., 2019), sleep fragmentation index (Conte et al., 2022), number of wakings (Min et al., 2014), and even sleep duration (<6.5 hours suggestive of poor sleep quality, Troynikov et al., 2019). The construct of sleep quality is often poorly understood (Claudino et al., 2019), with the use of self-report, SE, SL or PSQI often used to measure sleep quality (Claudino et al., 2019). This study provides novel findings suggesting that self-reported sleep quality from female athletes may be indicative of the number of wakings an athlete has experienced the previous night. This adds a new dimension for consideration in the understanding of this factor and furthers the understanding of sleep quality as a multifactorial construct. Night wakings can be due to environmental factors (e.g., heat, noise) leading to discomfort or disturbance, poor sleep regularity (Phillips et al., 2017), or psychological factors such as daytime stress (Herawati and Gayatri, 2019). Assuming an absence of clinical sleep disorder, many of these causative factors may be addressed by SH interventions, thus regular low self-reported sleep quality could infer the need for SH interventions.

8.2.3. Study 3

The experimental design adopted in **Study 3** was that of a randomised, controlled trial; an approach which Walsh et al. (2021) identified as a key future research directive to investigate sleep interventions. Prior investigations of this nature were notably absent from the research field. Indeed, to the authors knowledge, Vitale et al. (2019), was the only study to date to present a randomised, controlled trial on the efficacy of SH interventions, however the study length was only 3 days. Moreover, in terms of novelty of the subject matter, Walsh et al. (2021) suggested further research was needed into the effect of sleep interventions on strength-based performance.

Therefore, the aims of **Study 3** were to determine firstly, whether SH education affected strength and power variables via improved sleep indices and secondly, whether there were differences in sleep improvements following either individualised SH education or group-based SH education. To the authors knowledge, this was the first study to directly compare the efficacy of different methods of SH education. It is also novel in being the first to determine whether SH education could affect strength and power outcomes. The results from **Study 1** were used to guide key focus areas for SH education for both experimental groups. Results showed the addition of individualised SH significantly improved sleep duration, sleep latency, and sleep efficiency compared to controls, whilst a significant difference was also observed for sleep latency across weeks 1-7 for the individualised SH group. Participants within the individualised SH group showed significantly improved countermovement jumps compared to those receiving group-based SH education and a control group, with those within the individualised SH group presenting a 17.4% change from baseline, compared to 10.7% and 5.9% improvements across group-based SH education group and control group respectively; an improvement across all groups could perhaps be expected given the time in the season when data collection occurred. No significant differences between groups were shown in isometric mid-thigh pull scores. It could be concluded therefore, that individualised SH education was superior to group-based SH education in improving sleep factors and in terms of performance factors, jump performance was affected by sleep improvements, whereas strength performance was not significantly affected.

Although it was beyond the scope of this study to investigate underlying physiological mechanisms, it could be postulated that the observed sleep improvements increased intra and inter-muscular coordination, as well as neural drive, two key variables for successful jump performance. Insufficient sleep has been associated with increased adenosine, a neuromodulator that has a general inhibitory effect on neural activity (Boonstra et al., 2007), inhibiting neural drive. Furthermore, a lack of sleep has been shown to reduce joint coordination (Mah et al., 2019), which may negatively affect jumping biomechanics. By improving sleep indices, it is feasible jump performance may have been enhanced via the optimisation of neural factors and increased joint coordination. With this consideration, although the physical testing battery was limited at the request of coaching staff, further research should be directed towards the assessment of other performance tests, with dynamic, velocity components, similar to CMJ, as it could be hypothesised these are likely to be more greatly affected by sleep status than performance tests with a greater reliance on force.

The addition of individualised SH education, which could be considered a collaborative approach between athlete and educator, improved sleep factors to a greater extent than solely group-based SH education, which could be considered a more “teacher led” approach. The traditional “top down” teacher-led coaching style has been criticised in recent years (Woods et al., 2020), with the notion that a more individualised, athlete-centred approach should be favourable. This traditional approach reflects a group-based SH education delivery, with limited participant interaction and sessions being led by the researcher, as opposed to being collaborative. It would seem that results from **Study 3** concur with current coaching science, and an athlete-centred, individualised approach is more valuable for improving sleep than group-based SH education. One of the primary criticisms around “top down” coaching approaches is the lack of appreciation of individuality (Woods et al., 2020), which, given the vast inter-individual differences between athletes in terms of physiological and psychological factors, seems an illogical approach, yet perhaps continues in professional practice due to financial and logistical constraints. Similar to other physical and physiological attributes, previous evidence has highlighted the vast inter- and intra-individual differences in sleep, thus generic SH interventions may also be illogical (Fullagar et al., 2016). Otte et al. (2020) suggest each individual athlete should be supported in their own approach, whilst encouraging individual athletes’ self-awareness. The individualised SH intervention demonstrated in **Study 3** positively considers both these points, appreciating the athlete as an individual and encouraging self-awareness of sleep factors. Dupee et al. (2016) stated as athletes’ self-awareness increased, they were able to better self-regulate from both a physiological and psychological perspective, therefore future research could be guided towards a longitudinal study in this remit. Furthermore, gaining clarity around optimal dose responses of such interventions would be beneficial in developing future guidelines of such strategies.

