Investigating impacts of sleep on recovery and performance in Elite Rugby Union

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Thesis Abstract

Sleep plays a vital role in daily functioning of biological, cognitive, and physical performance for humans. Additionally, sleep has been widely regarded by athletes to play an important role in recovery from training and competition. Despite the increasing amount of sleep research in athlete populations, elite team sport athletes are still underrepresented in the literature, specifically in collision-based sports, despite the unique challenges facing this population. Therefore, this PhD thesis aims to enhance the understanding of sleep habits of professional, male Rugby Union athletes in both training and competition environments. Finally, the thesis evaluates interventions that could improve sleep in the same population.

Study One subjectively assessed the sleep habits of 224 Rugby Union athletes across multiple levels of competition in Rugby Union athletes (academy, semi-professional, and professional) who completed the Athlete Sleep Behaviour Questionnaire and the Pittsburgh Sleep Quality Index. The results highlighted that differences exist between different levels of competition for specific sleep behaviours; however, sleep behaviours could be improved for all levels of competition in Rugby Union athletes.

Study Two assessed the differences in sleep quality, quantity, and behaviours between 38 elite male and 27 elite female Rugby Union athletes via the Athlete Sleep Behaviour Questionnaire and the Pittsburgh Sleep Quality Index. Male athletes reported significantly longer sleep duration and higher sleep efficiency. The study highlighted that differences existed between elite male and female Rugby Union athletes and that elite male and female athletes face specific sleep challenges.

Study Three investigated nightly sleep duration during a three-week preseason training period in 29 professional Rugby Union athletes using wrist actigraphy. Aerobic capacity and body composition were assessed at Baseline, at Week 3, and at Week 5. Participants were split into two groups for analysis as less than 7 h 30 min per night or greater than 7 h 30 min per night. The results highlighted that longer sleep duration during a preseason phase may assist in enhancing physical qualities including aerobic capacity and body composition.

Study Four assessed the sleep and wake variability of 23 professional Rugby Union athletes during a preseason period of training. Sleep was monitored via wrist actigraphy for three weeks and the athletes completed a daily wellness questionnaire. Athletes were split into two groups based on their calculated sleep regularity index (regular and irregular). The regular group displayed significantly longer sleep duration and greater sleep efficiency and less wake episodes. The results highlighted that minimising variability in sleep onset and offset is beneficial for increasing sleep duration.

Study Five investigated the prevalence of naps on match day in 30 professional Rugby Union athletes and its subjective link to match performance across a 17-match season. Athletes were asked about their napping practices and their perceived performance during match play. Additionally, three team coaches evaluated match performance of each participant. The results highlighted that 86% of athletes used pre-match naps with a greater amount taken during away matches compared to home matches. Additionally, the odds of an athlete rating their performance as “good” was increased when they napped and won the match.

Study Six investigated the effectiveness of daytime naps on afternoon physical performance in a randomized cross-over design with 15 professional Rugby Union athletes. Athletes performed a nap or no nap condition on two occasions, separated by one week. Baseline testing of reaction time, self-reported wellness, and a 6-second peak power test on a cycle ergometer was completed in the morning followed by 2 x 45-minute training sessions. Athletes completed nap or no nap condition at 1200 h. Baseline measures were retested in the afternoon in addition to a 30-mintue fixed intensity interval cycle and a 4-minute maximal effort cycling test. The study highlighted that utilising daytime naps between training sessions on the same day, improved afternoon peak power and lowered perception of fatigue, soreness and exertion during afternoon training.

In summary the series of studies in this thesis provides a foundation for understanding sleep in elite Rugby Union athletes. Sleep challenges and disturbances are prevalent amongst Rugby Union athletes in both training and competition environments. Results show that methods such as consistency in sleep onset and offset, daytime naps, and extending sleep duration can have benefits for Rugby Union athletes. These studies provide valuable information on sleep habits of not only professional Rugby Union athletes but rugby athletes of all levels and codes, which can be used to inform sleep hygiene protocols to target aspects that are most relevant within a given population. Moreover, aspects such as allowance of daytime naps and consistency in schedule to allow for consistent sleep and wake times should be considered when designing recovery within training programs.

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List of Abbreviations

ASBQ	Athlete Sleep Behaviour Questionnaire
ASSQ	Athlete Sleep Screening Questionnaire
CV	Coefficient of Variation
HR	Heart Rate
IL-6	Interleukin-6
NREM	non-rapid eye movement
RH	Relative Humidity
PSQI	Pittsburgh Sleep Quality Index
PSG	Polysomnography
REM	Rapid eye movement
RMR	Resting metabolic rate
RPE	Rating of perceived exertion
SCN	Suprachiasmatic nucleus
SD	Standard deviation
SE%	Sleep efficiency percentage
SL	Sleep latency
SOT	Sleep onset time
SRI	Sleep Regularity Index
SWS	Slow Wave Sleep
TEE	Typical error of estimate
TST	Total sleep time
TTB	Total time in bed
WASO	Wake after sleep onset
WE	Wake episodes
WT	Wake time
1RM	One-repetition maximum

CHAPTER ONE:

Thesis Overview.

The main aim of the thesis was to investigate the sleep habits and behaviours of elite male Rugby Union athletes and the relationship between sleep and physical performance. The thesis comprises of six studies that aimed to assess sleep habits and behaviours (Study One and Two), investigate the relationship between sleep duration and physical performance during a pre-season phase of competition (Study Three), assess regularity of sleep onset and offset and its relationship to sleep metrics (Study Four), examine the prevalence and influence of daytime naps on competition days (Study Five), and finally, investigate the effects of a daytime nap on afternoon physical performance (Study Six).

The thesis is broken down in four parts. In the first part Study One and Study Two investigated the sleep behaviours and habits of Rugby Union athletes across all levels of competition. Given the findings from Part One, Part Two of the thesis (Study Three) investigated the relationship between sleep and physical performance for Rugby Union athletes. Following on from Part Three, Part Four (Study Four and Study Five) investigated commonly suggested sleep hygiene recommendations of maintaining consistent sleep onset and offset and daytime naps. The final part of the thesis (Part Four: Study Six) was designed to look at the impact of extending sleep (daytime naps) on subsequent physical performance.

The series of studies within this thesis enhances the current understanding of sleep and athletic performance and provides practical applications for coaches and practitioners to implement. The use of elite athletes provides novel findings which can be used in applied settings and therefore adds to the knowledge on sleep as a recovery method to improve physical and sporting performance.

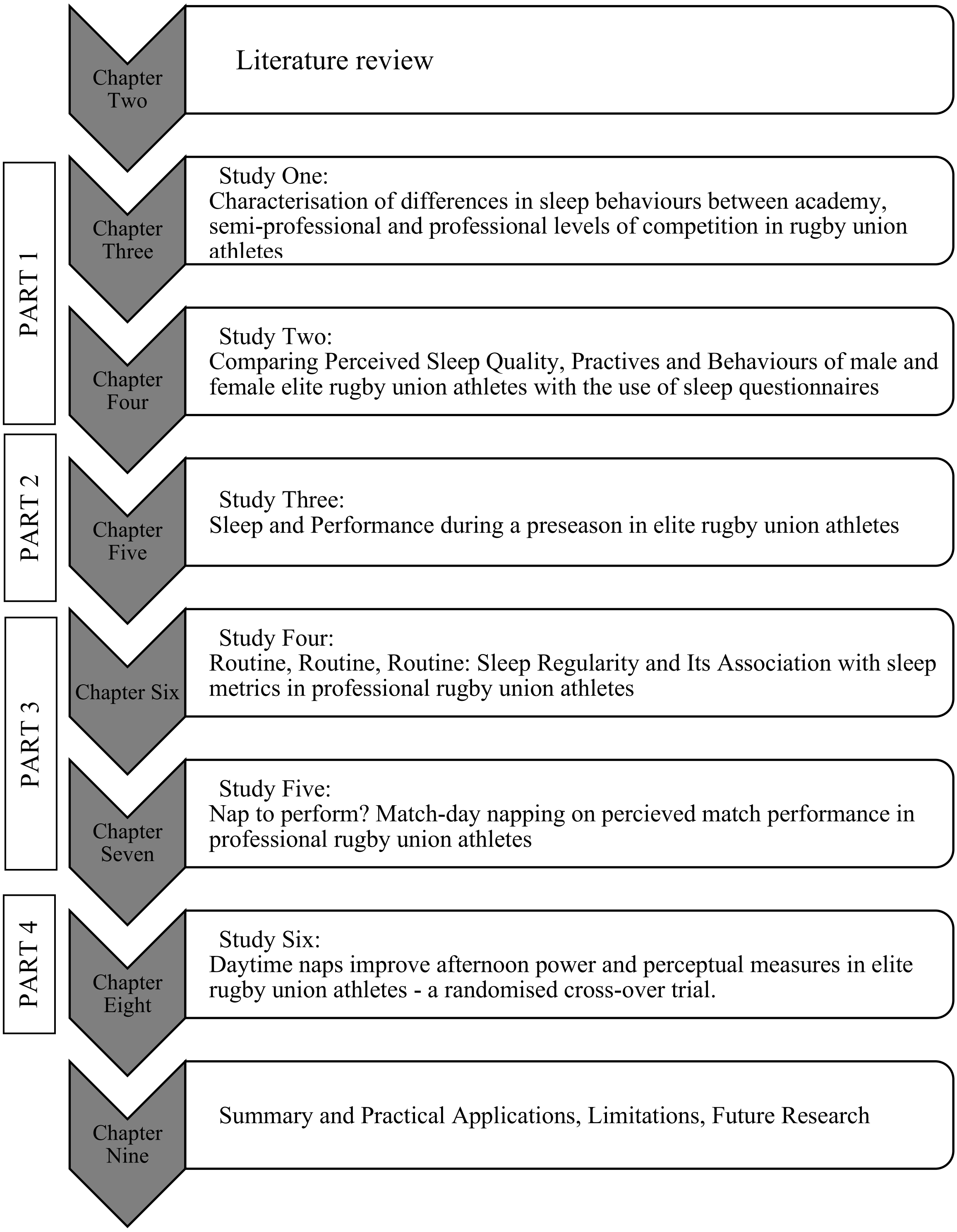

Figure 1. Schematic of thesis structure.

Chapter Organisation

The thesis compromises of nine chapters. Each of the experimental chapters (Chapters Three to Eight) are written as standalone chapters that are all published in various journals and are in standard manuscript format (abstract, introduction, methods, results, and discussion). Chapters Three to Eight appear in the same format as required by the individual journals that they were submitted. Due to the structure and nature of the thesis, with each chapter submitted as a standalone piece of research for publication there is a degree of repetition throughout. There is a single reference list of citations included at the end of the thesis for consistency and readability.

Research Outputs Arising from this Doctoral Thesis.

Peer Reviewed Journal Publications (n=6)

Chapter Three:
Teece AR, Beaven, C. M., Argus, C. K., Gill, N. D., & Driller, M. W. (2023). Characterization of differences in sleep behaviours between academy, semi-professional and professional levels of competition in Rugby Union athletes. *International Journal of Sports Science & Coaching*, 18(6), 2091-2098. https://doi.org/10.1177/17479541221127516

Chapter Four:
Teece AR, Beaven, C. M., Argus, C. K., Gill, N., & Driller, M. W. (2023). Comparing perceived sleep quality, practices, and behaviours of male and female elite Rugby Union athletes with the use of sleep questionnaires. *Sleep Science*, *16*(3), e271-e277. https://doi.org/10.1055/s-0043-1772788

Chapter Five
Teece, AR, Argus, C. K., Gill, N. D., Beaven, C. M., Dunican, I. C., & Driller, M. W. (2021). Sleep and performance during a preseason in elite Rugby Union athletes. *International Journal of Environmental Research & Public Health*, *18*(9), 4612. https://doi.org/10.3390/ijerph18094612.

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Chapter Seven
Teece AR, Beaven, C. M., Huynh, M., Argus, C. K., Gill, N. D., & Driller, M. W. (2022). Nap to perform? Match-day napping on perceived match performance in professional Rugby Union athletes. *International Journal of Sports Science & Coaching*, *18*(2), 462-469. https://doi.org/10.1177/17479541221084

Chapter Eight
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CHAPTER TWO

Literature Review

Introduction

Sleep is widely recognised as a critical part of athlete health, recovery, and performance. Sleep supports numerous physiological and psychological processes essential for elite sport, including tissue repair, hormonal regulation, immune function, emotional stability, and cognitive performance (Fullagar *et al*., 2015; Walsh *et al*., 2021). Within high-performance environments recovery windows are short and performance margins are narrow, sleep serves as a vital foundation for both physical restoration and mental resilience (Halson, 2014).

Despite its importance, athletes often experience irregular, fragmented, or insufficient sleep. Factors such as early training times, evening competitions, extensive travel, and psychological stress are common disruptors of sleep in elite sport (Samuels, 2008; Lastella et al., 2015). These disruptions are particularly relevant in team sports like Rugby Union, which involve not only intense physical contact but also complex tactical demands, variable scheduling, and frequent travel both domestically and internationally. All of which can negatively affect sleep quantity and quality (Dunican *et al*., 2019).

Furthermore, athletes in team environments face unique challenges that can influence sleep behaviours. Shared accommodations during travel, variations in team culture, and coaching practices surrounding rest and recovery can shape how and when athletes sleep (Roberts *et al*., 2019). While research has consistently shown the benefits of sleep for performance and recovery, its application within the dynamic, multifaceted context of elite Rugby Union requires specific exploration.

This literature review will begin by examining the physiological role and functional relevance of sleep in athletes. It will then review current methods used to assess sleep in applied sport settings, including both objective and subjective measures. The review will further explore how Rugby Union's physical and cognitive demands, travel schedules, and team-based structures influence sleep behaviours. This provides a foundation for understanding how sleep can be managed, monitored, and optimised within elite team sport environments.

Physiology of Sleep

Sleep is fundamental to human health, psychological well-being, and overall performance. It is defined as a reversible behavioural state in which individuals disengage from and become unresponsive to their external environment (Baranwal Yu &, Siegel, 2023; Franken *et al*., 2009; Halson, 2008). Sleep is regulated by two primary biological processes: the homeostatic drive, commonly referred to as sleep pressure (or Process S), and the circadian rhythm (or Process C) (Stiller & Postolache, 2005). The homeostatic drive refers to the accumulating need for sleep the longer an individual remains awake. This process drives a sleep pressure that builds progressively throughout waking hours and dissipates during sleep. This mechanism is closely associated with the accumulation of adenosine in the brain (Borbély, 1982). Adenosine levels increase with prolonged wakefulness and energy expenditure, contributing to the growing sensation of sleepiness (Porkka-Heiskanen, 1999). Once sleep is obtained, adenosine levels decline, reducing sleep pressure until the cycle repeats upon awakening.

The second regulatory mechanism, the circadian rhythm, is an internal biological clock that operates on an approximately 24-hour cycle, closely aligned with the light-dark patterns of the natural environment (Franken & Dijk, 2024). Circadian rhythms influence numerous physiological processes, including the sleep-wake cycle. Humans are biologically predisposed to be more alert during daylight hours and sleep during nighttime (Valdez, Ramírez, & García, 2003). Central to this rhythm is the suprachiasmatic nucleus (SCN) of the hypothalamus, which serves as the body's master timekeeper (Videnovic *et al.,* 2014). The SCN responds to environmental cues such as light exposure, helping synchronise internal processes with external time. Disruption to circadian rhythms, such as through irregular sleep schedules, jet lag, or excessive exposure to artificial light (particularly blue light), can significantly alter sleep timing and quality (Chellappa *et al.*, 2013). Such disturbances may continue for several days, leading to impaired sleep quantity and quality, with downstream effects on cognitive function, mood, and physical performance.

Sleep occurs in recurring cycles lasting approximately 90 to 120 minutes and consists of two primary states: non-rapid eye movement (NREM) sleep, which accounts for roughly 80% of total sleep time, and rapid eye movement (REM) sleep, which comprises the remaining 20%. According to the 2007 American Academy of Sleep Medicine nomenclature, NREM sleep is subdivided into three stages (N1, N2, and N3), each with distinct physiological characteristics (Baranwal, Yu, & Sigel, 2023; Tharion, 2023).

- N1 is a light transitional phase between wakefulness and sleep comprising ~5% of overall sleep.
- N2 is the most predominant stage during nocturnal sleep occupies ~50% of overall sleep and is characterised by specific EEG waveforms, including sleep spindles and k-complexes, which play a role in sensory processing and memory consolidation.
- N3 referred to as slow-wave sleep (SWS), characterised by high amplitude delta waves on EEG traces, is deepest stage of NREM sleep and is critical for physical restoration and immune function. The N3 sleep stage makes up ~ 25% of overall sleep. Importantly, the majority of daily growth hormone secretion occurs during SWS (van Cauter, Plat, & Copinschi, 1998), highlighting its essential role in physiological repair and adaptation (Halson, 2014).

Following the completion of NREM stages, sleep transitions into the REM phase, marked by rapid eye movements, vivid dreaming, and muscle atonia, a state of temporary paralysis that prevents individuals from physically acting out dreams. During REM sleep, the brain exhibits heightened activity levels, and this phase is strongly linked to psychological recovery, emotional regulation, memory consolidation, and synaptic plasticity (Franken, 2009). REM sleep is therefore considered critical for maintaining cognitive function and emotional health.

From a physiological perspective, sleep plays a crucial role in regulating endocrine, metabolic, and neurological functions. Slow-wave sleep is strongly associated with the release of growth hormone, a key driver of tissue repair, muscle recovery, and adaptation to training (Van Cauter *et al*., 2000). Similarly, sleep contributes to metabolic regulation through glucose homeostasis and appetite control, while REM sleep supports neural plasticity and the integration of motor memory (Walker & Stickgold, 2006). These processes highlight the fundamental role of sleep in both physical and cognitive domains relevant to athletic performance.

Measuring Sleep

The evaluation of sleep behaviours in athletes has become commonplace, highlighting the growing recognition of the pivotal role sleep plays in athletic performance. Accurate measurement of sleep is fundamental to understanding it role in performance and recovery. Methods available to researcher and practitioners are broadly categorised as either objective or subjective data. Objective measures predominately include polysomnography and actigraphy, both of which capture physiological or behavioural data independent of self-report (O'Donnell, Beaven, & Driller, 2018). Subjective measures by contrast rely on individuals own perception of their sleep and typically include validated questionnaires and sleep dairies. Each approach carries advantages and disadvantages and therefore the selection of an appropriate tool must consider numerous factors.

Polysomnography

Polysomnography (PSG) is widely regarded as the 'gold standard' of sleep measurement currently available, involving the simultaneous recording of multiple parameters throughout a sleep period. These include brain wave activity via electroencephalography (EEG), eye movements via electrooculography (EOG), muscle activity via electromyography (EMG), and cardiac activity via electrocardiography (ECG). PSG enables the identification of sleep stages, quantification of sleep architecture, and detection of sleep disorders such as sleep apnoea and periodic limb movement disorder (Kushida et al., 2005). Despite its precision, PSG carries significant practical limitations. The requirement for specialist laboratory conditions, trained personnel, and expensive equipment makes it largely impractical for use in applied team sport settings. Furthermore, the intrusive nature whereby athletes sleep in an unfamiliar laboratory attached to multiple electrodes raises questions around ecological validity, as findings may not accurately reflect the sleep an athlete experiences in their natural environment (Sargent et al., 2020). For these reasons, PSG is rarely employed as a primary measurement tool in athlete sleep research.

Actigraphy.

Actigraphy is the most widely used objective method of sleep monitoring in athlete populations, offering a practical and non-intrusive means of capturing sleep data across extended periods in real-world settings. Actigraphy devices are small, wrist-worn accelerometers that record movement continuously, typically in one-minute epochs, over periods of days or weeks. Raw movement data are processed via validated algorithms to produce a range of sleep indices including total sleep time, sleep onset latency, sleep efficiency, wake after sleep onset, and sleep onset and wake times. Actigraphy has demonstrated good validity when compared to PSG, with overall agreement of 91–93% for differentiating sleep from wake in healthy adults (Ancoli-Israel et al., 2003), and has since been validated across a range of athlete-specific populations (Driller et al., 2017). Dunican et al. (2018) compared two commercially available actigraphy devices against laboratory PSG in elite athletes and confirmed that actigraphy was appropriate for determining sleep onset time, sleep duration, and wake time. However, the authors cautioned that actigraphy may be less reliable for quantifying sleep latency, sleep efficiency, and wake after sleep onset, particularly in athletes who may remain physically still whilst awake due to fatigue. Despite these limitations, actigraphy is broadly considered a valid, reliable, and ecologically appropriate tool for sleep monitoring in elite athletes, due to a balance between measurement precision and real-world applicability.

Sleep questionnaires.

Sleep questionnaires are a subjective tool which offer a cost-effective and practical way of obtaining information on sleep patterns, sleep problems, sleep behaviours, and quality of sleep. Given these advantages, sleep questionnaires are widely used to assess sleep in both general population and athlete populations.

A variety of questionnaires have been developed and validated for use in the general population, including the Sleep Hygiene Index (SHI), the Epworth Sleepiness Scale (ESS), and the Pittsburgh Sleep Quality Index (PSQI). The SHI assesses the frequency of behaviours known to disrupt sleep, while the ESS measures daytime sleepiness across a range of situations. However, the PSQI is widely considered to be one of the most commonly used subjective sleep tools. (Fabbri et al., 2021). The PSQI is a 19-item self-report questionnaire which refers to an individual's sleep over the preceding month. It consists of seven equally weighted components covering: (1) subjective sleep quality, (2) sleep latency, (3) sleep duration, (4) habitual sleep efficiency, (5) sleep disturbances, (6) use of sleep medication, and (7) daytime dysfunction. Each component is scored on a scale from 0 to 3, and the component scores are summed to produce a global score ranging from 0 to 21, where higher scores indicate poorer sleep quality. A global score greater than 5 is indicative of poor sleep quality, representing either severe difficulty in at least two components or moderate difficulties in more than three components (Buysse et al., 1989).

Whilst the PSQI and other general population questionnaires have been extensively validated and applied across a range of clinical and non-clinical settings, it has been demonstrated that these tools fail to capture the unique sleep challenges faced by athletes (Samuels et al., 2015; Driller, Mah, & Halson, 2018). Factors such as early morning or late evening training sessions, travel across time zones, pre-competition arousal, and the physical demands of high-performance sport present sleep challenges that general questionnaires were not designed to assess. In response to this limitation, researchers developed athlete-specific sleep questionnaires, most notably the Athlete Sleep Screening Questionnaire (ASSQ) and the Athlete Sleep Behaviour Questionnaire (ASBQ).

The ASSQ is a 15-item self-report questionnaire developed by Samuels et al. (2015) It was designed to assess sleep quality, quantity, insomnia symptoms, and chronotype over the recent past, producing a Sleep Difficulty Score (SDS) which categorises athletes into four severity bands: none (0–4), mild (5–7), moderate (8–10), and severe (11–17). Importantly, the ASSQ primary purpose is to identify athletes who require referral for further clinical sleep assessment rather than to quantify sleep behaviour

The ASBQ, developed by Driller, Mah, and Halson (2018), was designed to identifying the specific sleep behaviours and practices that may be undermining an athlete's sleep. The questionnaire asks athletes to reflect on the frequency of 18 specific sleep-related behaviours over the preceding four weeks, with responses rated on a five-point scale from 1 (never) to 5 (always). A global score is produced by summing responses across all 18 items, returning a range of 18 to 90. It has been suggested that a global score of ≤36 represents good sleep behaviours, 37–41 moderate sleep behaviours, and ≥42 poor sleep behaviours (Driller et al., 2018). The ASBQ demonstrated acceptable reliability at validation (ICC = 0.87), and a subsequent reliability generalisation meta-analysis confirmed good internal consistency (Cronbach's alpha = 0.73) and excellent test-retest reliability (ICC = 0.88) across studies (Trabelsi et al., 2024). Crucially, the ASBQ was designed as a practical assessment tool rather than a clinical screening instrument, meaning it is most appropriately used to identify targets for sleep hygiene education and behavioural intervention.

Given the complementary nature of the PSQI and the ASBQ it could be advocated for their concurrent use in athlete populations indeed using the PSQI in athlete populations allows for comparison between athlete and non-athlete populations. Whilst the PSQI provides a well validated and globally recognised measure of sleep quality it has been demonstrated that it lacks the ability to detect athlete-specific behavioural differences. Driller et al. (2022) illustrated this limitation, finding no significant differences in PSQI global scores between individual and team-sport athletes despite clear differences emerging on the ASBQ. The ASBQ, by contrast, was specifically designed to identify maladaptive sleep practices unique to athlete populations, and has demonstrated the ability to differentiate sleep behaviours both between athletes and non-athletes (Driller et al., 2018) and across different sport types (Driller et al., 2022). Therefore, the concurrent use of a general sleep quality measure alongside an athlete-specific behavioural tool therefore offers a more complete picture of sleep in athletic populations, capturing both the severity of sleep disruption and the behavioural factors that may be contributing to it.

Sleep and Athletic Performance

Athletes across both individual and team sports often achieve less sleep than recommended, with shorter durations, delayed sleep onset, and lower perceived quality compared to non-athlete populations (Leeder *et al*., 2012; Gupta *et al*., 2017). Importantly, sleep plays a fundamental role in supporting both the physical and cognitive needs required for high-level athletic performance. Insufficient or disrupted sleep has consistently been linked to impairments in reaction time, decision-making, accuracy, and cognitive function, which are critical to performance in sporting environments (Fullagar *et al*., 2015; Watson, 2017). Even modest sleep restriction can lead to decrements in psychomotor vigilance, attentional control, and skill execution, thereby increasing the likelihood of errors during training and competition (Mah *et al*., 2011; Van Dongen *et al*., 2003). Conversely, sleep extension strategies have been shown to improve alertness, mood, and sport-specific skill performance, highlighting the potential performance benefits of optimising sleep (Mah *et al*., 2011).

In addition to its influence on cognitive and technical skills, sleep is fundamental to recovery from the physical demands of elite sport. During slow-wave sleep, the secretion of growth hormone facilitates muscle repair, protein synthesis, and glycogen restoration (Shapiro et al., 1981; Dattilo *et al*., 2011). Adequate sleep also supports immune regulation and helps reduce inflammation, both of which are critical for maintaining health and reducing time lost to illness or injury (Simpson *et al*., 2017). In contrast, chronic sleep restriction has been associated with impaired immune responses, elevated inflammatory markers, and greater susceptibility to soft-tissue injury (Milewski *et al*., 2014).

Together, these findings demonstrate that sleep is not only a passive state of rest but an active recovery process that underpins both readiness to perform and long-term athletic development and performance. In high-performance contexts, where training loads are high and recovery windows are often short, sleep represents a vital performance optimising strategy. However, the extent to which athletes achieve sufficient quality and duration of sleep remains highly variable, and the challenge of maintaining optimal sleep is particularly evident in team sports such as Rugby Union, where external demands such as travel, match scheduling, and competition stress frequently disrupt recovery processes.

Sleep Hygiene Strategies in Athletes

Optimising sleep in athletes requires consideration not only of duration but also of behavioural and environmental factors that influence sleep quality. Research has identified several practical sleep hygiene strategies that can support recovery and performance in high-performance populations. One of the most consistent findings is the benefit of maintaining a regular sleep–wake schedule, which helps stabilise circadian rhythms and improve both sleep quality and daytime functioning (Samuels, 2008; Lastella *et al*., 2015). Athletes who adhere to consistent bedtimes and wake times, even on non-training days, tend to experience shorter sleep latency and improved sleep efficiency.

Sleep extension interventions, in which athletes intentionally increase their nightly sleep opportunity, have also demonstrated performance benefits. Mah *et al.,* (2011) reported that basketball players who extended sleep to 10 hours per night for several weeks improved sprint performance, reaction time, and mood. Similar interventions in rugby codes and other team sports suggest that augmenting habitual sleep can buffer against training-induced fatigue and enhance skill execution (Fullagar *et al*., 2016).

Increasing daily sleep duration via daytime napping has emerged as an effective countermeasure for sleep debt. Napping is associated with improved cognitive performance (Farhadian *et al.,* 2021), memory consolidation (Lahl *et al.,* 2008), subjective alertness (Tietzel & Lack, 2001), and beneficial hormonal responses in IL-6 and cortisol (Vgontzas *et al.,* 2007). particularly in sports with late-evening competitions or early-morning training sessions (Lastella *et al.,* 2021). Short naps of 20–30 minutes can enhance alertness, reaction time, and mood without significantly interfering with nighttime sleep, whereas longer naps may risk sleep inertia if taken late in the day (Waterhouse *et al*., 2007; Petit *et al*., 2014; Romyn *et al.,* 2022). In a sporting context, O'Donnell and colleagues (2018) have shown improvements in lower-body power and higher ratings of match performance in elite Netball players following a short nap (<20 min).

Environmental factors, including sleep setting, light exposure, temperature, and noise, also have a significant influence on sleep quality. For example, optimising bedroom conditions ensuring darkness, reducing ambient noise, and maintaining a comfortable temperature, can facilitate deeper, more restorative sleep (Halson, 2014). In elite sport contexts, travel-related sleep disruption is particularly important, as time-zone shifts and unfamiliar accommodation can impair circadian alignment and reduce sleep efficiency. Strategies such as light exposure manipulation, napping, and maintaining consistent pre-sleep routines are commonly recommended to mitigate these effects during travel (Sargent *et al*., 2014).

Collectively, these strategies highlight that sleep hygiene in athletes is multifactorial, involving behavioural consistency, strategic napping, environmental optimisation, and management of travel-related challenges. Implementing these practices in applied settings can support both habitual and acute recovery, ultimately contributing to enhanced athletic performance.

Sleep in Rugby Union Athletes

Athletes in team sports, including Rugby Union, frequently achieve less sleep than recommended, with shorter durations, delayed sleep onset, and reduced perceived quality compared to non-athlete populations (Leeder *et al*., 2012; Gupta *et al*., 2017). Elite Rugby Union athletes are particularly susceptible to sleep disruption due to the combination of high physical load, cognitive demands, and other team factors, with muscle soreness, performance stress, and international travel across time zones all examples of factors likely to negatively affect sleep. Observational studies indicate that elite rugby players often obtain less than the recommended 7–9 hours of sleep per night, with average durations closer to 6–7 hours, and frequent reports of poor sleep quality (Caia *et al*., 2017; Dunican *et al*., 2019). Sleep duration and efficiency are further compromised during periods of intensified training, evening matches, or travel, with total sleep time sometimes reduced by more than an hour following late fixtures (O'Donnell *et al*., 2018). Individual variability is also evident within squads, influenced by chronotype, positional demands, and personal habits (Vitale *et al*., 2019).

The team environment further impacts sleep behaviour. Shared accommodation during travel, early morning team meetings, and team routines can all limit opportunities for rest (Fullagar *et al*., 2015). Factors, including coaching expectations and the prioritisation of recovery within squad schedules, can either support or challenge healthy sleep practices (Walsh *et al*., 2020). Collectively, these findings highlight that while sleep is critical for recovery and performance, elite Rugby Union athletes face multiple interacting challenges that place them at risk of inadequate and disrupted sleep.

Research investigating sleep in Rugby Union has focused on habitual sleep patterns and quality across training and competition periods. While these studies have provided valuable insights, several gaps remain. Few studies have examined the efficacy of daytime napping as a strategy to counteract sleep loss or enhance alertness and afternoon physical performance amongst

Rugby Union athletes. Similarly, there is limited investigation into the benefits of maintaining a consistent sleep onset and wake schedule, despite its known influence on sleep efficiency and circadian stability. Finally, although cognitive performance decrements associated with poor sleep are documented, there is a lack of research directly linking sleep with physical performance outcomes, such as sprint ability and strength, in elite Rugby Union contexts. Addressing these gaps is essential to inform evidence-based sleep strategies that can be integrated into a complete performance and recovery programs for Rugby Union athletes.

Conclusion

In summary, the literature demonstrates that sleep is a critical determinant of recovery, cognitive function, and physical performance in athletes, yet elite Rugby Union players face multiple challenges that may compromise both the quantity and quality of sleep. Observational studies have highlighted habitual sleep deficits, variability across positions and chronotypes, and the influence of team environments, travel, and match scheduling (Caia *et al.*, 2017; Dunican *et al*., 2019; Vitale *et al*., 2019; Fullagar *et al*., 2015). Despite these insights, several gaps remain that this thesis aims to address. Firstly, although sleep has been studied in team sport populations, there is limited research specifically focused on Rugby Union, making it difficult for practitioners to identify which aspects of sleep most strongly affect this group. Secondly, it is unclear how sleep behaviours differ across competition levels or between male and female athletes. Thirdly, while periods of high training load, such as pre-season, are likely to disrupt sleep, the impact on markers of physical performance remains poorly understood. In addition, there is a paucity of research investigating sleep regularity, including how consistency of sleep onset and wake times may influence overall sleep quality and quantity in Rugby Union athletes. Finally, although daytime naps are a recognised strategy for mitigating sleep debt, little is known about their prevalence or their acute effects on afternoon physical performance following morning training sessions, despite the frequent requirement for twice-daily training in elite programs.

Addressing these gaps, the key research questions guiding this thesis are:

- What are the differences in sleep behaviours and habits across multiple levels of Rugby Union, including differences between male and female athletes?
- How does sleep duration affect physical performance adaptations during a training block?
- Does sleep regularity impact quality and quantity of sleep among Rugby Union athletes?
- What is the prevalence of daytime napping within Rugby Union environments?
- Does a daytime nap between sessions improve metrics of physical performance in the afternoon?

By systematically investigating these questions, this thesis seeks to provide evidence-based insights into sleep behaviours, recovery strategies, and performance optimisation specific to elite Rugby Union athletes.