8.2.4. Study 4

Previous evidence suggested growing interest around the use of alternative methods of SH delivery, particularly around the use of visual media formats, with Hassanin et al. (2023) reporting short SH education videos to be beneficial in improving sleep metrics for adolescents, and Asih et al. (2024) who found media-based SH interventions to positively improve the sleep of pregnant women. Furthermore, Nisa et al. (2021) advocated the use of

WhatsApp messaging to promote knowledge around sleep factors. Based on the results from **Study 3**, which showed individualised SH education to be of greater benefit than group-based SH education, there was a need to consider alternative, time-efficient methods of individualised SH education for athletes, which would widen the scope of application to a greater number of sport settings. Therefore, the aims of **Study 4** were to determine the efficacy of a media-based SH education intervention, and to investigate whether this could improve sleep for female athletes' mid-season. Given "lack of time" and "lack of resources" were the most cited barriers to sleep monitoring from a range of practitioners working within elite sport (Hough et al., 2021) and that approximately 70% of athletes use their electronic device in the evening (Knufinke et al, 2018), the development of media-based SH education that facilitates repeated exposure to SH education with minimal additional coach workload, warranted investigation.

Whilst it is assumed all coaches aim to operate with best practice, the realities of implementing an individualised sleep education programme to a large squad or cohort of athletes may be challenging from a time-management perspective. To the authors knowledge, only two previous studies had investigated the use of individualised SH education for athletes; Driller et al. (2019) n=9, and Edinborough et al. (2023), n=1. Both these aforementioned studies were conducted with male athletes (and one being a case study), therefore there was a need for further investigation of individualised SH education with female athletes. Liang et al. (2024) stated the use of technology and gamification could be useful in increasing engagement with SH behaviours, and amongst other populations, the use of alternative media-based SH education strategies were evident (Hassanin et al., 2023; Asih et al., 2024).

Findings suggested media-based SH education was beneficial in improving sleep efficiency, sleep latency, and ASBQ score. Additionally, this was the first study to present sleep improvements via SH interventions for female athletes' mid-season. Miles et al. (2019) stated one barrier to delivering sleep hygiene education is the consideration of "players not liking it". Interestingly, within the aforementioned study, the coaches of female athletes were more likely to identify with this statement than the coaches of male athletes (19% vs 3%). In **Study 4**, the ease of implementation of the strategy was high (rated 7.00 ± 2.19 for ease of implementation, on a 10-point scale), with total adherence to the intervention 97%. This suggests a promising approach to SH education, with findings within **Study 4** seemingly disagreeing with the statements within Miles et al. (2019). Although athlete perception of the intervention within the study was not directly measured, no participants withdrew from the study, nor raised any informal concerns during the testing period. It could be postulated that the variation of delivery of SH across the surveyed athletes in Miles et al. (2019) could account for the difference in perspective, thus giving further support towards the use of media-based interventions. The SH education within this study was based on published literature, and the identified priority areas from **Study 1**. However, the influence of moderating factors (e.g., chronotype, age) on factors such as sleep regularity should be considered and may allow for more bespoke individualisation of the intervention to occur. Further research is needed to investigate whether integrating this consideration into the intervention may increase effectiveness, and also whether chronotype may influence the efficacy.

A summary of all experimental hypotheses from each experimental chapter is presented below in **Table 8.1**, with each hypothesis either supported or unsupported.

Table 8.1: Experimental hypotheses from each study chapter.

Hypotheses	Supported	Unsupported
Study 1: Sleep habits, sleep hygiene and chronotype across a female athlete population		
Participants with evening chronotype will have a worse sleep hygiene status	✔	
Participants from team sports will have a worse sleep hygiene status than those from individual sports	✔	
Study 2: Does self-reported sleep duration and quality reflect actigraph reported sleep duration and quality in female footballers?		
There will be good agreement between self-reported and actigraph reported sleep duration		✔
Actigraph reported sleep efficiency will predict for self-reported sleep quality		✔
Study 3: Can sleep hygiene interventions affect strength and power outcomes for female athletes?		
Sleep hygiene education will have a positive effect on strength performance		✔
Sleep hygiene education will have a positive effect on power performance	✔	
Individualised sleep hygiene education will be more effective in enhancing sleep indices than group-based sleep hygiene education	✔	
Study 4: The use of individualised, media-based sleep hygiene education for professional female athletes		
Individualised, media-based sleep hygiene education will be effective in improving sleep factors for professional female athletes	✔	

8.3. Critical insight across all studies

The analysis and critical insight across pooled data provides additional information across common areas of study. Research around chronotype preference of female athletes is scarce, yet knowledge around this factor provides value in the determination of athletes who may have poorer sleep habits. Chronotype distribution amongst female athletes in **Study 1** (n=144 athletes from football, rugby, volleyball, athletics, taekwondo, tennis) was reported as 54% morning preference, 23% intermediate, and 23% evening types, with the conclusions that previously reported chronotype data on mixed participant cohorts (Biggins et al., 2019; Lastella et al., 2016), were perhaps not representative of female athletes. Interestingly, chronotype data from **Study 3** (n=36 footballers) presents a picture with greater similarity to previously published literature, with chronotype distribution as follows: 35% morning type, 55% intermediate, and 10% evening, with **Study 4** presenting a similar distribution (morning 31%, intermediate, 44%, evening 25%). This discrepancy may represent the unique characteristics of footballers in comparison to athletes from other sports and is perhaps suggestive of nuance in the interpretation of comparative data from different sports. Furthermore, the observed differences between the studies within this thesis directs further research, suggesting the need for sports-specific data in this remit. As previously mentioned, identifying chronotype preference is of value in identification of athletes who may be at risk of poorer sleep habits.

The ASBQ was used across **Studies 1, 3, and 4**, which may be of value in providing normative data for comparison purposes. Driller et al. (2019) suggested global scoring categorisation as follows (further detail can be found in **Chapter 3, General Methods**): ≤36 suggests good sleep behaviours, whilst scores ≥42 suggest poor sleep behaviours. **Table 8.2** below presents mean ± SD for ASBQ scores across studies.