CHAPTER THREE

Characterization of differences in sleep behaviours between academy, semi-professional and professional levels of competition in Rugby Union athletes.

Chapter Three:
Teece AR, Beaven, C. M., Argus, C. K., Gill, N. D., & Driller, M. W. (2023). Characterization of differences in sleep behaviours between academy, semi-professional and professional levels of competition in Rugby Union athletes. *International Journal of Sports Science & Coaching*, 18(6), 2091-2098. https://doi.org/10.1177/17479541221127516

Abstract

Athletes display differing sleep habits to non-athletic populations; similarly, differences occur in sleep habits between athletes from different sports. There is currently limited research investigating the differences in sleep habits and behaviours between different levels of competition within the same sport. A total of 224 Rugby Union athletes (109 academy, 38 semi-professionals, 84 professionals) completed the Athlete Sleep Behaviour Questionnaire and the Pittsburgh Sleep Quality Index. Professional athletes displayed a significantly longer self-reported sleep duration compared to semi-professional and academy athletes (7 h 52 min±51 min vs. 7 h 16 min ±1 h 15 min vs. 7 h 19 min ±1 h 12 min, $p < 0.01$). Pittsburgh Sleep Quality Index global scores revealed a significantly lower ($p=0.04$, $d=0.3$) score for professional athletes (5.2±2.5 AU) than academy athletes (6.0 ±2.7 AU). Individual components of the Pittsburgh Sleep Quality Index revealed significant differences ($p < 0.05$) between groups for sleep duration and daytime dysfunction. No significant differences ($p > 0.05$) were observed between levels of competition for the Athlete Sleep Behaviour Questionnaire global score; however, significant differences ($p < 0.05$) were observed for 6 of the 18 items. This study was the first to investigate sleep behaviours across multiple levels of competition in Rugby Union athletes. Professional athletes displayed longer sleep duration compared to semi-professional and academy level athletes. Additionally, results highlighted that differences exist between levels of competition for specific sleep behaviours. This study identified that sleep behaviours could be improved for all levels of Rugby Union athletes

Introduction

Elite athletic performance is underpinned by the ability to recover from the stress placed upon the body via training and competition (Bishop, Jones, & Wood, 2008). Sleep plays an essential role in recovering from training and competition (Walsh *et al*., 2020) and has been suggested to be the best psychological and physiological recovery tool accessible to athletes (Leeder *et al*., 2012). However, despite the importance of sleep for elite athletes, research has shown that athletes often display worse sleep patterns and behaviours than the general population (Leeder *et al*., 2012; Driller, Dixon, & Clark, 2017; Bender, van Dongen, & Samuels, 2018; Whitworth-Turner *et al*., 2018). Additionally, athletes appear to face a unique set of challenges that can affect gaining adequate sleep (Driller, Mah, Halson, 2018). To date, research has focused on the differences in sleep behaviours between athletes and the general population; however, limited research has focused on how sleep behaviours differ between levels of competition within the same sport and collision-based athletes.

Prior research conducted by Driller *et al.* (2018) reported differences between athletes and non-athletes on the Athlete Sleep Behaviour Questionnaire (ASBQ), a questionnaire tailored specifically to athletes and designed to assess sleep behaviours. The athlete population reported higher scores in 10 of the 18 items of the ASBQ which included; higher use of stimulants, more frequent training or competition late at night, more often sleeping in foreign environments, and travel impeding a consistent sleep-wake routine, which have all been previously suggested to impact on athletes sleep negatively (Fowler, Duffield, & Vaile, 2015). Additionally, researchers have suggested other sleep disturbances, including increases in core temperature and cortisol (Oda & Shirakawa, 2014; O'Donnell *et al*., 2018), increased muscle fatigue and soreness (Taylor Rogers, & Driver, 1997), hydration status (Halson, 2008), and scheduling of training and competition (Sargent *et al*., 2014) may also affect sleep in athletes.

Research has suggested that poor sleep (<7 h) in athletes can be detrimental to performance and recovery (Charest & Grandner, 2020). Prior research has shown that a lack of sleep can negatively affect training outcomes (Cook *et al*., 2012), skill execution (Cook *et al*., 2011), skill development (Lowe, Safati, & Hall, 2017), and reaction time (Taheri & Arabameri, 2012). Additionally, a lack of sleep has been linked to a higher instance of illness and injury (Milewski *et al*., 2014; Hausswirth *et al*., 2014). Moreover, researchers suggest that athletes may require more sleep than the general recommendations to recover from the effects of training and competition (Walsh *et al*., 2020). Despite the adverse implications of not gaining adequate sleep, Rugby Union athletes appear to obtain less than the 7–9 h of sleep recommended per night in adult populations (Watson *et al*, 2015). Indeed, Dunican *et al.* (2018) reported that professional Rugby Union athletes during the off-season obtain an average of 6 h 30 min sleep per night when measured via polysomnography. Additionally, Shearer *et al.* (2015) reported that following a match, Rugby Union athletes displayed a sleep duration of 6 h 2 min and commonly display sleep disorders and excessive daytime sleepiness (Dunican *et al*., 2018). At the same time, research has highlighted that gaining more sleep supports increases in performance and reduces stress hormones in Rugby Union athletes (Teece *et al*., 2021; Swinbourne *et al*., 2018).

Whilst the research has highlighted that athletes are required to contend with a specific set of sleep challenges, it is currently unknown how those challenges impact Rugby Union athletes across different levels of competition. In many team sport athletes, such as Rugby Union, athletes are typically required to progress through multiple levels of competition to reach an elite level (Duthie, 2006). Each level of Rugby Union has its own unique set of environmental and physical challenges, and it is unlikely that factors affecting sleep are uniform across all levels of competition. For example, professional Rugby Union players sleep may be impacted to a greater extent by higher training loads11 and more frequent travel (Waterhouse *et al*., 2007). Conversely, sleep in the academy and semi-professional Rugby Union athletes may be more greatly impacted by training schedules needing to fit around work and study commitments than their professional counterparts.

Understanding how to improve sleep in Rugby Union athletes is of interest to practitioners and researchers. A better understanding of sleep behaviours across different competition levels in Rugby Union athletes may help practitioners and researchers better understand the nuances of sleep challenges specific to each competition level in Rugby Union. Additionally, normative data may provide future sleep education guidelines specific to each competition level within Rugby Union athletes. Therefore, this study aimed to characterise and determine the sleep habits of male Rugby Union athletes across different levels of competition including the academy, semi-professional, and professional athletes

Methods

Participants

A convenience sample of 224 male Rugby Union players participated in the current investigation. The participants included 109 academy level players (mean age ± SD, 19.7 ± 2.4 y) who competed in either age-group provincial level or local club competition, 38 semi-professional level players (24.6 ± 4.2 y) who competed in a provincial competition for 6 months of the year, and 84 professional players (24.6 ± 3.7 y) who competed in international and provincial competitions full time. According to the guidelines proposed by McKay *et al.* (2022) our participants would be classified as world-class, elite, and highly trained for professional, semi-professional, and academy Rugby Union players, respectively. All participants were aged between 18 and 37 years at the time of taking part in the study. Informed consent was obtained by all participants before completing the questionnaires. Ethical approval was obtained from University of Waikato Human Research Ethics committee (HREC#2017-19).

Procedures

The participants were asked to fill out two sleep questionnaires: the ASBQ and the Pittsburgh Sleep Quality Index (PSQI). The questionnaires were administered via an online electronic survey (Google forms, Google LLC, CA, USA) and were filled out by the participants in a single session. Participants were all in the in-season phase of the competition when completing both questionnaires. Both questionnaires asked participants to answer questions relating to their normal sleep behaviours over the previous month, in accordance with official instructions for each questionnaire. In addition, participants were required to report their current level of competition at the time of taking part in the study; the options included club, provincial, Super Rugby, and international. The participant's responses were broken down into these categories for analysis purposes. To ensure that the correct athletes from each competition classification were filling out the questionnaire each team/group of athletes was targeted individually and sent the link, with team coaches assisting in the classification for each athlete.

Athlete sleep behaviour questionnaire (ASBQ)

The ASBQ is an 18-item questionnaire that asks questions about sleep habits and behaviours thought to be of common concern for elite athletes (Driller, Mah, & Halson, 2018). The questionnaire was designed as a tool to identify areas of practical improvement to sleep behaviours rather than a clinical screening tool. The questionnaire asks participants how frequently specific behaviours occur; never, rarely, sometimes, frequently, always. Each response is weighted from 1=never to 5=always (Table 1). A global score is produced at the end of the questionnaire by summing the answers from each of the 18 items. Global scores can range from 18 to 90, and it is suggested that a global score of ≤ 36 would equate to good sleep behaviours, with a score of ≥ 42 equating to poor sleep behaviours. The ASBQ has been shown to be a valid measurement tool, with moderate to large correlations being seen between the ASBQ and existing sleep questionnaires (Driller, Mah, & Halson, 2018). Furthermore, it has also been shown to have acceptable levels of test-retest reliability (ICC =0.87) when administered twice within a week (Driller, Mah, & Halson, 2018).

Pittsburgh sleep quality index

The PSQI is a commonly used 19-item self-rated questionnaire that is designed to assess sleep quality and disturbances over a one-month period (Buysse *et al*., 1989). The questions are grouped into seven component scores which consist of (1) sleep duration, (2) sleep disturbance, (3) sleep latency, (4) daytime dysfunction, (5) habitual sleep efficiency, (6) subjective sleep quality, and (7) sleep medication. All seven components are each equally weighted on a 0–3 interval scale. and are summed to produce a global score for the PSQI. Global scores range from 0 to 21, with higher scores indicating worse sleep quality. It is suggested that a global score of > 5 equates to having severe sleep difficulties in at least two areas or moderate sleep difficulties in more than three areas outlined above. The PSQI has been shown to have acceptable levels of reliability and validity with diagnostic sensitivity of 89.6% and specificity of 86.5% to distinguish between “good” and “poor” sleepers (Buysse *et al*., 1989).

Statistical analyses

Descriptive statistics are shown as means ± SD unless otherwise stated. Statistical analysis was performed using SPSS V26.0 (IBM Corporation; Chicago, IL, USA). Comparison of athletes was performed for ASBQ and PSQI Global scores using independent sample t-tests. Global scores were normally distributed as assessed by Shapiro-Wilk’s test ($p > 0.05$). There was homogeneity of variances between groups, as assessed by Levene’s test for equality of variance

($p > 0.05$) no outliers existed in that data as assessed by inspection of a boxplot. Additionally, each item for the ASBQ and PSQI questionnaires were compared between groups using a multivariate analysis of variance (MANOVA) with statistical significance set at $p < 0.05$. Where a significant difference between groups occurred, post-hoc tests were applied using a Bonferroni correction for multiple comparisons to establish where the differences existed. For the MANOVA, playing standard (academy, semi-professional or professional) served as independent variables while components of each questionnaire were used as dependent variables. Effect sizes (Cohen's d) were calculated between academy, semi-professional and professional athletes for each questionnaire item. They were interpreted using thresholds of 0.2, 0.5, and 0.8 for small, moderate, and large, respectively (Cohen, 1988).

Results

Analysis of PSQI global scores showed a significantly lower ($p=0.04$) score between the academy and professional athletes associated with a small ($d=0.31\pm0.14$) effect size favouring professional athletes (Table 1).

Table 1. Global scores for the ASBQ, PSQI questionnaires, self-reported sleep duration from the PSQI questionnaire and p-value and effect size comparisons between academy, semi-professional and professional athletes. Data shown as mean ± SD unless otherwise stated

				Academy vs. Semi-professional		Academy vs. Professional		Semi-Professional vs. Professional	
	Academy (n= 109)	Semi-Professional (n=38)	Professional (n=84)	P-value	Effect-size (*d*)	P-value	Effect size *(d)*	P-value	Effect size (*d*)
ASBQ (AU)	43.2 ± 6.5	44.7 ± 7.3	42.9 ± 6.5	0.22	0.22 ± 0.19 *Small*	0.78	0.04 ± 0.14 *Trivial*	0.17	0.26 ± 0.19 *Small*
PSQI (AU)	6.0 ± 2.7	5.7 ± 3.8	5.2 ± 2.5	0.64	0.09 ± 0.19 *Trivial*	0.04	0.31 ± 0.14 *Small*	0.31	0.17 ± 0.20 *Trivial*
Self-Reported Sleep Duration (h:min)	7:19 ± 1:12	7:16 ± 1:15	7:52 ± 0:51	0.83	0.02 ± 0.19 *Trivial*	<0.01	0.36 ± 0.14 *Small*	<0.01	0.47 ± 0.20 *Small*

ASBQ: Athlete Sleep Behaviour Questionnaire; PSQI: Pittsburgh Sleep Quality Index

No significant differences were observed between academy, semi-professional, and professional athletes in ASBQ global score (p=0.60). However, analysis of individual components of the PSQI questionnaire showed significantly lower component scores ($p < 0.05$) between groups for 2 of the 7 components, again favouring the professional athletes (Figure 2). Furthermore, each item of the ASBQ was analysed for differences between groups. The analysis revealed significant differences ($p < 0.05$) between groups for 6 of the 18 items in the ASBQ questionnaire (Figure 3). Self-reported sleep duration from the PSQI questionnaire revealed longer sleep duration in the professional athletes compared to both the academy ($p < 0.01$) and semi-professional athletes ($p < 0.01$, Table 1).

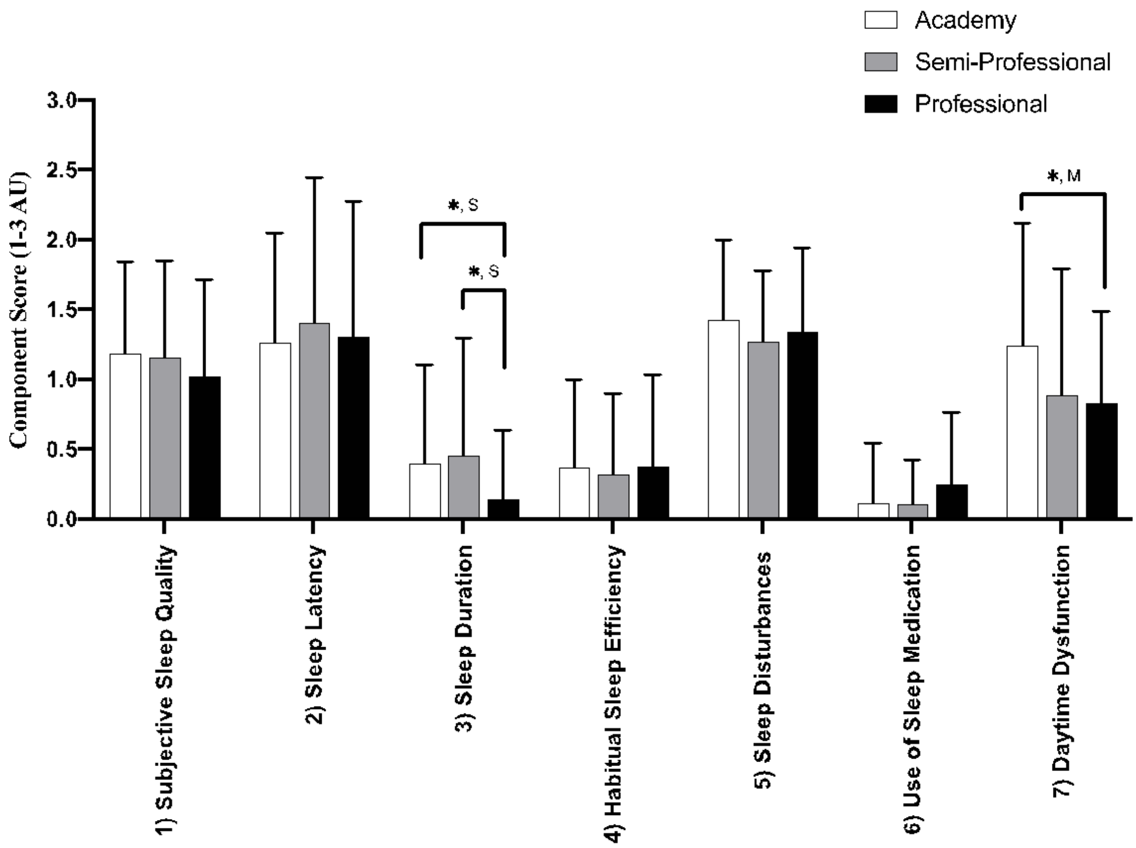

Figure 2. Mean scores out of 3 for academy athletes (n=109), semi-professional athletes (n=38), and professional athletes (n=84) for all 7 components of the Pittsburgh Sleep Quality Index (PSQI) questionnaire. * indicates significance ($p < 0.05$). S=small effect size, M = moderate effect size. NB. A lower score indicates a more desirable sleep behaviour

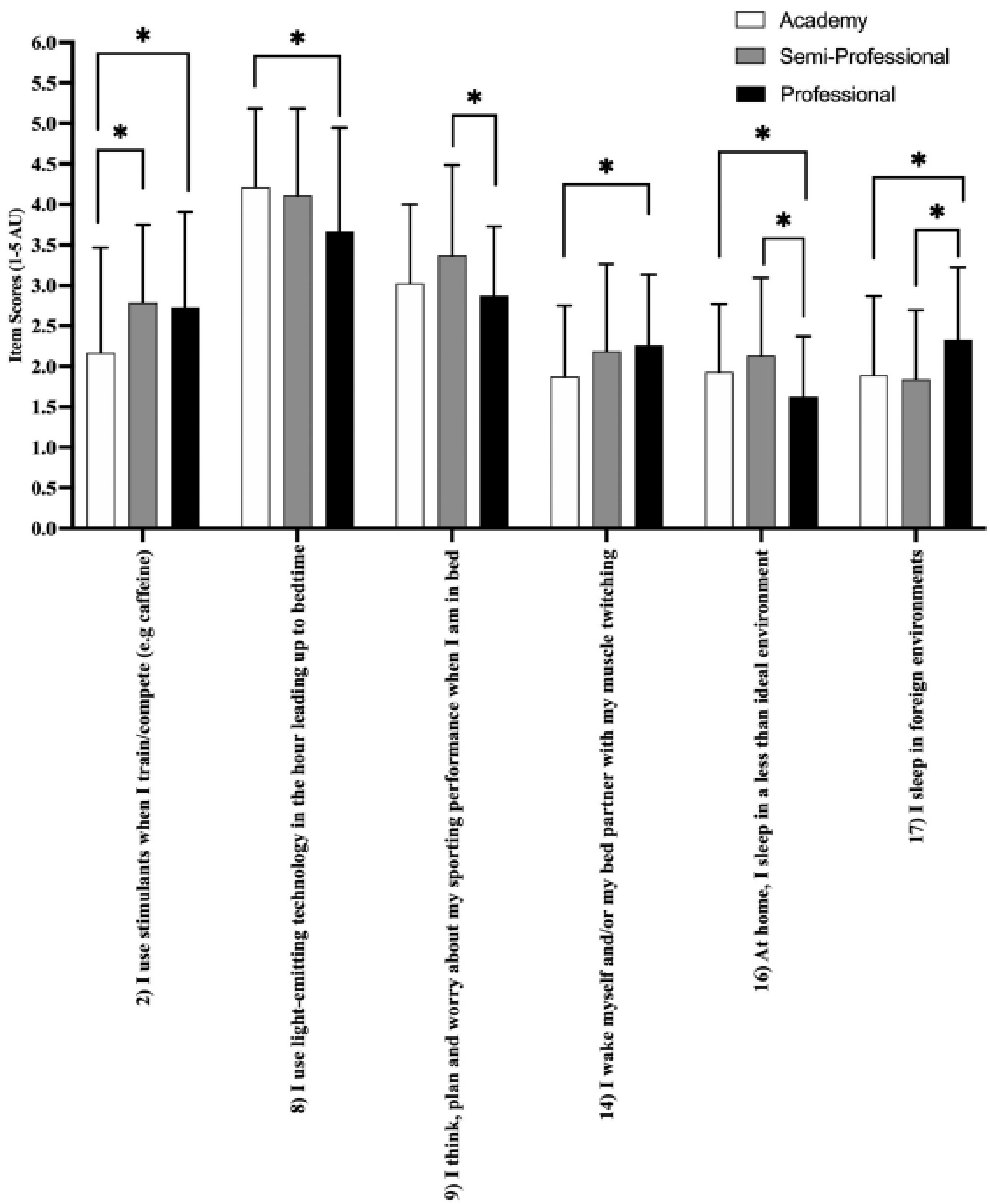

Figure 3. Mean scores out of 5 for academy athletes (n=109), semi-professional athletes (n=38), and professional athletes (n=84) for 6 of the 18 items of the ASBQ where significant differences between groups were observed. *Indicates significant difference. NB. A lower score indicates more desirable sleep behaviour. ASBQ: Athlete Sleep Behaviour Questionnaire.

Discussion

This investigation aimed to characterize differences in sleep behaviours and challenges across academy, semi-professional and professional Rugby Union athletes. Key findings highlighted that sleep challenges are inconsistent across each level of competition, indicating professional, semi-professional, and academy-level athletes each have specific sleep challenges to cope with.

Additionally, the results highlighted that despite sleep durations meeting sleep guidelines (>7 h), Rugby Union athletes may display sub-optimal sleep quality as a result of poor sleep behaviours, irrespective of competition level. The findings from this study suggest that Rugby Union athletes at different levels of competition display differing sleep behaviours.

Professional athletes displayed significantly longer self-reported sleep duration compared to academy and semi-professional athletes. The professional athlete group in the current study reported a longer average sleep duration of 7 h 52 min than previously reported self-perceived sleep durations in professional Rugby League athletes of 7 h 16 min (Caia *et al*., 2018) and 7 h 6 min during a game week in professional Rugby Union athletes (Dunican *et al*., 2019). Numerous factors can influence sleep duration in Rugby Union athletes; however, the differences in sleep duration observed may be in part caused by differences in training schedules. Prior research has suggested that early morning and late-night training can negatively affect sleep duration (Sargent *et al*., 2014; Fullagar *et al*., 2016). Sargent *et al.* (2014) have shown that a reduction in sleep occurs when training starts before 08:00 h. Additionally, late-night training after 18:00 h is commonly associated with later sleep onset and less total sleep obtained (Fullagar *et al*., 2016; Sargent & Roach, 2016). Academy and semi-professional Rugby Union athletes are often required to train around work and study commitments. These commitments require training to be scheduled early morning (before 08:00 h) or evening (e.g., after 18:00 h), potentially limiting the sleep duration. Conversely, professional Rugby Union players are rarely required to train before 08:00 h or late at night, providing professional athletes greater opportunity to optimize sleep duration.

Despite professional athletes displaying longer self-reported sleep duration, individual items of the ASBQ highlighted professional Rugby Union players displayed counter-productive behaviours to optimal sleep. The results showed that muscle twitching during sleep might be a pertinent issue affecting sleep among professional athletes compared to academy Rugby Union athletes. Professional athletes are required to withstand greater training demands compared to academy and semi-professional Rugby Union athletes. Al-Attar *et al.* (2020) reported academy Rugby Union athletes complete ~7.9 km in total running distance within a week, and semi-professional Rugby Union athletes cover ~16.2 km per week. Comparatively, total running distance in professional Rugby Union athletes of ~23.0 km has been reported (Posthumus *et al*., 2021). Increased training load has been suggested to increase muscle fatigue, which can potentially cause greater movement and more awakenings during sleep therefore negatively affecting sleep (Taylor, Rogers, & Driver, 1997). Consequently, higher training loads experienced by professional athletes may explain increased muscle twitching during sleep observed in the current investigation.

Moreover, results from the current study showed that professional Rugby Union players are more frequently required to sleep in foreign environments (e.g., hotels). This finding may be attributed to an increase in domestic and international travel required due to the current nature of playing rugby at a professional level (Bond, Frawley, & Duffield, 2017). Unfamiliar sleep locations have been previously associated with poor sleep quality, possibly caused by a lack of comfort or familiarity within the environment (Le Bon *et al*., 2001). Prior research on professional Rugby League athletes has shown that sleeping in foreign environments caused a decrease in total sleep time and a decrease in sleep efficiency compared to sleeping in their home environment (Thornton *et al*., 2017). Furthermore, domestic and international travel can lead to travel fatigue and jet lag which have both been shown to negatively affect the quality and quantity of sleep in athlete populations (Janse van Rensburg et al., 2021). Therefore, due to the travel requirements for professional Rugby Union athletes, practitioners should aim to implement specific strategies pre, during, and post domestic and international travel to minimize the adverse effects upon sleep (Janse van Rensburg *et al*., 2021).

Our findings identify that problems falling asleep may affect sleep duration amongst semi-professional athletes due to thinking or worrying about sporting performance. Thinking or worrying about sporting performance whilst in bed has previously been reported to affect athletes" sleep (Driller, Mah, & Halson, 2018; Juliff, Halson, & Peiffer, 2015). In the current investigation, semi-professional athletes displayed higher instances of thought about their sporting performance whilst in bed compared to professional athletes. Self-reflection of practice is important for learning and understanding amongst athletes and has been reported to improve awareness of factors that limit and improve performance (Neil *et al*., 2013), improve decision-making skills, and better understand team and individual roles (Richards, Collins, & Mascarenhas, 2012). We posit that due to semi-professional athletes often being required to train later at night, athletes may be reflecting upon their training performance whilst in bed because of the proximity in which training and bedtime occur for this population.

It is important to note that due to semi-professional athletes training at night, it is also possible that increased cardiac autonomic activity observed after training may also have an effect on sleep onset latency (Costa *et al*., 2019). Although, the proximity of competition and sleep may be relevant for professional athletes due to being required to compete at night (O'Donnell, Beaven, & Driller, 2018). Questionnaires can ask about sleep habits over a month; therefore, we suggest that professional athletes do not commonly identify thoughts about performance whilst in bed as a habit as this only occurs once a week in season. Conversely, semi-professional athletes are required to train late at night multiple times a week, forming a habit.

Sleep environments are an important aspect of maximizing sleep quality (Caddick *et al*., 2018). Aspects of the sleep environment that have been shown to impact sleep quality cited by Caddick *et al.* (2018) include light, noise, and temperature. The current investigation suggests that the sleep environment may affect sleep amongst academy and semi-professional Rugby Union athletes. Academy and semi-professional athletes reported higher incidence of sleeping in a less than ideal environment than the professional Rugby Union cohort. This finding suggests that for academy and semi-professional athletes improving their sleep environment via methods of reducing the amount of light, noise and controlling temperature to be conducive to sleep may help to improve their sleep.

The use of electronic devices such as laptops, tablets, and phones in the hour leading up to sleep has been suggested to affect sleep quality and quantity (Bowler & Burke, 2019; Driller & Uiga, 2019). The current study identified that academy-level players reported more frequent use of light-emitting technology in the hour leading up to bed than professional-level players. Exposure to blue-light emitting technology has been shown to alter homeostatic sleep regulation by suppressing melatonin's nocturnal release, which may delay sleep onset (Chellappa *et al*., 2013). Interestingly, the academy players also displayed greater daytime dysfunction compared to professional players. Driller and Uiga (2019) showed that using light-emitting technology for an hour before bed may increase sleepiness the following morning. Additionally, Bowler and Bourke (2019) suggested the use of technology disrupts sleep onset and can affect daytime dysfunction the next day. Therefore, the increased use of light-emitting technology seen in the academy players may in part explain the increase in daytime dysfunction observed in academy level athletes. Furthermore, while not investigated in the present study it must be noted that the type of activity engaged in on technology can also contribute to difficulties falling asleep (Hisler Twenge, & Krizan, 2020). Indeed, active engagement in media, such as video games or social media posting increased sleep onset latency compared to passive engagement (watching a TV or movie) (Weaver *et al*., 2010).

Results from the global scores for PSQI and ASBQ in the current study revealed that all levels of Rugby Union exceeded the suggested thresholds previously outlined by Driller, Mah, & Halson (2018) and Buysse *et al.* (1989). Buysse and colleagues (1989) suggested that a PSQI global score of > 5 indicates "poor" sleep behaviours. A score of > 5 would indicate serious sleep difficulties in at least two components of sleep outlined in the questionnaire or moderate disturbances in at least three components of sleep described in the questionnaire. Additionally, a ASBQ global score that equals or exceeds six has been deemed to equate to "poor" sleep behaviours (Driller, Mah, & Halson, 2018). The global scores indicate that Rugby Union athletes display "poor" sleep behaviours irrespective of competition level. These findings highlight that sleep behaviours can be improved across all levels of competition in Rugby Union athletes and further methods or strategies of improving sleep quality in Rugby Union athletes are needed. Targeting maladaptive sleep behaviours via the use of the ASBQ may allow practitioners and researchers to use specific interventions that help Rugby Union athletes to change habits associated with individual items.

Due to the nature of collecting data in professional athlete populations, there are a number of limitations in the current study which were difficult to control. Sleep duration was obtained via subjective measures, with athletes self-reporting their sleep duration. This potentially resulted in overestimation of sleep duration (Caia *et al*., 2018). Whilst the use of objective data via actigraphy or polysomnography would have provided more accurate information on sleep quantity, collecting this objective data on 224 athletes across numerous locations and training environments was not possible. We also acknowledge that this study was limited to only male athletes across these three competition levels. Future research should aim to compare male and female Rugby Union players and their sleep behaviours across different levels of competition.

Conclusion

The current investigation showed that Rugby Union athletes at different levels of competition display differing sleep behaviours. However, the results highlighted that on average all Rugby Union athletes met current guidelines for sleep duration (7–9 h per night) but demonstrated poor sleep quality irrespective of competition level. Sleep disruption amongst professional Rugby Union athletes is suggested to be susceptible to the use of ergogenic aids, increased frequency in awakenings, prolonged awakenings at night, and travel leading to being required to sleep in unfamiliar environments. Semi-professional athletes sleep appears to be most impacted by the use of ergogenic aids when in training and competition and thought or worry about sporting performance whilst in bed. Furthermore, semi-professional and academy athletes' sleep appears to be impacted by a poor sleep environment. Finally, our results showed that academy players sleep might be largely affected by the use of electronic devices in the lead up to bed, causing greater daytime dysfunction. This information may be helpful to tailor future sleep education and allowing practitioners to target suboptimal sleep behaviours relevant to each level of competition in Rugby Union athletes.

CHAPTER FOUR

Comparing perceived sleep quality, practices and behaviors of elite male and female Rugby Union athletes with the use of sleep questionnaires

Chapter Four:
Teece AR, Beaven, C. M., Argus, C. K., Gill, N., & Driller, M. W. (2023). Comparing perceived sleep quality, practices, and behaviours of male and female elite Rugby Union athletes with the use of sleep questionnaires. *Sleep Science*, *16*(3), e271-e277. https://doi.org/10.1055/s-0043-1772788

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Prelude: In study one, we identified that sleep habits and behaviours were poor in Rugby Union athletes across all levels of competition. In an attempt to further investigate the challenges Rugby Union athletes face with regards to sleep, study two investigated the differences in sleep habits and behaviours between elite male and female Rugby Union athletes.

Abstract

Objective To evaluate the differences in subjective sleep quality, quantity, and behaviours among male and female elite Rugby Union athletes through two common sleep questionnaires.

Materials and Methods A sample of 38 male and 27 female elite Rugby Union athletes filled out the Athlete Sleep Behaviour Questionnaire (ASBQ) and the Pittsburgh Sleep Quality Index (PSQI). Global scores and individual items for each questionnaire were compared to assess differences between sexes.

Results Male athletes reported significantly longer sleep duration (7 h 50 ± 50 min versus 7 h 12 ± 58 min respectively; $p < 0.01$; $d = 0.70$) and higher habitual sleep efficiency (88% versus 83% respectively; $p < 0.05$; $d = 0.54$) when compared with female athletes. Individual items of the ASBQ revealed significant differences between male and female athletes for five questions. Male athletes displayed higher instances of taking stimulants before training or competition and consuming alcohol within 4 hours of going to bed. Conversely, female athletes expressed greater thought or worry while in bed and a higher instance of training late at night.

Discussion Male athletes displayed better self-reported sleep quality and quantity than female athletes; however, the present study highlighted that male and female elite Rugby Union athletes face specific challenges that differ. It appears that the differences observed between male and female elite Rugby Union athletes may be due to differing levels of professionalism or differences in training or competition schedules.

Introduction

Sleep is regarded as one of the best tools available to athletes to recover from training and competition (Venter, 2014) As such, sleep has received considerable attention within competition and training settings, especially over the last decade (Walsh *et al*., 2020; Lastella, Memon, & Vincent, 2020). Moreover, it has been suggested that athletes may require greater amounts of sleep than the general population to recover from the considerable physiological and psychological stress of training and competition (Roberts *et al*., 2019). Despite the need for increased sleep duration, research has highlighted that athletes face several unique challenges that can affect the amount of sleep they gain each night (Lastella *et al*., 2015). Sleep challenges relevant to athletes are often associated with training, travel, and competition (Janse van Rensburg, 2021; Taylor, Rogers, & Driver, 1997), and they include waking up tired, excessive daytime sleepiness (Silva *et al*., 2019), problems falling asleep, waking up throughout the night, and sleeping in unfamiliar environments (such as hotels) (Juliff, Halson, & Peiffer, 2015). Disturbed sleep has been repeatedly reported to negatively affect daytime physical and cognitive performance (Walsh *et al*., 2020); therefore, it is a relevant area of concern within athlete populations.