Table 8.2: Pooled mean ± SD data for ASBQ scores.

Study	Mean ± SD	n scoring ≤36	% relative to sample group	n scoring ≥42	% relative to sample group
Study 1	42.3 ± 10.2	19	13.1	25	17.3
Study 3	30.2 ± 5.9	20	58.7	1	2.9
Study 4	37.0 ± 6.4	3	18.7	1	6.2
Pooled data	36.5 ± 7.5	42	21.6	27	13.9

Interestingly, pooled ASBQ data across all studies is suggestive of sleep habits of 21.6% of participants being almost considered as "good", using the above categorisations. However, individual discussions and objective sleep data did not concur with this perception, with many areas of improvement identified from both. Indeed, the ASBQ results from **Study 3** suggests 58.7% of athletes in that study present with good sleep habits, yet again specific to within this study, other sleep measures seemingly disagreed with this interpretation. This raises concerns with dictating a "good" and "bad" threshold, indeed despite seemingly having "good sleep behaviours", participants in **Study 3** showed the potential for improvement of ASBQ in response to intervention, with significant mean score reductions of 2.7 (p=0.002) post individualised SH intervention. However, as highlighted from conclusions in **Study 2**, self-report of sleep measures has the potential for inaccuracy, and whilst the ASBQ has previously been validated against PSG amongst athletes (see **Chapter 3, General Methods**), nuance may suggest the need of demographic-specific validation studies. Furthermore, the use of ASBQ and similar questionnaire-based tools may provide more value in the analysis of individual questions, rather than global score.

The concept of meaningful change builds on the belief that statistical significance alone may not be sufficient to establish an intervention benefit (Trigg et al., 2023). Meaningful change is usually calculated from TEM, normative data, consensus statements or meta- analysis (Trigg et al., 2023), yet to the authors knowledge, no published guidelines currently exist on what is considered meaningful change in the remit of sleep improvements for athletes. In the absence of published literature detailing what should be considered meaningful change with regards to measured sleep variables, it was not possible to determine limits for measures *a priori*. To be able to discern between what is a measurement error and what is a real change of practical significance is an important factor for coaching staff and athletes to enable accurate interventions.

Using baseline data from **Studies 2, 3 and 4**, TEM and %CV was calculated for the following actigraph-measured variables: sleep duration, sleep latency and sleep efficiency (**Table 8.3**). Due to the number of available units, **Study 2** used Actigraph GTX (Florida,USA), and **studies 3 and 4** used GeneActiv (Activinsights, Cambridge, UK), therefore baseline data from **studies 3 and 4** were amalgamated prior to calculation of TEM and %CV.

Table 8.3: TEM and %CV for Actiwatch GTX (Florida, USA) and GeneActiv (Activinsights, Cambridge, UK).

Device	Sleep duration (min)		Sleep latency (min)		Sleep efficiency (%)	
	TEM	%CV	TEM	%CV	TEM	%CV
Actiwatch GTX	11.2	13.2	6.2	7.4	6.8	n/a
GeneActiv	3.3	7.7	3.4	26.5	0.5	n/a

Considering **Table 8.3** above, **Table 8.4** below presents post-intervention changes to actigraph-derived sleep variables from within this thesis, to attempt to establish a minimum threshold for meaningful change.

Table 8.4: Improvements in sleep indices following SH interventions, from studies within this thesis and published literature.

Study	Sleep duration (min)	Sleep latency (min)	Sleep efficiency (%)	Device used
Study 3	31.0*	4.2*	7.0*	GeneActiv, Activinsights
Study 4	13.1	3.6*	4.1*	GeneActiv, Activinsights
Fullagar et al. (2016)	45.0*	8.6	4.6	Sensewear Actigraphy
Van Ryswk et al. (2017)	19.0	not reported	2.2*	Actiwatch 1 and 2, Phillips Respironics
O'Donnell and Driller (2017)	22.3*	2.6	2.6	Readiband, Fatigue Science
Caia et al. (2018)	20.0*	2.2	0.5	Actiwatch 2, Phillips Respironics
Driller et al. (2019)	11.0	29.0*	5.0*	Readiband, Fatigue Science
Vitale et al. (2019)	30.0*	4.8*	0.3	Actiwatch 2, Phillips Respironics

Statistically significant changes are marked with *.

All the statistically significant changes in the studies within this thesis, and that of published studies were above the TEM presented in this thesis, however, as shown in **Table 8.4**, different devices were used. **Studies 3 and 4** used GeneActiv devices (**Table 8.3**) with TEM 3.3 min for sleep duration, 3.4 min for sleep latency and 0.5% for sleep efficiency. None of the other studies mentioned within **Table 8.4** report TEM of the measurement device.

Smallest worthwhile change can be defined as any change that is above TEM (Ulupinar et al., 2023). With that consideration, all changes reported in experimental chapters can be considered as worthwhile change, however the question remains as to what constitutes a level of change that has a practical impact on performance? To the authors knowledge, no current guidelines exist on what is considered practically meaningful change in the remit of sleep parameters for athletes. Sleep deprivation studies are of use in providing the converse view of practical changes in response to sleep manipulation, with studies demonstrating sleep restriction of multiple hours to impact jump performance (Cullen et al., 2019) and sports-specific performance, specifically the accuracy of skills (Fullagar et al., 2015). Equally, sleep extension studies (via timing manipulations and daytime napping) have shown positive effects on sprint and sports-skills performance with increased sleep durations of 86 min (Schwartz and Simon, 2015) and 110 min (Mah et al., 2011). To the authors knowledge, the increased SD of 31 min presented in **Study 3** is one of the lowest increases to show a benefit to physical performance, specifically jump performance. Whilst previously the practical impact of smaller, positive changes to sleep factors are perhaps not as well understood, this could be suggestive that smaller increases to SD warrants further investigation, and currently ~30 min increase in SD could be considered the smallest worthwhile change to impact performance.