Previous research has suggested that while sleep may be poor across athlete populations, challenges and habits differ between individual and team-sport athletes (Juliff, Halson, & Peiffer, 2015). Indeed, previous research (Lastella *et al*., 2015; Driller *et al*., 2022) has shown significant differences between total sleep time and sleep efficiency between team and individual sports athletes. Furthermore, within team-sport athletes, sleep challenges may differ depending on the athlete's level. Caia *et al.* (2017) showed that habitual sleep-wake patterns were different between senior and junior male Rugby League athletes, and that sleep differs among playing levels in Rugby League. Numerous sleep challenges have been reported by team-sport athletes, which include caffeine consumption (Dunican *et al*., 2018), increased training volume (Teece *et al*., 2021), scheduling of training and competition (Swinbourne *et al*., 2016), obstructive sleep apnea, movement while asleep (Dunican *et al*., 2019), muscle soreness (Gill, Beaven, & Cook, 2006), and domestic or international travel (Smithies *et al*., 2021).

One method that may help to improve sleep quality and quantity among athletes is the use of sleep hygiene education, which has been previously described as adopting behavioural changes that promote and facilitate sleep and avoiding behaviours that have been suggested to interfere with sleep (Stepanski & Wyatt, 2003). Sleep hygiene education provides athletes with tools and strategies to maximize the quality and quantity of sleep by focusing on lifestyle and environmental factors (Stepanski & Wyatt, 2003; de Sousa, Araújo, & de Azevedo, 2007). Driller, Lastella, & Sharp (2019), reported that individualized sleep education provided to elite cricket athletes through the Athlete Sleep Behaviour Questionnaire (ASBQ) can improve subjective and objective sleep measures. Additionally, O'Donnell and Driller (2017) reported that sleep hygiene education was effective in improving sleep quantity in female elite athletes.

However, there are differences in sleep quality between male and female athletes (Silva et al., 2019; Koikawa *et al*., 2016). Research on differences in sleep according to sex (Mong & Cusmano, 2016) has revealed that female athletes display better quality and quantity than male athletes when sleep is assessed via polysomnography, including longer total sleep time, shorter sleep onset latency, shorter wake time, and improved sleep efficiency. Furthermore, it appears that differences occur within sleep architecture, with males spending more time in stages 1 and 2 of sleep and a reduced time in slow-wave sleep and rapid-eye-movement sleep compared with females (Mong & Cusmano, 2016; Mallampalli & Carter, 2014). However, when research has utilised subjective measures to assess sleep differences between sexes, females report greater sleep problems than males, including shorter sleep duration, difficulties falling asleep, and more wake periods throughout the night (Silva *et al*., 2019). Conversely, male athletes are reported to be at a greater risk of snoring, increased risk of obstructive sleep apnea, increased sleep latency, and decreased sleep efficiency (Dunican *et al*., 2019).

Research has highlighted that there may be several causes for the differences observed in sleep quality and quantity between sexes (Mallampalli & Carter, 2014). Differences in sex hormones may play a role in sleep quality. In males, testosterone levels have been linked to sleep quality, with low testosterone levels being shown to decrease sleep efficiency and increase nocturnal awakenings (Koikawa *et al*., 2016). Furthermore, research suggests that sleep in females is sensitive to hormonal changes in ovarian steroids (Alonso, Genzel, & Gomez, 2021). Differences in circadian rhythms may also play a role in sleep quality and quantity, and they appear to differ between sexes (Koikawa *et al*., 2016; Mallampalli & Carter, 2014), with core temperature nadir and peak secretion of melatonin observed to be earlier in females than males (Cain *et al*., 2010). Despite the earlier circadian timing in females, sleep times are reported to be similar between both sexes (Koikawa *et al*., 2016), potentially causing desynchronization between circadian and sleep timing, which may contribute to females subjectively reporting more subjective sleep problems than males.

While to date it is clear that there are differences in sleep between the sexes, research investigating sleep challenges and habits in elite team-sport athletes has focused mostly on male athletes. Given the increasing professionalism of women in team sports, it is important to understand the challenges pertinent to female elite team-sport athletes and if they are different to those reported in male athletes. Therefore, the current study aimed to evaluate the differences in subjective sleep quality, quantity, and behaviours among male and female elite Rugby Union athletes through two common sleep questionnaires: the ASBQ and the Pittsburgh Sleep Quality Index (PSQI).

Material and Methods

Participants

A convenience sample of 65 male and female elite Rugby Union athletes participated in the current study. Based on the recommendations by Lakens (2022), when the entire target population is measured, there is no need to perform a hypothesis test. Therefore, due to the fact that we sampled the entire population available (international level Rugby Union athletes representing their country), sample size calculation was deemed unnecessary in this instance. The participants included 38 male (age: mean ± standard deviation [SD] = 26.6 ± 3.3 years) and 27 female (mean age: 25.7 ± 4.3 years) athletes who were of international standard and represented their country in the sport of Rugby Union. The study was approved by the institutional Human Research Ethics Committee (HREC#2017–19). The study was outlined to all participants, and informed consent was obtained from them before they filled out the questionnaires.

Procedures

Each participant was required to fill out two separate sleep questionnaires, the PSQI (Buysse *et al*., 1989) and the ASBQ (Driller, Mah, & Halson, 2018), which were applied through an online electronic survey (Google Forms, Google LLC, Mountain View, CA, United States). Both questionnaires were filled out in a single sitting, and the participants were required to be at least four weeks into their competition phase of the season, which typically involves four field training sessions, three gym-based sessions, and one game per week for elite male athletes. Typically, elite female athletes in season complete three field training sessions, three gym-based sessions, and one game per week. The questionnaires asked participants questions relating to their typical sleep patterns over the month prior to taking part in the study, in accordance with the official instructions for each questionnaire.

Pittsburgh Sleep Quality Index (PSQI)

The PSQI is a 19-item self-rated questionnaire that aims to assess sleep quality and sleep disturbances over a 1-month period. It is commonly used in sports settings due to the ease of application and quick completion time (Walsh *et al*., 2020). Specific questions are grouped to create seven components: 1) subjective sleep quality; 2) sleep latency; 3) sleep duration; 4) habitual sleep efficiency; 5) sleep disturbances; 6) use of sleep medication; and 7) daytime dysfunction. Each of these components is equally weighted on an interval scale ranging from 0 to 3, and the component scores are summed to produce a global score ranging from 0– to 21, with higher scores suggesting lower sleep quality. It has been recommended that a global score > 5 equates to poor sleep behaviours, severe sleep difficulties in at least two components, or moderate sleep difficulties in more than three components (Buysse *et al*., 1989). The test-retest reliability of the PSQI has been shown to be strong, with a test-retest correlation r value of 0.85 (Buysse *et al*., 1989).

Athlete Sleep Behaviour Questionnaire (ASBQ)

The ASBQ is an 18-item self-rated questionnaire that asks questions about sleep behaviours and habits over a 1-month period. The questionnaire was designed as a tool to identify areas of practical improvement in sleep habits and behaviours thought to be of common concern for elite athletes rather than a clinical screening tool (Driller, Mah, & Halson, 2018). Each question asks participants how often specific behaviours have occurred on an interval scale ranging from

1 to 5 (1 = never; 2 = rarely; 3 = sometimes; 4 = frequently; 5 = always). A global score is produced by adding the individual answers on each item. A global score ≤ 36 indicates 'good' sleep behaviours, while a score ≥ 42 indicates 'poor' sleep behaviours (Driller, Mah, & Halson, 2018). The test-retest reliability of the ASBQ has been shown to be very high, with a test-retest correlation r value of 0.88 and an intraclass correlation coefficient (ICC) of 0.87 (Driller, Mah, & Halson, 2018).

Statistical Analyses

Descriptive statistics are shown as mean ± SD values, unless otherwise stated. The statistical analysis was performed using the IBM SPSS Statistics for Windows (IBM Corp., Armonk, NY, United States) software, version 27.0. A comparison of male and female athletes was performed for both questionnaires and for each of their items using independent samples t-tests, with statistical significance set at $p < 0.05$. There were no outliers in the data, as assessed by boxplot inspection. Global scores and each individual question were normally distributed as assessed by the Shapiro-Wilk test ($p > 0.05$), and there was homogeneity of variances as assessed by the Levene test for equality of variances ($p > 0.05$). Cohen effect sizes (d) were calculated between male and female athletes for both questionnaires and each question. Effects sizes were interpreted using thresholds of 0.2, 0.5, and 0.8 for small, moderate, and large respectively. An effect size of 0.2 was considered trivial, and the effect was deemed unclear if the 95% confidence interval (95%CI) overlapped the thresholds for both positive and negative effects (Cohen, 1988).

Results

The analysis of the PSQI global scores revealed a significant difference ($p < 0.01$; $d = 0.78$; Table 2) between athlete groups, with male athletes displaying a lower score. Additionally, 3 of the 7 individual components of the PSQI revealed significant differences ($p < 0.05$; Table 2) between groups. There was no significant difference between males and females in terms of ASBQ global scores ($p = 0.08$; Table 2). However, the effect size analysis revealed a small effect size between groups, with the male group displaying lower global scores (Table 2). In total, 5 (Q2, Q3, Q4, Q9, and Q10) of the 18 individual items of the ASBQ questionnaire revealed significant differences ($p < 0.05$, Figure 4) between the male and female groups.

Table 2. Comparison of effect size regarding global scores on Athlete Sleep Behaviour Questionnaire (ASBQ) and Pittsburgh Sleep Quality Index (PSQI) between male (n = 38) and female (n = 27) elite Rugby Union athletes.

Questionnaire	Male (mean ± SD)	Female (mean ± SD)	*p*-value	Effect size (*d*)
ABSQ	43.9 ± 5.3	46.5 ± 6.5	0.08	0.44 *Small*
PSQI	5.0 ± 2.2	7.2 ± 3.3	<0.01	0.78 *Moderate*

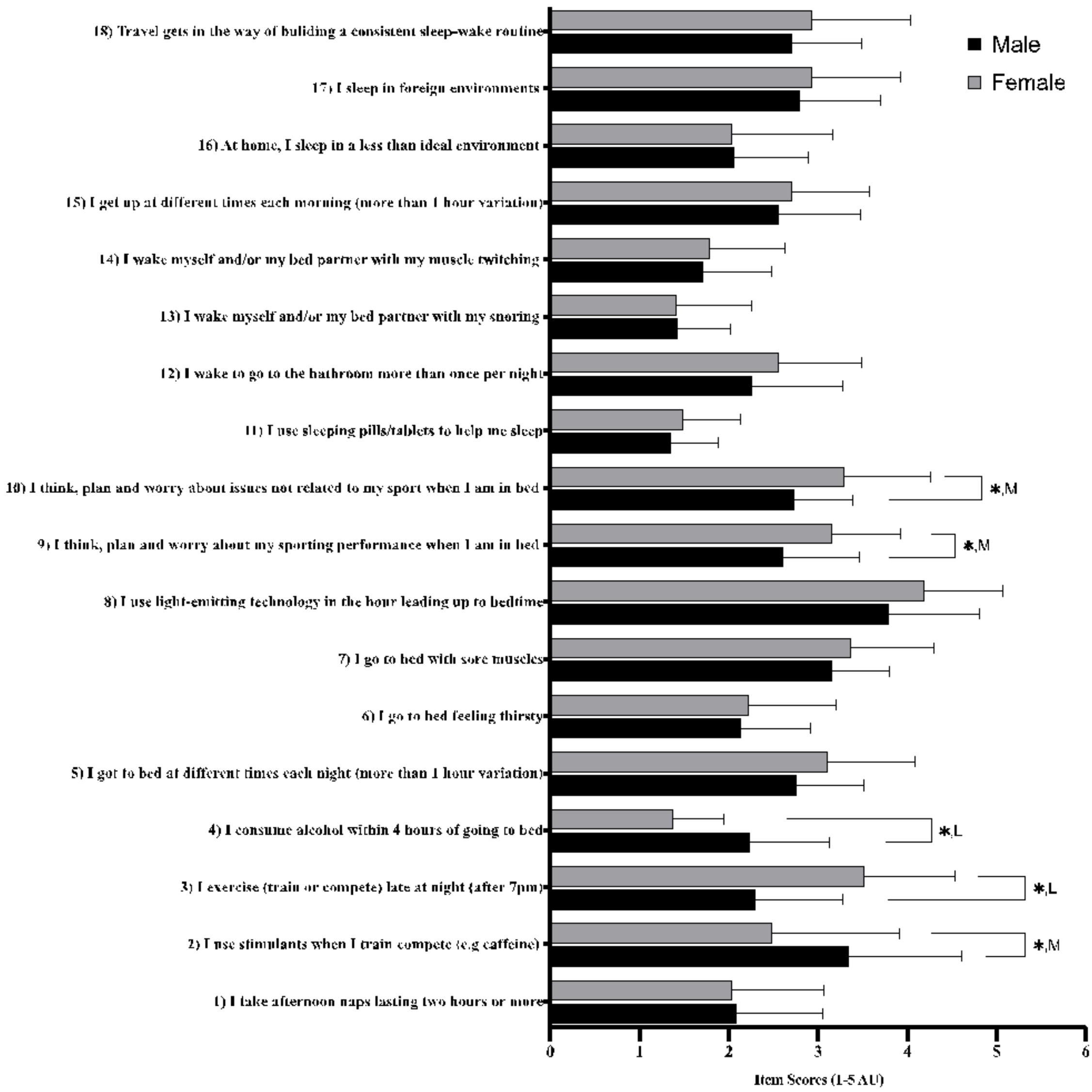
The self-reported sleep time, wake time, and sleep duration from the PSQI showed significant differences ($p < 0.05$; Table 3) between male and female groups. The female group reported that they went to bed significantly earlier than male athletes (10:10 p.m. ± 0:47 a.m. and 10:35 p.m. ± 0:39 a.m. respectively; $p = 0.02$).

Table 3. Comparison of effect sizes regarding individual component scores on the Pittsburgh Sleep Quality Index (PSQI) between male (n = 38) and female (n = 27) elite Rugby Union athletes

	Male (mean ± SD)	Female (mean ± SD)	*p*-value	Effect size (*d*)
Component 1: Subjective sleep quality	1.0 ± 0.5	1.2 ± 0.6	0.28	0.27 *Small*
Component 2: Sleep latency	1.0 ± 0.6	1.2 ± 0.6	0.10	0.42 *Small*
Component 3:	0.0 ± 0.2	0.4 ± 0.6	**<0.01**	0.76

Sleep duration				*Moderate*
Component 4: Habitual sleep efficiency	0.3 ± 0.6	0.8 ± 0.8	**0.03**	0.54 *Moderate*
Component 5: Sleep disturbances	1.5 ± 0.6	1.6 ± 0.7	0.49	0.16 *Trivial*
Component 6: Use of sleep medication	0.1 ± 0.4	0.6 ± 0.8	**<0.01**	0.71 *Moderate*
Component 7: Daytime dysfunction	0.8 ± 0.6	1.1 ± 0.9	0.08	0.41 *Small*

Additionally, the female group reported getting up significantly earlier than the male group (6:54 a.m. ± 1:08 a.m. and 07:31 a.m. ± 1:07 a.m. respectively, $p = 0.03$). The male group reported a significantly longer sleep duration compared with the female group (7 h 50 ± 50 min and 07h 12 ± 58 min respectively; $p < 0.01$; $d = 0.70$). In total, 35% of the male and 70% of the female athletes had PSQI global scores > 5, indicating that most female athletes displayed poor subjective sleep quality.28 Furthermore, 69% of the male and 66% of the female athletes had ASBQ global scores > 42, indicating poor overall sleep behaviours (Driller, Mah, & Halson, 2018). Additionally, 7% of the female and 2% of the male athletes had scores < 36, which indicates good overall sleep behaviours.



Discussion

The present study aimed to investigate the differences in sleep behaviours, habits, and subjective sleep quality between male and female elite Rugby Union athletes through two common sleep behaviour questionnaires. The main findings were that male athletes reported longer perceived sleep duration and better sleep efficiency than female athletes. Female athletes went to bed significantly earlier and got up significantly earlier than male athletes; additionally, female athletes displayed sleep behaviours consistent with having problems falling asleep. The results from the current investigation highlight that male and female elite Rugby Union athletes display sleep complaints which are consistent with those reported by other athlete populations. Moreover, sleep behaviours appear to differ between male and female elite Rugby Union athletes.

In the current study, the male athletes reported a sleep duration of 7 h 50 min, which was significantly longer than the self-reported sleep duration of 7 h 12 min in the female cohort. The self-reported sleep duration was similar to those previously reported among highly-trained male and female athletes. Swinbourne *et al.* (2016) reported that 152 male athletes and 23 female highly trained athletes displayed self-reported sleep durations of 8.0 h and 7.1 h respectively. The current study and the study conducted by Swinbourne *et al. (*2016) used self-reported sleep duration via the PSQI; therefore, it is interesting that the highly-trained male and female athletes in their study perceived their sleep duration to be similar to that reported by elite male and female Rugby Union athletes in the current investigation using the same sleep questionnaire.