In **Study 4**, SL improved by 3.6 minutes, a statistically significant finding, which is only marginally above TEM. Therefore, the practical implications of this improvement in SL remain questionable, given only a true change of 0.2 min can be observed. To the authors knowledge, no previous studies have investigated the practical effects of smaller changes to SL. If this result is viewed alongside the other significantly improved sleep variables post-intervention (SE, ASBQ score), rather than in isolation, it gives rise to a picture of overall improved sleep status, which perhaps suggests the need for a holistic approach in this remit. Equally, if the intervention used in **Study 4** is implemented with the sole aim of improving SL, this may not be the optimal approach. Future research should be directed towards investigating how changes of the magnitudes observed in recent studies affect physiological and psychological variables, with an aim to develop further understanding of what should be considered the smallest worthwhile change of all sleep parameters, from a practical perspective. Currently, within the research body, there have been minimal attempts to quantify statistically significant changes to sleep factors with a view for practical significance. Given current knowledge around optimal sleep parameters for athletes, it could be postulated that any changes in sleep measures, above TEM, which are still sub-optimal for each sleep variable constitutes a worthwhile change in terms of progression towards optimal sleep indices. As presented in **Chapter 2, Literature review**, current considerations for what is considered optimal for sleep variables is as follows: SD ~8.3 hours (Sargent et al., 2021), SL <30 min (Halson et al., 2021), SE >85% (Troynikov et al., 2019).

8.4. Novelty of research and progression of the field

To the authors' knowledge, this is the first body of research to investigate sleep factors specifically for female athletes. This is a worrying acknowledgement and provides further evidence of the literature gap on female athletes' performance. Research into SH interventions for female athletes were needed, given female athletes are at greater risk of sleep issues than male counterparts (Walsh et al., 2021). All work within this thesis has been written with consideration for applied practice. This thesis provides the following novel research findings:

- Athletes presenting an evening chronotype are likely to have a worse SH status
- Sleep regularity, active behaviours in the evening and psychological factors are the most problematic areas of SH for female athletes.
- Sleep duration of female athletes should be objectively monitored, and coaches should not rely solely on self-reported measures of this parameter.
- Sleep indices affect jump performance of female athletes; however, strength performance is not significantly affected by sleep status.
- Individualised SH education provides superior benefits to sleep than group-based SH education.
- Individualised SH delivered via visual media messaging can have significant beneficial effects on sleep factors, and this method may increase the applicability of individualised SH in a female athlete population.
- Sleep hygiene education can be effective in improving the sleep of female athletes' mid-season.

Collated novel findings can be used to provide practical recommendations for female athletes. Results of **Study 1** suggest sleep hygiene interventions for female athletes should focus around the areas of sleep regularity, active behaviours and psychological factors, and SH interventions should be delivered in an individualised format where possible. Given the potential error in self-reported sleep durations, as presented in **Study 2**, sleep durations of athletes should be objectively reported. If self-reported sleep quality scores are used within athlete monitoring, this may be indicative of the number of wakings an athlete experiences per night; information which may direct the practitioner towards a SH intervention. The direct comparison of SH education methods in **Study 3** is a novel approach and provides key information for future research directions.

Furthermore, this thesis provided novelty in methodological approaches, with **Study 2** building on previously identified methodological errors, whilst **Study 3** adopted an experimental design identified in an expert consensus review (Walsh et al., 2021) as lacking in the field. **Study 4** investigated a novel method of SH education, using visual media, which, to the authors knowledge, provided the first example of this amongst an athletic cohort. Whilst overall, data on female athlete sleep was lacking, the experimental studies within this thesis fill precise research gaps, notably investigating individualised SH approaches with female athletes and investigating the impact of sleep interventions on strength and power-based performance, two key areas previously identified as lacking in the field (Walsh et al., 2021).

8.5. Practical applications and dissemination of findings

Impact within the scientific research community is important, but wider reach of key findings, and the dissemination into practical application is paramount. This section considers the practical use of the findings within this thesis, considering key demographics and practical examples of the applicability of this research.

8.5.1: Coaches and athletes

Current guidance for Sports Science or Strength and Conditioning coaches, in the field of sleep, is lacking. With lack of knowledge and resources being cited as a key reason for coaches not engaging with sleep considerations for their athletes (Miles et al., 2019), there was a need to build a more substantial research body, with a practical focus, to enable practitioners within sports settings to be able to monitor and educate athletes on sleep factors, which may be one method of improving physical performance. Based on this consideration, a new flow diagram is offered, with the aim of removing a lack of education as a constraint to implementing sleep considerations for female athletes, providing a simple resource for coaches to refer to when planning sleep strategies for female athletes. **Figure 8.2** below presents the flow diagram detailing the process of monitoring and managing sleep issues in an athletic cohort.