The discrepancies observed in sleep duration in the current investigation may have been influenced by numerous factors, which may include differences in training loads (McFadden *et al*., 2020), sex hormones (Mong & Cusmano, 2016), and circadian rhythms (Cain *et al*., 2010). However, we suggest that the disparities in sleep duration may be caused by the impact of training schedules due to differences in levels of professionalism between male and female elite Rugby Union athletes. Indeed, the New Zealand Rugby Union Player's Association (NZRPA, 2018) reported that female elite Rugby Union athletes could receive a maximum retainer of $20,000 NZD per year, while their male counterparts receive approximately $75,000 to $195,000 NZD annually. This discrepancy in salary would suggest that female elite Rugby

Union athletes may be required to have other part-time jobs, which would classify them as semi-professional. Previous research by Pink *et al.* (2018) has shown that semi-professional athletes are required to manage double careers and face the challenge of substantial work or study commitments in addition to training and competing at high standards. The requirements of managing a double career may dictate that training occurs early in the morning or late at night to accommodate commitments such as work or study. Previous research by Swinbourne *et al.* (2016) reported that when highly-trained athletes are required to train before 8 a.m., there is a reduction in sleep duration. Additionally, training after 6 p.m. has been associated with delaying sleep onset and decreasing sleep duration in elite football athletes (Fullagar, *et al*., 2016). Female athletes within the current study displayed an average wake up time at 6:54 a.m., which may be due to being required to train earlier in the morning. Furthermore, female athletes reported more frequently training after 7 p.m. These findings support the suggestion that female athletes have a less than optimal training schedule, which may limit their sleep duration.

Female athletes in the current study reported having more thoughts about sports and non-sport-related matters while in bed compared with male athletes. Thought or worry before sleep has been suggested to contribute to increased cognitive arousal (Carney & Waters, 2006), which has been linked to an increase in sleep onset latency and a decrease in sleep quality (Wicklow & Espie, 2000). A study by Correia and Rosado (2019) with 601 Portuguese athletes highlighted that female athletes presented higher levels of sport anxiety compared with male athletes. Furthermore, Ramis *et al.* (2015) emphasised that female athletes display higher levels of worry than male athletes. It is plausible that the increased levels of anxiety or worry experienced by female athletes may explain why they have reported increased thoughts or worry about sports and non-sport matters while in bed in the current investigation.

In addition, female athletes displayed higher use of sleep medication than male athletes within the current investigation. Sleep medication has been previously reported to be used by athletes in an attempt to reduce cognitive arousal following training or competition (Taylor *et al*., 2016). Additionally, it has been highlighted among people who have more than one job, which is the case in semi-professional athletes, that relaxation is an essential component before going to sleep (Jansen *et al*., 2003). Relaxation includes time with family or friends, resting or reading, and is an important aspect of recovery from work, and unwinding before sleep (Virtanen *et al*., 2009). Within the current investigation, female athletes may have found it hard to fit relaxation into their pre-bed routine due to training schedules caused by double careers. As previously mentioned, female athletes in the current investigation trained late at night more frequently; additionally, they reported going to bed at 10:10 p.m. Due to the proximity between training and bedtime in the current investigation, female athletes would likely have minimal time to undertake relaxation before bed. Indeed, research has highlighted that relaxation strategies are an important requirement in preventing sleep-onset insomnia by reducing anxiety (Viens *et al*., 2003). Therefore, it is plausible that female athletes may have utilised sleep medication to reduce arousal in the absence of relaxation in an attempt to reduce worry or thoughts, and to reduce the latency of sleep onset. It is important to note that sedatives have been shown to be addictive in athlete populations, and they can cause long-term health and performance issues (Baird & Asif, 2018). Therefore, it may be important for female athletes who utilise sleep medication to seek alternative methods to improve their sleep.

An interesting finding from the current investigation was that male athletes reported higher frequencies of alcohol consumption within our hours of going to bed. Research has highlighted that alcohol can negatively affect the quality and quantity of sleep (Halson, 2008) by affecting sleep architecture and causing an increased number of awakenings or light stage-1 sleep in the second half of the night (Roehrs & Roth, 2001). Alcohol consumption is common among Rugby Union athletes, specifically in the hours following a match (Prentice, Stannard, & Barnes, 2014), and it has been previously reported to be higher amongst male than female Rugby Union athletes (Quarrie *et al*., 1996). We suggest that the differences observed in alcohol consumption within four hours of going to bed might be due to scheduling regarding male Rugby Union matches. International Rugby Union matches are commonly scheduled to kick off at night, around 7:00 to 8:00 p.m. Due to the length of a match, night-time kick-offs result in matches typically finishing between 9:00 and 10:00 p.m. Furthermore, Shearer *et al.* (2015) reported that male elite Rugby Union athletes go to bed at 0:49 a.m. the night of a match. Therefore, it is plausible that any post-match alcohol consumption among male elite Rugby Union athletes is likely to occur within 4 hours of bedtime on match day.

Male Rugby Union athletes also displayed a higher instance of stimulant use before training and competition than female athletes. Anecdotally, male Rugby Union athletes are more likely to have greater access to stimulants due to supplements being supplied to professional athletes by team support staff. Furthermore, previous research has reported that males use more pre-workout supplements than females (Dreher *et al*., 2018), which often contain multiple stimulants, including caffeine, β-alanine, and creatine (Harty *et al*., 2018). Jagim, Camic, & Harty (2019) reported that while pre-workout stimulants are used among female populations, females are more likely to experience side effects, including skin reactions and nausea. Therefore, the differences in stimulant use observed in the current investigation may be caused by female athletes experiencing greater side effects, resulting in a decrease in use among them. Furthermore, stimulants have been proposed to negatively affect sleep; when caffeine is consumed within 6 hours of an athlete's proposed bedtime, for example, an increase in sleep latency has been observed (Dunican *et al*., 2018; Halson, 2008). Additionally, this finding may highlight the need to educate male elite Rugby Union athletes on the adverse effects stimulant use can have on sleep.

A limitation of the current study was the lack of objective sleep measures. All behaviours, quality and quantity regarding sleep were collected via subjective sleep questionnaires. Including objective sleep measures such as actigraphy or polysomnography may have enabled the researchers to report in greater detail the differences in sleep quality and quantity among male and female elite Rugby Union athletes. Additionally, a greater understanding of each the training schedules and loads of each group in the month leading up to data collection may have enabled greater insight into the sleep behaviours of athletes.

Conclusion

The current investigation showed different sleep behaviours between male and female elite Rugby Union athletes. The male athletes displayed significantly longer sleep duration compared with the female athletes. Furthermore, male athletes may benefit from education on the effects alcohol consumption and stimulant use can have on sleep. Female athletes reported having more thoughts about sports and non-sport-related issues while in bed and greater use of sleep medication, so this may be an issue in which education is warranted. The present investigation highlights key differences between male and female elite Rugby Union athletes. Additionally, the findings may provide practitioners with insights into challenges specific to male and female Rugby Union athletes and areas in which sleep can be improved.

CHAPTER FIVE

Sleep and Performance During a Preseason in Elite Rugby Union Athletes

Chapter Five
Teece, AR, Argus, C. K., Gill, N. D., Beaven, C. M., Dunican, I. C., & Driller, M. W. (2021). Sleep and performance during a preseason in elite Rugby Union athletes. *International Journal of Environmental Research & Public Health*, *18*(9), 4612. https://doi.org/10.3390/ijerph18094612.

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Prelude: Based on the information that characterised sleep in Rugby Union athletes in studies one and two, in study three we aimed to investigate the relationship between nightly sleep duration and changes in physical performance over a 6-week pre-season training period.

Abstract

Background: Preseason training optimises adaptations in the physical qualities required in Rugby Union athletes. Sleep can be compromised during periods of intensified training. Therefore, we investigated the relationship between sleep quantity and changes in physical performance over a preseason phase in professional Rugby Union athletes. **Methods:** Twenty-nine professional Rugby Union athletes (Mean ± SD, age: 23 ± 3 years) had their sleep duration monitored for 3 weeks using wrist actigraphy. Strength and speed were assessed at baseline and at week 3. Aerobic capacity and body composition were assessed at baseline, at week 3 and at week 5. Participants were stratified into 2 groups for analysis: 7 h 30 min sleep per night (HIGH, n = 14). **Results:** A significant group x time interaction was determined for aerobic capacity ($p = 0.02$, $d = 1.25$) at week 3 and for skinfolds at week 3 ($p < 0.01$, $d = 0.58$) and at week 5 ($p = 0.02$, $d = 0.92$), in favour of the HIGH sleep group. No differences were evident between groups for strength or speed measures ($p \geq 0.05$). **Conclusion:** This study highlights that longer sleep duration during the preseason may assist in enhancing physical qualities including aerobic capacity and body composition in elite Rugby Union athletes.

Introduction

Repeated performance is underpinned by an athlete's ability to recover from multiple physical and psychological stressors (Bishop, Jones, & Woods, 2008; Venter, 2014). Thus, optimal recovery is essential to maximise an elite athlete's performance (Gill, Beaven, & Cook, 2006; Vaile, Halson, & Graham, 2010). Elite athletes utilise numerous recovery strategies (Tavares *et al*., 2017; however, sleep is perceived by athletes and researchers to be the most important recovery tool available (Venter, 2014). Prior research has shown that sleep duration can be compromised during periods of high training demands, such as those experienced during preseason training (Fullagar *et al*., 2015; Killer *et al*., 2017; Taylor, Rogers, & Driver, 1997; Thornton *et al*., 2017). Decreased sleep duration can have detrimental effects on athletic performance through impaired cognitive performance, endocrine, mood and metabolic function (Cook *et al*., 2012; Halson, 2014). However, to date, there has been limited research investigating the relationship between sleep and changes in physical performance markers during periods of increased training demands in team sport athletes.

In Rugby Union, preseason training aims to enhance physical capacities, including power, speed, strength, aerobic and anaerobic fitness, and body composition (Argus *et al*., 2010; Duthie, Pyne, & Hooper, 2003; Tavares *et al*., 2019). To achieve this, athletes are required to train multiple times a day over consecutive days, which results in a period of intensified training. Research has highlighted that sleep can be negatively affected during intensified training periods such as those seen in the preseason (Killer *et al*., 2017, Taylor, Rogers, & Driver, 1997; Thornton *et al*., 2017; Thornton *et al*., 2018). In addition to this, Rugby Union athletes have previously been reported as having higher instances of sleep disorders and excessive sleepiness (Dunican *et al*., 2019). Therefore, sleep may also be a consideration when factoring in player loads during an intensified training period (Dunican *et al*., 2017). While not in Rugby Union, Killer and colleagues (2017), reported a progressive decline in sleep efficiency due to increased wake bouts and movement time during sleep throughout a nine-day intensified training period in highly trained cyclists. Additionally, Thornton and colleagues reported that increases in training volume (e.g., training duration, total distance and high-speed running) could decrease sleep duration and efficiency during periods of intensified training in elite Rugby League athletes (Thornton *et al*., 2017; Thornton *et al*., 2018). Increases in training volume have been previously linked to greater muscle soreness (O'Connor, Morgan, & Raglin, 1991). Increases in muscle soreness have been suggested to affect sleep continuity resulting in an increased number of awakenings per night, potentially affecting sleep duration (Taylor, Rogers, & Driver, 1997).

A reduction in sleep efficiency and duration seen during intensified training periods may be detrimental to maximising physiological adaptation and muscle recovery (Dattilo *et al*., 2011). Researchers have suggested that reductions in sleep duration may inhibit muscle growth and recovery (Datillo *et al*., 2011) and lead to a catabolic environment (Spiegel, Leproult, & van Cauter, 1999; van Cauter *et al*., 2008) with the potential to attenuate muscular adaptation associated with resistance training (Cook *et al*., 2012; Spiegel, Leproult, & van Cauter, 1999; Beaven, Cook, & Gill, 2008). Reductions in sleep duration are also known to lead to an imbalance in hormones necessary for the control of appetite and satiety (i.e., leptin and ghrelin), which have been associated with decreases in resting metabolic rate and increased hunger, and caloric consumption and weight gain (Dattilo *et al*., 2011; van Cauter *et al*., 2008; Taheri *et al*., 2004), which may impact individual athletes depending on the body composition requirements of the sport and or playing position.

In contrast to the reported adverse effects of a reduction in sleep, increasing sleep duration may be beneficial for moderating stress responses and performance during periods of intensified training (Swinbourne *et al*., 2018). Swinbourne and colleagues (2018) investigated the effects of three weeks of sleep extension (>8 h) on sleep, stress markers and performance in highly trained male Rugby Union athletes and observed a mean improvement of 4.3% in reaction time and a reduction of 18.7% in cortisol levels. The findings reported by Swinbourne and colleagues (2018) suggest that longer sleep duration during the preseason phase in Rugby Union may assist in moderating stress responses, potentially supporting optimal adaptive outcomes.

To the best of the authors' knowledge, there are no studies investigating the relationship between sleep and changes in physical performance markers, including strength, speed, fitness and body composition over an intensified micro-cycle of training (e.g., 3–5 weeks) in elite Rugby Union athletes. Therefore, the current study aimed to examine the relationship between sleep and physical performance changes throughout a preseason training phase in a group of professional Rugby Union athletes.

Materials and Methods

Participants

A total of 29 professional Rugby Union athletes (mean ± SD; age, 23 ± 3 years; body mass, 104.9 ± 10.7 kg; stature, 187.0 ± 6.9 cm) from a New Zealand Super Rugby team volunteered to participate in the current study. The Super Rugby competition is the premier professional club rugby competition in the southern hemisphere and involves 15 teams from New Zealand, Australia, South Africa, Argentina and Japan. All athletes undertook a 3-week off-season training program prior to the study to ensure athletes arrived at the start of the preseason in appropriate physical condition to meet the subsequent training demands. Written informed consent was obtained from participants, and ethical approval (Ethics number: FEDU066/16) was obtained from the Institutions Research Ethics committee.

Research Design

A pre-post observational study design was utilised for the current investigation. Markers of strength, aerobic fitness, speed and body composition were collected across several sessions throughout the study period. Their relationship to sleep metrics was examined across a five-week training period. Sleep groups were split retrospectively based on average nightly sleep duration. The LOW sleep group displayed an average sleep duration of 6 h 55 min, less than the 7 h, which has been deemed to demonstrate "sleep loss" (Walsh *et al*., 2020). Conversely, the HIGH sleep group displayed an average sleep duration of 7 h 49 min, which lies within the recommended sleep duration of 7–9 h in adult populations (Watson *et al*., 2015). The athletes completed a three-week training block during the preseason phase of the competition. Each week within this phase comprised of four training days, which consisted of two speed sessions, four gym-based resistance training sessions, five conditioning sessions and eight rugby specific sessions per week. The 3-week training period was followed by a 2-week maintenance training block, which consisted of three gym-based resistance training sessions and four conditioning sessions per week. All training programs were designed and monitored by the team's strength and conditioning and coaching staff. Increases in the on-field training load, assessed by GPS, was planned across the three weeks as follows: Week 1—22 km ± 3 km (8 sessions); Week 2—30 km ± 4.5 km and an 8 km hill walk (11 sessions); Week 3—39 km ± 5.8 km (11 sessions).

Procedures

Sleep Monitoring

Quantitative sleep measures were collected throughout the study via the use of wrist actigraphy (ReadiBand^{TM}, Fatigue Science, Vancouver, BC, Canada). Athletes were required to wear a wrist actigraph on either wrist (Driller, O'Donnell, Tavares, 2017) throughout the entire 3-week training block and were encouraged to wear the actigraph at all times except during contact training. Athletes were asked to maintain their regular sleep routines throughout the study. For the duration of the study, athletes slept in their residential homes. At the beginning of each day, actigraphy data were wirelessly downloaded to an iPad, and then analysed by online software (16 Hz sampling rate; ReadiBand^{TM}, Fatigue Science, Vancouver, BC, Canada). Athletes were blinded to their sleep results throughout the duration of the study. The raw activity data were translated into sleep–wake indices including total sleep time (TST), sleep efficiency (SE%), sleep latency (SL), wake after sleep onset (WASO) and wake episodes (WE). The ReadiBand^{TM} has been validated against polysomnography (PSG) and has been deemed to be acceptable with an approximately 90% agreement in total sleep duration when compared to PSG (Dunican *et al*., 2018). The inter-device reliability of the ReadiBand^{TM} has also been shown to have high levels of agreement (Driller, McQuillan, & O'Donnell, 2016).

Athletes were asked to complete a sleep diary every day of the three-week preseason training period. Every morning, athletes were asked to report the previous night's sleep duration (reported in hours and minutes) and their sleep quality on a scale of 1 to 7 (1: very poor, 7: excellent). These data were collected via the wellness questionnaire described below.