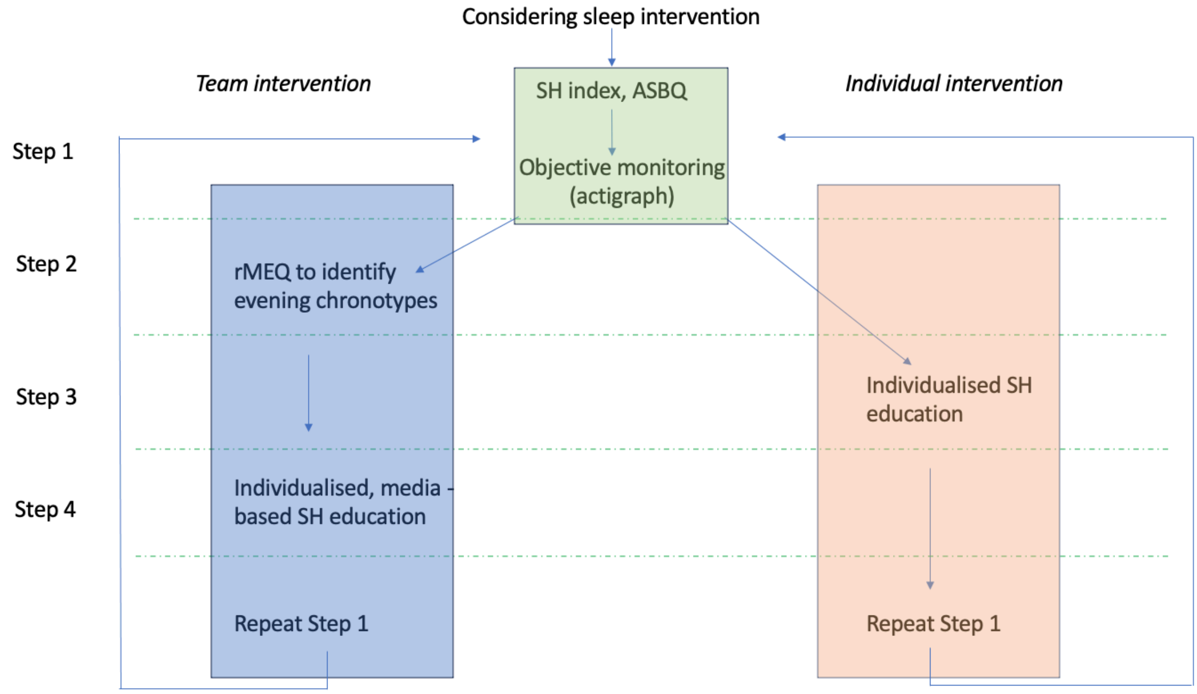

Figure 8.2: A novel flow diagram for coaches to follow in the process of monitoring and educating on sleep factors. Step 1 should occur multiple times throughout the year. If objective monitoring is unavailable, coaches should proceed with subjective monitoring in the form of pre-existing, validated questionnaires. Step 2 should be conducted multiple times throughout the year, given the potential for chronotype shift. Step 3 can be delivered either as media-based intervention or face-to-face depending on resource availability. Step 4 is suggested as

a media-based intervention due to the multiple athletes that would need to be considered in a team sport setting.

Typically, within sports environments anecdotal observations suggest changing habitual behaviours of coaches can be challenging, with time pressures and fear of failure commonly contributing to an unwillingness to try new approaches (Martens and Vealey, 2024). Because of this, the coaching landscape can often be slow to respond to advances in research which guides optimal practice. Therefore, **Figure 8.2** aims to simplify the process of monitoring and educating on sleep factors, reducing the potential time pressure of devising initial strategies.

The following infographic was presented at the Long-Term Athlete Development Conference (2024) (**Figure 8.3**), based on work within this thesis. With 41% of sports support staff reporting a lack of knowledge to be a significant barrier to implementing sleep hygiene strategies, and 44% reporting a lack of resources (Miles et al., 2019), this infographic addresses both of those concerns, and as a minimum, provides a resource for coaches to refer their female athletes to, as well as hopefully stimulating discussions amongst coaching staff.

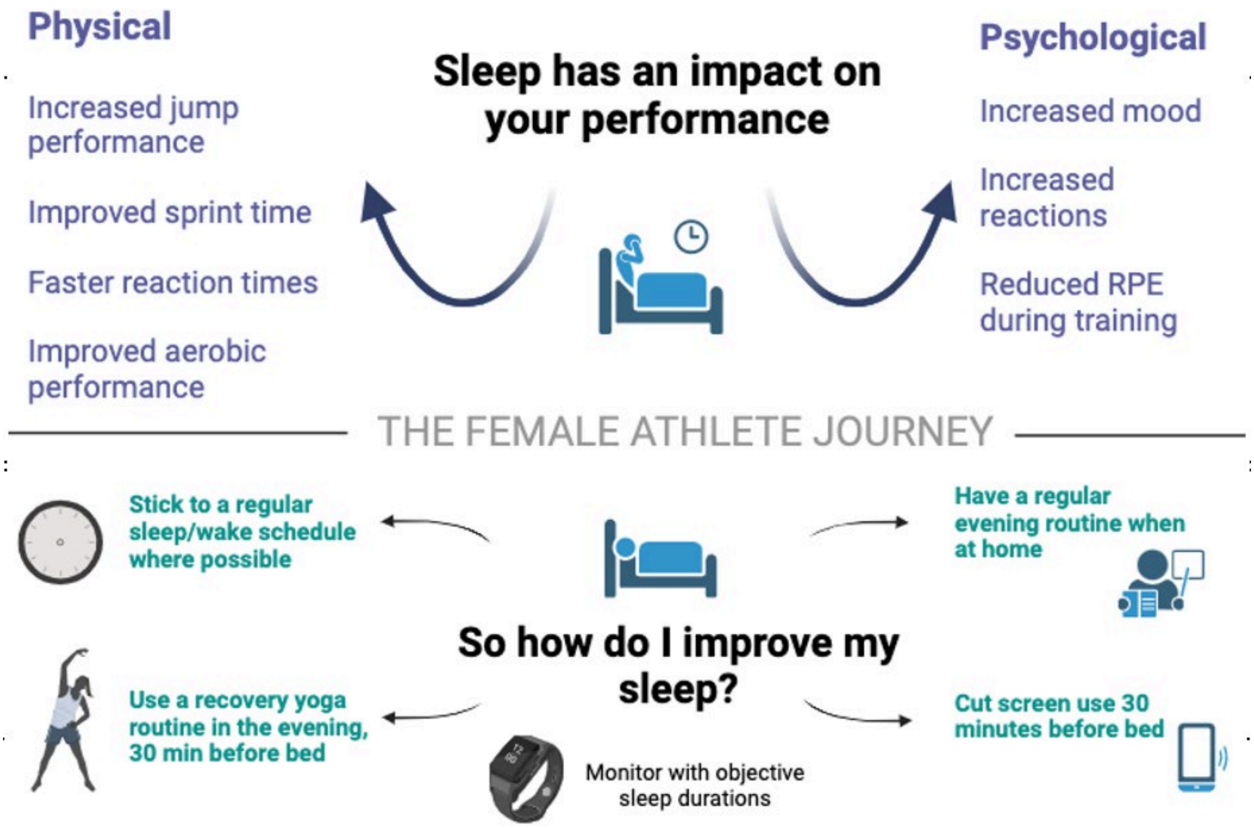

Figure 8.3: An infographic presenting the importance of sleep for athletes, and key SH considerations for female athletes.

Furthermore, the direct engagement of athletes with any performing-enhancing measure is key. With that in mind, a specific scoring system based on work within this thesis was developed (**Figure 8.4**) and has since been adopted within one WSL club and one Women's Championship club. The development of this tool built on the primary SH areas for improvement detailed in **Study 1**, whilst building on the concept from **Study 4**, that media-based tools may be valuable in the engagement of athletes with sleep interventions. The idea behind the development of this tool was to provide an athlete-facing document which will provide direct engagement with positive sleep practices. Additionally, the scoring system provides an additional interest stream, a notion which Liang et al. (2024) stated to be important, whilst also giving coaches the ability to prioritise interventions via data review. Future research should be guided towards determining the validity and reliability of this tool.

Sleep checklist for home environment

	Possible points	Day of the week						
Regularity		M	T	W	T	F	S	S
Going to bed within 20 min of previous bedtime	1							
Getting up within 20 min of previous get-up time	1							
Environment								
Dark room	1							
No light or noise disturbances	1							
Psychological								
Relaxation in the evening	1							
Going to bed feeling calm	1							
Evening behaviours								
No screens 30 min before bed	1							
Use lamps in the evening, avoid bright lights	1							
TOTAL								

Figure 8.4: The SH checklist for home environment, derived from key priority areas identified in this thesis. Athletes are asked to record a point for each item they complete each day; if they do not complete an item it is scored as a 0. Current suggestions are to use across chosen weeks within the home training environment. Interpretation of this SH checklist is currently via identification of commonalities in scoring deficits across a week, which can then guide further discussion with the individual athlete. Further research is indicated for potential validation of this tool, and in the development of scoring indicator boundaries via comparison to objective sleep parameters.

Athlete adherence and "buy-in" to any recovery intervention is important in the success of the intervention (Shearer et al., 2015). Adherence to interventions such as SH education are likely to be greater if the coach takes an athlete centred approach (David et al., 2018), with factors such as "attentive listening" and "empathy" suggested to be of considerable importance in the delivery of coaching interventions. This in turn affects outcome success of the intervention (David et al., 2018). Delivery of educational interventions within this thesis was done with effort towards building rapport with the athlete, with factors such as attentiveness and focusing on positive outcomes, considered within session design. As such, coaches aiming to implement findings from within this thesis may also consider a similar approach, and recognise the potential impact of the educator on the outcome success of the SH education.

8.5.2 The recognition of sleep factors within professional practice

The remit of Strength and Conditioning Coaches and Sports Science professionals must be redefined to include wider considerations such as sleep practices, which evidently have the potential to impact sports performance. Performance must be viewed with a holistic lens, to appreciate wider contextual factors that can be manipulated. The prevalence of interest around this research throughout the development of this thesis, from both governing bodies and various clubs, has been encouraging and perhaps supports the conclusions from Miles et al. (2019) who suggested further coach development is needed in this area. It is hoped coaches of female athletes will look to monitor their athletes' sleep status objectively and provide SH education to optimise this factor, with the studies within this thesis detailing how and why this should be done. The field of research around athletes and sleep is growing, yet there are still further research questions that need answering.

8.6 Reflections from undertaking applied research

This thesis focused on female athletes, a demographic for whom research was lacking, as presented within **Chapter 1, Introduction**. Throughout the process of completing this research, there have been several reflective considerations that may offer value for researchers who wish to conduct similar studies with competitive female athletes.

One difficulty with undertaking applied research in the field of sport is that the study methods must be considered within the constraints of the individual club and/or athletes. Thus, often there is a compromise between “gold standard” methodology and that of practical realities. For example, in **Study 2**, a longer testing period would have been favourable, yet this was restricted at the request of coaching staff within the club. Similarly, across all studies, larger sample sizes would have been preferable, yet were limited due to player availability at the time of testing and enforced limitations of the time of testing from the football club. Furthermore, an element of flexibility when conducting intervention-based studies in this environment is needed; all studies were developed in concordance with coaching staff, whilst in practice, dates and times were subject to change at the last minute. Prior to **Studies 2, 3 and 4**, additional time and effort had to be put into gaining approval from the legal team at the club, whose primary concerns were around that of data protection. This was mitigated via presentation of data storage methods, and demonstrating GDPR compliance.