Sleep Questionnaires

The Athlete Sleep Behaviour Questionnaire (ASBQ) and the Pittsburgh Sleep Quality Index (PSQI) were collected to assess various aspects of sleep behaviour. The ASBQ is an 18-item survey that includes specific questions about sleeping habits and behaviours common for elite athletes (Driller, Mah, & Halson, 2018). Each response for the 18 items is summed to provide a global score with a higher global score indicating poorer sleep behaviour. The PSQI is one of the most commonly used subjective sleep measures (Buysse, Reynolds, & Monk, 1988). The PSQI is a 19-item questionnaire designed to assess sleep quality and disturbances in clinical and non-clinical populations. The questionnaire produces a global score which can range from 0 to 21, with higher scores indicating poorer overall sleep. Typically, both questionnaires ask athletes about sleep habits over the last month; however, for the purpose of this study, the questionnaires were modified to ask about sleep habits over the past 3 weeks. The ASBQ and PSQI were collected at the beginning of the study (Day 1) and then again at the completion of the three-week preseason training period (Day 21). Both questionnaires were required to be filled out at the same time of day and were administered using Google Forms (Google LLC, Mountain View, CA, USA).

Physical Assessments

Maximal Strength Testing

Maximal strength was assessed from one-repetition maximum (1RM) testing of the back squat, bench press and weighted chin-up exercises. Prior to testing, athletes undertook a generalised warm-up that consisted of foam rolling, static and dynamic stretching and basic locomotion. Testing protocols used for bench press and squat exercises have been previously described by Schoenfeld and colleagues (2015). Each participant was required to perform three submaximal warm-up sets consisting of 2–6 repetitions (reps) with progressively larger loads. Athletes then performed sets of 1–2 reps of increasing weight until a 1RM was attained. Weighted chin-up testing followed protocols previously described by Coyne and coworkers (2015). Athletes performed five bodyweight chin-ups, followed by a set of three, then two reps with increasing external loads. After warm-up repetitions, athletes performed only single repetitions until a 1RM was attained. Three to five minutes of recovery was allowed between attempts. Each maximal effort set was used to predict each athlete's 1RM using the equation 1RM = ([102.78–2.78(R)]/100) (Brzycki, 1993). This equation has been shown to have a strong correlation between predicted and actual 1RM for bench press ($r = 0.993$) and back squat ($r = 0.969$) exercises (LeSuer et al., 1997). Testing of all maximal strength exercises occurred at baseline and at week 3 during a single session at each time point.

Barbell Bench Press Testing Protocol

Athletes self-selected their hand position and were required to lower the bar to the chest lightly touching before vertically pushing the bar until the arms were fully extended. Athletes could not bounce the bar off their chest, display excessive back arching or receive any help from spotters (Schoenfeld et al., 2015).

Back Squat Testing Protocol

Athletes self-selected their hand and foot position and were required to descend until the upper thigh was below parallel with the floor (below 90°). Once the athlete had achieved adequate depth, they were required to ascend to the standing position without any assistance. Depth of the squat was visually assessed by the strength and conditioning staff, and athletes were allowed to wear weightlifting belts, but no other supportive equipment was allowed (Schoenfeld *et al*., 2015).

Weighted Chin up Testing Protocol

Athletes were required to pull vertically until their chin was over the height of the bar and were required to display a controlled return to the starting position. Athletes were not permitted to utilise their legs or any swinging motion, push off the floor to assist or create any elastic energy to utilise. External weight was added by attaching weight plates to the athletes via a weight belt and chain secured around the hips (Coyne *et al*., 2015). The external weight added was dependent upon the strength of each individual athlete. The total 1RM weight was established by summing the athlete's body weight (kg) and weight added.

Speed Testing

Speed was measured over both 5 m and 10 m from a standing start position. The athletes were required to perform 2 to 3 trials of maximal effort sprints. Athletes were instructed to stand 50 cm behind the first timing gate prior to starting (Duthie *et al*., 2006). Sprint speed was measured using infrared timing lights (Fusion Sport, Brisbane, Australia). The above protocol has been previously established for 10-m trained athletes with intra-trial reliability of r = 0.86 (Baker & Nance, 1999). Speed testing was conducted at baseline and at week 3 within a single session at both time points. All tests were conducted indoors on artificial turf. Prior to testing, participants were able to complete their own individual self-selected warm-up, followed by a standardised warm-up, which consisted of light jogging, short accelerations and dynamic stretching.

Aerobic Fitness

Aerobic fitness was assessed at three time points of the study using the Bronco shuttle test. The Bronco test is widely used in rugby environments and consists of running 1200 m in a shuttle (out and back) manner (Deuchrass *et al*., 2019). Each athlete completed a 20-m shuttle, followed by a 40-m shuttle, then a 60-m shuttle. Following the completion of the 60-m shuttle, the participant is considered to have completed one repetition. Participants are required to complete five repetitions as quickly as possible without any rest. The test was performed at baseline, after the three-week preseason training phase, and following the two-week maintenance phase of training. Each test was completed on the same standard-sized Rugby Union field at every time point (Baseline test = 23 ◦C, 60% relative humidity (RH), at week 3 = 20 ◦C, 74% RH, at week 5 = 19 ◦C, 58% RH). Handheld stopwatches were used to record finishing times for each participant. Prior to testing, participants were able to do their own individual self-selected warm-up, followed by a standardised warm-up which involved run-throughs over 40 m at an increasing tempo (60, 70 and 80% effort), dynamic stretching and change of direction activities at an increasing tempo (60, 70 and 80% effort). Before each test, the participants were reminded of the test protocols and were instructed to give maximal effort throughout the whole test. Aerobic fitness was assessed at baseline, at week 3 and at week 5. The typical error of estimate (TEE) for the Bronco test in elite Rugby Union athletes is 3.02 s, with a coefficient of variation (CV) of 1.0% (unpublished observations from our laboratory).

Body Composition

Bodyweight and skinfold measurements were obtained as measures of body composition for the current study. Body weight was measured to the nearest 0.1 kg using digital scales (Wedderburn, New Zealand). Skinfolds were assessed at eight sites following the protocols of the International Society of the Advancement of Kinanthropometry and summed for the analyses (Norton *et al*, 1996). Bodyweight and skinfolds were obtained at the beginning of the study, following the 3-week preseason training period and after the two-week maintenance training period. All skinfold and body weight measures were assessed by the same accredited professional. Assessment of body composition took place at baseline, at Week 3 and at Week

5 during a single session. The TEE for the sum of 8 skinfold test in elite Rugby Union athletes is 4.1 mm, with a coefficient of variation (CV) of 4.7% (unpublished observations from our laboratory).

Wellness Assessments

A wellness questionnaire based on the recommendations of Hooper and Mackinnon (1995) was completed on the mornings of all training days for the three-week preseason training period. The wellness questionnaire comprised of five questions that included ratings of fatigue, general muscle soreness, general stress, sleep quality and mood. The questionnaire used a 1 to 7 Likert-type scale where 1 represented a low score (e.g., relaxed) and 7 represented a high score (e.g., high stress). A total wellness score was calculated for each athlete ranging from 5 to 35, with lower scores being considered to represent greater wellness.

Training Load

Locomotion activity was measured during all on-field team training, units and speed sessions throughout the 3-week preseason phase using an 18 Hz GPS unit (Apex Pro Series Pod, STATSports, Belfast, UK). Each unit was worn on the upper back between the scapulae. To decrease variability, the same GPS unit was used by each participant for all sessions. After the completion of each session, the raw data were downloaded and analysed using the company's software (Sonra software, STATSports, Belfast, UK).

Statistical Analyses

All descriptive statistics are reported as means ± 95% confidence intervals unless otherwise stated. The data for sleep measures, changes in performance, wellness scores and training load were pooled, and Pearson's correlations were used to determine if any relationships were present between sleep, changes in performance, markers of subjective wellness and training load. Correlations were interpreted using thresholds of < 0.05 for all analyses. A two-way mixed ANOVA, with 2 (group: HIGH, LOW) × 3 (time: Week 1, Week 3, Week 5) factors was performed for all physical performance measures and sleep questionnaires. Analysis of the studentised residuals was verified visually with histograms and by the Shapiro–Wilk test of normality. The presence of outliers was assessed via inspection of boxplots. Mauchly's test of sphericity was used to establish equal variance within-subjects for all variables ($p > 0.05$). The main effects were run to identify where statistically significant differences existed. When the main effects were found, post-hoc analysis was performed. Additionally, a Wilcoxon signed-rank test was performed to determine if there were differences in individual scores for sleep questionnaires. Effect-size statistics were calculated using Cohen's d and interpreted using thresholds of 0.2, 0.5 and 0.8 for small, moderate and large, respectively (Cohen, 1988). An effect size of <0.2 was considered trivial, and the effect was deemed unclear if the 95% confidence interval overlapped the thresholds for both positive and negative effects (Batterham & Hopkins, 2006).

Results

The Pearson's correlation correlational analyses revealed no significant correlations ($p \geq 0.05$) between sleep and wellness measures or performance markers, with all r-values in the trivial–moderate range, as seen in Table 4. As a result, we stratified our data into two groups, (LOW: 7 h 30 min sleep per night, n = 14) for all remaining analyses. Differences observed between HIGH and LOW sleep groups for average nightly sleep duration, weekly total sleep duration, and overall total sleep duration are shown in Table 5. Results from the 2-way mixed ANOVA showed that there was a significant group x time interaction for skinfolds, $F(1,27) = 7.89$, $p < 0.01$ and Bronco performance, $F(1,22) = 7.60$, $p = 0.01$, but not for any other performance measure ($p > 0.05$). The HIGH group displayed significantly greater reductions in skinfold measurements at Week 3 ($p < 0.01$, Table 6) and Week 5 ($p = 0.02$, Table 6) compared to the LOW sleep group. The difference in the magnitude of change in the sum of 8 skinfolds between HIGH and LOW sleep groups was 5.4 mm at week 5, which is greater than the TEE (4.1 mm) of the test from our unpublished observations. Additionally, the HIGH sleep group displayed significantly greater improvements in Bronco performance at Week 3 ($p = 0.02$, Table 6) when compared to the LOW sleep group. The difference in Bronco performance improvements between HIGH and LOW sleep groups was 3.9 s at Week 3, which is greater than the TEE (3.02 s) of the test from our unpublished observations. Sleep questionnaire analysis revealed a significant group x time interaction for ASBQ global scores, $F(1,27) = 6.39$, $p = 0.01$ (Table 7) with the HIGH sleep group showing significant improvement (larger reduction in global score) compared to the LOW sleep group. Additionally, no group x time interactions were found for PSQI global scores between sleep groups (Table 7). The Wilcoxon signed-rank test displayed significantly different question scores from baseline to Week 3 for Q3, ($z = -2.06$, $p = 0.03$) and Q15 ($z = -2.06$, $p = 0.03$) of the ASBQ in the HIGH sleep group. No significant group x time interactions were observed between groups for any wellness measures. However, a significant increase ($p < 0.01$) in fatigue was observed from Week 1 to Week 3 across the entire cohort.

Table SEQ Table * ARABIC 5. Pearson's r-values for correlations between sleep variables, changes in performance markers and wellness measures

	Body Weight	Skinfolds	1RM Squat	1RM Bench	1RM Chin-Up	Bronco	5 m Speed	10 m Speed	Fatigue	Muscle Soreness	Stress	Quality (Self-Reported)	Wellness
Total Sleep time	−0.227 [S]	−0.237 [S]	0.068	−0.071	0.206 [S]	−0.097	0.015	0.202 [S]	0.033	−0.027	0.092	−0.125 [S]	−0.007
Sleep Efficiency	−0.149 [S]	−0.156 [S]	−0.058	0.133 [S]	0.121 [S]	0.215 [S]	0.388 [M]	0.267 [S]	−0.305 [M]	0.302 [M]	0.136 [S]	−0.030	0.197 [S]
Sleep Latency	−0.037	−0.102 [S]	0.010	−0.053	−0.058	−0.108 [S]	−0.349 [M]	−0.393 [M]	−0.109 [S]	−0.151 [S]	−0.199 [S]	−0.051	−0.149 [S]
Wake Episodes	0.128 [S]	0.179 [S]	0.114 [S]	−0.007	−0.137 [S]	−0.165 [S]	0.049	−0.049	−0.217 [S]	−0.227 [S]	0.136 [S]	−0.068	−0.096
Wake after sleep onset	0.108 [S]	0.184 [S]	0.051	−0.024	−0.101 [S]	−0.201 [S]	0.170 [S]	0.071	−0.229 [S]	−0.239 [S]	0.125 [S]	0.038	−0.074

[S] = small correlation, [M] = moderate correlation.

Table SEQ Table * ARABIC 4. Differences in sleep duration as assessed via wrist-actigraphy (mean ± SD) for the HIGH and LOW sleep groups across a 3-

	Sleep Duration Nightly (h:min)	Sleep Duration Week 1 (h:min)	Sleep Duration Week 2 (h:min)	Sleep Duration Week 3 (h:min)	Sleep Duration Overall (h:min)
HIGH	7:49 ± 0:15	63:42 ± 4:25	54:06 ± 1:40	54:03 ± 3:28	171:52 ± 6:40
LOW	6:55 ± 0:22	56:34 ± 5:15	48:01 ± 3:33	48:59 ± 2:41	152:36 ± 8:12
HIGH–LOW	0:54 ± 0:06 [L]	7:08 ± 3:42 [L]	6:05 ± 2:08 [L]	6:04 ± 2:23 [L]	19:16 ± 5:40 [L]

[L] = large effect sizes. HIGH: >7.5 h average per night (n = 14), LOW: <7.5 h average per night (n = 15).

Table 6. Data (mean ± 95% confidence limits) for raw change of physical performance measures between Week 1 and Week 3 and raw changes of skinfold, bodyweight and Bronco changes between Week 1 and Week 5 for the HIGH and LOW sleep groups including p-values and effect size comparisons between groups

Measure	Condition	Raw Change Week 1 to 3 (Mean ± CI)	*p*-Value	Effect Size (*d*) ± 95% CI	Raw Change Week 1 to 5 (Mean ± CI)	*p*-Value	Effect Size (*d*) ± 95% CI
Skinfold (mm)	HIGH LOW	−8.9 ± 5.9 −6.0 ± 4.0	0.007 *	0.58 ± 0.65 *moderate*	−11.4 ± 8.0 −6.0 ± 3.6	0.020 *	0.92 ± 0.70 *large*
Bodyweight (kg)	HIGH LOW	0.4 ± 1.6 −0.5 ± 1.2	0.091	−0.70 ± 0.72 *moderate*	0.3 ± 1.7 −0.4 ± 1.2	0.158	−0.53 ± 0.74 *unclear*
Bronco (sec)	HIGH LOW	−5.4 ± 3.02 −1.5 ± 3.11	0.022 *	1.25 ± 0.81 *large*	−7.3 ± 5.9 −3.0 ± 9.2	0.277	0.40 ± 0.72 *unclear*
1RM Squat (kg)	HIGH LOW	−5.1 ± 10.0 −5.0 ± 10.0	0.750	−0.15 ± 0.84 *unclear*	-	-	-
1RM Bench Press (kg)	HIGH LOW	−6.1 ± 4.8 −3.3 ± 6.9	0.284	0.48 ± 0.75 *unclear*	-	-	-
1RM Chin-Up (kg)	HIGH LOW	−6.1 ± 6.6 −5.6 ± 7.0	0.853	0.08 ± 0.74 *unclear*	-	-	-
5 m Speed (sec)	HIGH LOW	−0.01 ± 0.03 0.01 ± 0.03	0.799	0.64 ± 0.98 *unclear*	-	-	-
10 m Speed (sec)	HIGH LOW	0.03 ± 0.05 0.02 ± 0.02	0.400	−0.48 ±1.03 *unclear*	-	-	-

* indicates significant difference between groups ($p < 0.05$). HIGH: >7.5 h average per night ($n = 14$), LOW: <7.5 h average per night ($n = 15$).

Table 7. Data (mean ± 95% confidence limits) for pre- and post-global scores for ASBQ and PSQI sleep questionnaires between Week 1 and Week 3 for the HIGH and LOW sleep groups, including p-values and effect size comparisons between time points.

Measure	Condition	Pre (Mean ± SD)	Post (Mean ± SD)	*p*-Value	Effect Size (*d*) ± 95% CI
ASBQ	HIGH LOW	44.5 ± 5.7 41.1 ± 4.9	41.0 ± 5.0 41.8 ± 5.1	0.022 * 0.509	−0.63 ±0.76, *moderate* 0.13 ±0.73, *unclear*
PSQI	HIGH LOW	5.7 ± 2.9 5.0 ± 1.8	5.5 ± 2.4 5.5 ± 2.0	0.671 0.135	−0.08 ±0.75, *unclear* 0.26 ±0.80, *unclear*

* indicates significant difference between groups ($p < 0.05$). HIGH: >7.5 h average per night ($n = 14$), LOW: <7.5 h average per night ($n = 15$).

Discussion

The aim of this study was to investigate the relationship between sleep duration and changes in physical performance throughout a 5-week preseason training phase in elite Rugby Union athletes. Key findings indicate that when the group stratified into two quantile groups, those obtaining greater amounts of sleep (>7 h 30 min) resulted in positive changes in aerobic fitness and body composition compared to those who obtained < 7 h 30 min of sleep per night. Additionally, we observed a decrease in weekly sleep duration and increased fatigue from Week 1 to Week 3 for both groups, suggesting sleep duration is negatively impacted during a preseason phase of training.