During **Study 3**, where individual SH discussions were had with players, there were occasional challenges in keeping discussions on topic, whilst also being conscious to maintain a standardised time frame for the sessions (30 min for initial session, 20 min for subsequent session). To facilitate open and honest engagement, building rapport and understanding is key in this context - participants were encouraged to ask questions and focus on their own specific sleep requirements, however on occasion, questions did deviate from precise relevance to the subject matter. Using a positive and holistic approach supports open interactions (Mu'ammal et al., 2022), therefore all questions were given as much consideration as any other points raised by participants, with discussion then steered onto more relevant topics by the researcher. As mentioned within the discussion of **Study 3**, being towards the "insider" end of the researcher spectrum in this context, is likely to have aided the success of the intervention. Predictably given the nature of delivery, these issues were not present during group discussions conducted in **Study 3**, nor during the group briefing in **Study 4**.

8.7 Limitations across all studies

Whilst limitations of each individual study are presented within study chapters, this section aims to summarise some general limitations to all experimental studies within this thesis. The sampling approach adopted for all studies within this thesis was that of convenience sampling, however **Study 2** and **Study 4** were both potentially underpowered. In these instances, it was not possible to increase sample size to the required number of participants, as the size of the squad and player availability were constraints. As previously mentioned in **Chapter 1, Introduction**, squad size of women's teams are commonly much smaller than that of comparable men's teams in the same club. To increase sample size via recruitment across an additional club, would have increased variability amongst participants, reducing homogeneity and potentially validity of data. Both studies still add valuable information regarding the sample group yet should be interpreted with appreciation for the potentially limited generalisability of findings. Although the SH interventions used in both **Study 3** and **Study 4** were longer than that seen in previously published work of a comparable nature (Fullagar et al., 2016, O'Donnell and Driller, 2017), a longer intervention period may have been of interest with a view to maximising impact of the intervention. A longer follow up period may have also been beneficial in all experimental studies to provide further conclusions regarding the long-term efficacy and potential decay of SH interventions.

Given that all studies were conducted in a field-based environment, controlling for external factors such as nutrition was not feasible given the researcher contact time with participants and the infrastructure of athlete support within the club setting. Specifically, the use of caffeine may have negatively affected sleep data, whilst other nutritional metabolites, such as antioxidants, may reduce inflammation positively affecting sleep (Doherty et al., 2023), which may have skewed results. With sleep and inflammation presenting a bi-directional relationship (Irwin, 2019), injury status may have also affected sleep data within this study. As stated in **Chapter 3, General Methods,** participants were only excluded if they presented a "substantial" injury, yet smaller injury concerns are likely to have occurred throughout the testing periods due to the nature of training and competition, which may have affected sleep data. Not controlling for these contributory factors may also be viewed as a strength of the thesis, as the results are presented with greater ecological validity and are representative of current situational practice of female athletes. In this instance, it is likely the implementation of strict controls around diet and injury status would have further reduced participation in the experimental studies.

8.8. Directions of future research

The findings of this thesis present an opportunity for further research in the field. Building on the findings of **Study 4**, which demonstrated significant improvements to sleep indices following the use of media-based SH interventions, further research is indicated to investigate this method. Specifically, a larger sample group, across different sports and adopting a randomised, controlled trial would be of value in formulating robust conclusions surrounding this method. Additionally, longitudinal studies investigating SH interventions would be of value. There remains a lack of research investigating long-term effects of individualised SH education methods, and a longitudinal study within this remit would add value to the research body. Longer follow up periods were not possible for **Studies 3 and 4** due to enforced constraints from the staff at the football club, however, this should be a key research direction given the previously evidenced transient effects of some SH interventions (Vitale et al., 2019, Caia et al., 2018). Understanding not only how to improve sleep indices in the short term via SH interventions, but how to provide potential “top ups” to sustain these improvements over the duration of a competitive season would be valuable from the perspective of athlete recovery, physical performance, and overall health.

Study 1 demonstrated the differences between sleep factors of athletes from team sports and individual sports. Comparison of responses to SH interventions from athletes of different sport types may provide an interesting research direction and may provide value for coaches within multi-sport programmes, such as university scholarship programmes, in the planning of such interventions. Work within this thesis chose not to control for MC phase throughout data collection periods to give a broad application of data for female athletes across various cycle phases, however, attempting to quantify sleep parameters within different phases of the MC may be useful for female athletes, in the context of identification of periods during which SH interventions may provide greater value. Furthermore, how this is modulated throughout different ages is yet to be determined and could provide a future research directive.