While this is the first study to evaluate the link between sleep duration and performance metrics during a preseason phase in elite Rugby Union athletes, previous research has evaluated the efficiency of sleep extension on athletic performance (Swinbourne *et al*., 2018; Fullagar *et al*., 2015; Schwartz & Simon, 2015; VanHelder & Radomski, 1989; Mah *et al*., 2011). Prior sleep extension research has shown that an increase in sleep duration can positively impact physical and sport-specific performance. Schwartz and Simon (2015) showed that extending sleep by 1 h 43 min for one week significantly improved tennis serving accuracy by 6.1% in collegiate athletes. Additionally, Swinbourne and colleagues (2018) reported that increasing sleep duration by an hour per night led to a small improvement of 4.3% in reaction time performance in elite Rugby Union athletes. Lastly, Mah and colleagues (2011) showed improvements in sprint time and shooting accuracy in collegiate basketball athletes when sleep was extended from 6 h 36 min during a baseline period to 8 h 30 min over a 5–7 week duration. While the present study did not investigate sleep extension, the results revealed that the HIGH sleep group displayed significant physical performance changes and slept longer than the LOW sleep group. Therefore, it could be suggested that the findings from the current study were similar to those previously reported (Schwartz & Simon, 2015; Mah *et al*., 2011).

Although speculative, the positive effects observed in Bronco performance may be related to an increased amount of slow-wave sleep (SWS). Increased sleep duration results in an increased amount of SWS (van Cauter, Leproult, & Plat, 2000); this is associated with higher levels of growth hormone production, which plays an important role in protein synthesis, muscle growth and repair (Dattilo *et al*., 2011; Cuneo *et al*., 1991). Higher growth hormone levels have been shown to positively affect aerobic exercise capacity, specifically VO_2 max and work rate (Widdowson & Gibney, 2008; Widdowson *et al*., 2009). Given that Bronco performance heavily relies on aerobic capacity, the current findings support the beneficial effects of obtaining more sleep on aerobic capacity during preseason periods in elite Rugby Union athletes.

Further, higher growth hormone levels have been linked to elevated levels of resting metabolic rate (RMR) (Jørgensen *et al*., 1998). RMR is the largest component of energy expenditure and therefore influences body composition (Benedict *et al*., 2011). The regulation of ghrelin and leptin have also been linked to sleep duration and are important for body composition. As skinfold measurements are highly influenced by energy intake and RMR, the changes in skinfold measurements observed in the current investigation may suggest that obtaining more sleep can lead to more advantageous outcomes in body composition.

No differences were observed between groups for strength or speed throughout the 3-week training phase. Additionally, results revealed that both groups displayed decreases in strength markers at Week 3. The observed lack of change in speed performance is contrary to previous results by Mah and colleagues (2011), who demonstrated improvements in sprint performance when sleep duration was extended. Discrepancies in findings between this study and the previous study, as mentioned above may be explained in part by study duration. In the study conducted by Mah, the period between baseline testing and retesting was 7 weeks, whereas the present study was just 3 weeks. In the present study, the 3-week period may not have been an adequate duration to reveal improvements in strength and speed performance measures. Additionally, previous research has highlighted that when concurrent training is utilised, increases in running volume can inhibit strength development and cause decrements in strength and power (Nader, 2006; Wilson *et al*., 2012). The interference between running volume and strength is potentially due to high levels of fatigue and muscle soreness caused by high eccentric damage due to running (Wilson *et al*., 2102). Interference caused by a weekly increase in running load in the current study may explain why we observed an increase in aerobic fitness and a decrease in strength and speed markers across the 3-week period (Blagrove, 2014).

The decrease in sleep duration of 1 h 13 min less sleep per night from Week 1 to Week 3 observed for both groups is likely due to increased fatigue. Thornton *et al.* (2017). previously reported similar decreases in sleep duration compared to the current study. Thornton and colleagues (2017) showed an increase in training load and decreased total wellness during a 2-week training camp, which was associated with a decrease in sleep duration of 1 h 39 min per night compared to a pre-camp period. We observed a significant increase in fatigue scores and increased training load from Week 1 to Week 3. Increases in fatigue and training load have been linked to greater sleep disruption leading to lower sleep efficiency and sleep duration (Taylor, Rogers, & Driver, 1997; Bonnet, 1987). Therefore, our findings suggest that the decrease in sleep duration seen across both groups may result from increased training loads resulting in increased fatigue

The current study highlighted a moderate improvement in the HIGH sleep group for the ASBQ questionnaire global score, which suggests that the HIGH sleep group displayed better sleep behaviours during the 3 weeks than the month leading up to the study. No significant differences were seen for either sleep group for PSQI global scores. It should be noted that the current study's sleep groups displayed global scores of 5 and above at baseline and after Week 3. A global score of 5 or greater has been suggested to indicate that an individual has moderate sleep difficulties in at least three areas or severe difficulties in at least two areas (Buysse et al., 1988). Therefore, our data suggest that elite Rugby Union athletes display poor sleep behaviours. These data highlight the necessity for appropriate sleep education in this population to support physical adaptations during preseason periods.

Given the restraints of conducting research on professional athletes, we acknowledge several limitations in the current study. The study was designed to have minimal impact on training, performance and each athlete's regular routines; therefore, we could only employ an observational study design, with retrospective analysis. Thus, numerous areas were difficult to control. Firstly, we were unable to control training during the 2-week maintenance period (between Weeks 3–5, where athletes were not required to come into the club for training), nor were we able to monitor sleep during this period. Athletes were provided with a training program to complete throughout the 2-weeks; however, we had no control over how strictly the athletes adhered to the program. Secondly, we were unable to control numerous aspects of nutrition. Whilst athletes were provided with the same breakfast and lunch during the preseason phase (Weeks 1–3), we were unable to control caloric intake for all meals. An addition to strengthen the study design would have been to measure all physical performance measures at every time point (Week 1, Week 3 and Week 5), allowing comparisons to be drawn across the 5 weeks for all physical performance measures. Future research should employ an experimental design investigating the differences in physical performance outcomes between a short sleep duration group (e.g., 8 h) during a period of intensified training. Additionally, researchers should investigate ways of preventing the decrement in sleep duration seen during intensified periods of training (e.g., sleep education, effects of light intensity/device use before sleep and the effects of nutritional interventions to enhance sleep).

Conclusions

The current investigation is the first to show a relationship between sleep duration and changes in physical performance in an elite Rugby Union environment during a preseason phase of training. The results suggest that, when grouped for sleep duration, athletes who obtained more sleep displayed greater positive changes in aerobic fitness and body composition than athletes who slept less. Additionally, results showed that sleep duration can be negatively affected during the preseason, which is likely due to an increase in training volume and an increase in fatigue. The current study provides some promising results concerning the effects of sleep duration on physical performance throughout the preseason in elite Rugby Union athletes and therefore warrants further investigation.

CHAPTER SIX

Routine, Routine, Routine: Sleep regularity and its association with sleep metrics in professional Rugby Union athletes.

Chapter Six

Teece AR, Beaven, C. M., Suppiah, H., Argus, C. K., Gill, N., & Driller, M. (2024). Routine, routine, routine: Sleep regularity and its association with sleep metrics in professional Rugby Union athletes. *Sports Medicine - Open*, *10*(51). https://doi.org/10.1186/s40798-024-00709-5.

Prelude: In study three we identified that greater nightly sleep was associated with improvements in physical performance across a period of intense training. In this study we aimed to look at impact of sleep routine, which is a commonly reported sleep hygiene principle, on quality of nighttime sleep in Rugby Union athletes.

Abstract

Background: Maintaining a consistent sleep and wake time is often reported as a key component of circadian rhythmicity and quality sleep. However, the impact of sleep onset and offset time variability on overall sleep outcomes are underreported in elite athlete populations. This study investigated the relationship between sleep onset and offset time variability using the sleep regularity index (SRI) and measures of sleep and well-being in professional Rugby Union athletes. Twenty-three professional male Rugby Union athletes (mean ± SD, age: 23 ± 3 y) underwent sleep monitoring via wrist actigraphy for three weeks during a pre-season phase of training and completed a daily wellness questionnaire. Median SRI was calculated and used to stratify the trainees into two quantile groups: >76.4 SRI (Regular, n = 11) and <76.4 SRI (Irregular, n = 12).

Results: The regular sleep group showed significantly longer total sleep duration ($p = 0.02$, $d = 0.97$) compared to the irregular group (7:42 ± 0:29 vs 7:18 ± 0:20 h:min per night, respectively). Furthermore, while not statistically significant, the regular sleep group showed greater sleep efficiency and less wake episodes compared to irregular sleepers, as demonstrated by *moderate* effect sizes (d = 0.71 and 0.69, respectively).

Conclusions: The results from this study indicate that minimizing variability in sleep onset and offset time is beneficial for increasing sleep duration and may improve sleep efficiency during pre-season training in elite male Rugby Union athletes. This study provides evidence for the importance of including sleep-wake routines as a key component of sleep education interventions.

Key Points**:**

- When compared to irregular sleepers, regular sleepers demonstrated significantly longer total sleep duration (~24 minutes per night) over a three-week period (>9 hours more of total sleep).
- Regular sleepers experienced fewer wake episode during the night, and had *moderately* higher sleep efficiency than irregular sleepers.
- The median sleep regularity index in this male, professional Rugby Union cohort was 76.4, considerably lower than that reported in previous reports of elite team sport athletes.
- This study provides further support for the inclusion of promoting regular sleep-wake routines as a key component of sleep hygiene education.

Background

Sleep is an important aspect that impacts recovery, skill execution, training, adaptation, and performance among elite-level athletes (Cook *et al*., 2012; Teece *et al*., 2021; Walsh *et al*., 2020). However, despite the importance of sleep, numerous studies have reported that elite athletes often experience insufficient quality and quantity of sleep (Walsh *et al*., 2020; Leeder *et al*., 2012). Due to the numerous challenges faced by elite athletes, including competition and training (Driller & Cupples, 2019; Pitchford *et al*., 2017; Sargent, Halson, & Roach, 2012), travel (Smithies *et al*., 2021), training volume (Taylor, Rogers, & Driver, 1997) and other social factors (Nédélec *et al*., 2018), their sleep and wake routines may be highly variable and therefore are an area of interest. The sleep regularity index (SRI) has been suggested as a useful metric to inform consistency or variation in sleep and wake times (Halson *et al*., 2022). The SRI calculates night-to-night shifts in sleep periods and is intended to reflect daily fluctuations in sleep and wake timings. The SRI produces a score out of 100, with 0 indicating no overlap between sleep-wake cycles from one day to the next, and 100 indicating an identical routine from one day to the next. Currently, few studies evaluate the SRI in elite athlete populations, where keeping a consistent routine may be problematic.

Consistent sleep-wake cycles have been reported to be important for maximising the quality and quantity of sleep and are an important component of sleep hygiene education (O'Donnell & Driller, 2017; Driller, Lastella, & Sharp, 2019). Indeed, prior research has shown that shifting a sleep-wake cycle by as little as one hour can impact an individual's quality and quantity of sleep for up to five days, which highlights the importance of consistency in sleep-wake cycles (Valdez, Ramírez, & García, 2003). Furthermore, Lack *et al.* (1986) reported that delaying sleep by approximately two hours on weekends resulted in longer sleep onset and reduced sleep duration on weekdays. As noted, sleep-wake cycles can be hindered within athlete populations by factors such as daily and weekly changes in training or competition schedules and travel (Pitchford *et al*., 2017; Sargent *et al*., 2014). Sargent *et al.* (2014) reported that elite swimmers reported delaying their sleep time the night before a rest day and delayed their wake time on the morning of rest days compared to training days. This pattern suggests that rest days may be seen as an opportunity for athletes to catch up on sleep lost and further supports that sleep-wake cycles may be highly variable among athlete populations.

To date, limited studies have evaluated the consistency or variation of sleep and wake time among elite athletes. Caia *et al.* (2017) examined intraindividual sleep variability of junior and senior Rugby League athletes and found that senior athletes showed less variability in sleep-wake patterns, time in bed, sleep duration, and sleep efficiency compared to junior athletes. Furthermore, Halson *et al.* (2022) investigated the variation of sleep and wake times of 203 elite team sport athletes using the SRI. Halson and colleagues reported that athletes displayed a median SRI of 85.1 (out of 100). Athletes were divided into two groups, irregular sleepers who displayed an average SRI score of 76.5 out of 100, and regular sleepers who displayed an average SRI score of 90.1 out of 100. Regular sleepers displayed significantly greater sleep efficiency and less variability in total sleep time and sleep efficiency compared to irregular sleepers. However, results from this study found that regularity in sleep did not influence total sleep duration in this group of athletes across four different sports. Given the differences in schedules and routines between sports, further investigation of the SRI within a single sport is warranted.

The current investigation is the first study to examine sleep regularity in a cohort of professional male Rugby Union athletes, comparing SRI scores to metrics of sleep quality and quantity. The aims of this study were to 1) investigate SRI in a cohort of professional Rugby

Union athletes over a three-week pre-season period, and; 2) compare sleep indices and measures of wellness between regular and irregular sleepers in professional Rugby Union athletes.

Methods

Participants

A total of 23 professional male Rugby Union athletes (mean ± SD; age, 23 ± 3 y; body mass, 104.9 ± 10.7 kg; stature, 187.0 ± 6.9 cm) from a New Zealand Super Rugby team volunteered to participate in the current study. Inclusion criteria included athletes being from the same professional Rugby Union team and being free from any clinically diagnosed sleep disorder. Injured athletes were excluded from the study, and the study took place during the early pre-season phase of training (November – December 2019). Written informed consent was obtained from the participants, and ethical approval was obtained from an Institutional Research Ethics Committee (FEDU066/16) and complied with the Declaration of Helsinki for Human Research of 1974 (latest revision in 2000).

Experimental Approach

An observational study design was used for the current investigation. Quantitative sleep and wellness assessments were collected throughout a three-week pre-season training phase. The relationship between qualitative sleep and wellness measures to sleep and wake variance via the use of the sleep regularity index (SRI) was examined across the study period. The three-week training period comprised of two speed sessions, four gym-based resistance training sessions, five conditioning sessions, and eight rugby-specific sessions spread across four training days each week. Each training day commenced at 8:00 a.m. with players arriving at the training facility. The first section of training took place between 9-11:00 a.m. which was either a unit specific session or a gym session each lasting an hour in duration. The second block of training which was team training commenced at 2:30 p.m. and concluded approximately 4:00 p.m. The team's professional strength and conditioning and coaching staff designed and monitored all training programs. On field training load was assessed via GPS and was planned across the period of the study average weekly running load across the study period was 23.9 ± 3.3 km and 23.3 ± 3.1 km for the irregular and regular groups respectively ($p = 0.74$).

Procedures

Sleep Monitoring

Quantitative sleep measures were collected using wrist actigraphy devices (ReadiBand™, Fatigue Science, Vancouver, BC, Canada) sampling at 16 Hz throughout the three-week training block. Athletes were required to always wear wrist actigraphy on either wrist (Driller, O'Donnell, & Tavares, 2017) except during contact training throughout the study. Additionally, athletes were instructed to maintain their regular sleep routine throughout the study. All athletes slept in their home sleep environments for the duration of the study period. At the beginning of each day, the actigraphy data were wirelessly downloaded to online software (ReadiBand™, Fatigue Science, Vancouver, BC, Canada), which automatically scored the raw data. The data collected by the wrist actigraph was translated into sleep-wake indices, including total sleep time (TST), total time in bed (TTB), sleep efficiency (SE% - calculated by dividing TST by TTB), sleep latency (SL), wakefulness after sleep onset (WASO), wake episodes (WE), sleep onset time (SOT), and wake time (WT) for each sleep period. The ReadiBand™ has been validated against polysomnography (PSG) and has been deemed acceptable, with accuracy levels of ~ 93% reported previously (Russell *et al.*, 2015).

The ReadiBand™ has also been shown to be comparable to the manually-scored actigraph (Edgar *et al*., 2023). Additionally, the inter-device reliability of the ReadiBand™ has shown high levels of agreement (ICC ≥0.90) for the sleep monitoring device used in the current study (Driller McQuillan, & O'Donnell, 2016).

Wellness Assessment

A wellness questionnaire based on previous work by Hooper and Mackinnon (1995) was completed on the morning of all training days of the data collection period. The wellness questionnaire was specifically designed for this study and asked athletes to rate their fatigue, general muscle soreness, stress, and sleep quality on a 1 to 7 Likert-type scale. On the scale, 1 represented a low score (e.g., positive result) and 7 represented a high score (e.g., negative result) for each measure. An overall wellness score for each athlete was calculated by combining responses to each question. Scores ranged from 4 to 28, with a lower score being considered to represent greater overall wellness. Research from our laboratory has shown that the wellness questionnaire displays acceptable day-to-day reliability with an ICC of 0.73 and a typical error (TE) of 1.63%.

Sleep Questionnaires

The Athlete Sleep Behaviour Questionnaire (ASBQ) and the Pittsburgh Sleep Quality