9. CONCLUSIONS

This thesis has explored gaps in the current literature around female athletes' sleep habits and sleep hygiene. Furthermore, this thesis provides novel considerations of practical application from each study chapter presented. The concluding statements of this thesis are that female athletes should be objectively monitored for sleep factors and chronotype, which can then be used to prioritise and highlight educational interventions. Sleep hygiene education plays a key role in improving sleep indices, and SH education for female athletes should focus around the areas of active behaviours in the evening, sleep regularity and psychological factors. This should be delivered in a bespoke, individualised manner where possible, being cognisant of the context-specific integration of each point, for each athlete. Whilst existing evidence suggested sleep may impact sprint, endurance and sport-specific skills, this thesis adds further information to the field with the knowledge that sleep affects jump performance, yet strength performance is not significantly affected for female athletes. Considering this, the implementation of individualised SH interventions may be a consideration for coaches looking to gain performance improvements in this area, without additional physical loading. It would seem that including individualised SH education offers greater benefit than solely group-based SH education, concurring with much of the current literature in sports coaching, suggesting an individualised, athlete-led approach to be optimal (Dupee et al., 2016). However, there may be instances in professional sport where time constraints prevent what is considered best practice in this remit. Therefore, the final study chapter of this thesis suggests a novel, media-based delivery of individualised SH which may be effective in improving sleep indices, removing contact time as a barrier to implementation of individualised SH education. Given the aforementioned importance of sleep to a variety of performance attributes, expanding the different methods of individualised SH delivery is a positive action in removing potential barriers to application. This thesis is the start of an exciting branch of female athlete-specific sleep research, which has the potential to be highly impactful in the field of performance sport.

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12. APPENDICES

Appendix A: Reduced morningness:eveningness questionnaire

1. What time would you get up if you were completely free to plan your day?

2. During the first half an hour of waking, how tired do you feel?
   -Very tired
   -Fairly tired
   -Fairly refreshed
   -Very refreshed

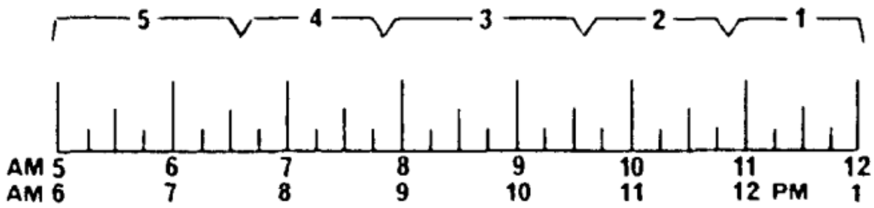
3. At what time of the evening do you feel tired and in need of sleep?

4. At what time of day do you think you reach your “feeling best” peak?

5. One hears about “morning” and “evening” people. Which one of the below do you consider yourself to be?
   -Definitely a morning type
   -Rather more a morning type than an evening type
   -Rather more an evening type than a morning type
   -Definitely an evening type

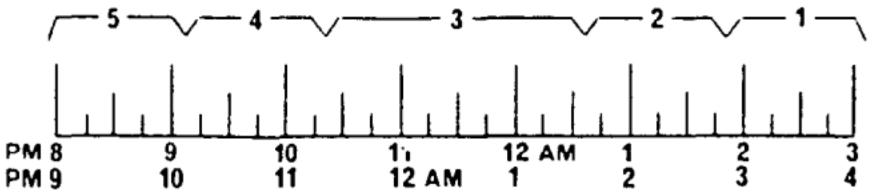
Scoring: Reduced morningness:eveningness questionnaire

1. What time would you get up if you were completely free to plan your day?

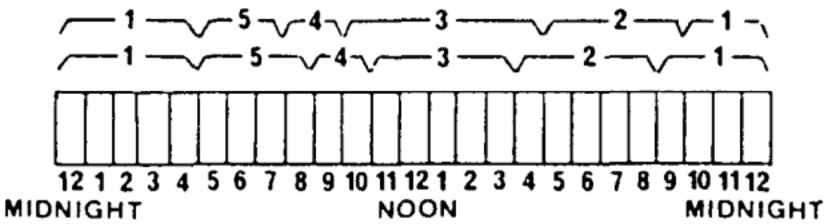


2. During the first half an hour of waking, how tired do you feel?
   -Very tired - 1
   -Fairly tired - 2
   -Fairly refreshed - 3
   -Very refreshed - 4

3. At what time of the evening do you feel tired and in need of sleep?



4. At what time of day do you think you reach your "feeling best" peak?



5. One hears about "morning" and "evening" people. Which one of the below do you consider yourself to be?
   -Definitely a morning type - 6
   -Rather more a morning type than an evening type - 4
   -Rather more an evening type than a morning type - 2
   -Definitely an evening type - 0

Scoring summary:

	Score
—Definitely Morning Type	22–25 (DM)
—Moderately Morning Type	18–21 (MM)
—Neither Type	12–17 (NT)
—Moderately Evening Type	8–11 (ME)
—Definitely Evening Type	4–7 (DE)

Grouped classifications:

Morning type 18-25
Neither 12-17
Evening type 4-11

Appendix B: Athlete Sleep Behaviour Questionnaire

Scoring: 1 – Never, 2 – Rarely, 3 – Sometimes, 4 – Frequently, 5 – Always

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In recent times (over the last month)…

I take afternoon naps lasting two or more hours

I use stimulants when I train/compete (eg, caffeine)

I exercise (train or compete) in the evening (after 7pm)

I consume alcohol within 4 hours of going to bed

I go to bed at different times each night (more than 1 hour variation)

I go to bed feeling thirsty

I go to bed with sore muscles

I use light emitting technology in the hour leading up to bed (eg, phone, tablet)

I think, plan and worry about my sporting performance when I am in bed

I think, plan and worry about issues not related to my sport when I am in bed

I use sleeping pills/tablets to help me sleep

I wake to go to the bathroom more than once per night

I wake myself and/or my bed partner with my snoring

I wake myself and/or my bed partner with my muscle twitching

I get up at different times each morning (more than 1 hour variation)

At home, I sleep in a less than ideal environment (eg, noisy, uncomfortable, too bright)

I sleep in foreign environments (eg, hotel rooms)

Travel gets in the way of building a consistent sleep-wake routine

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TOTAL GLOBAL SCORE: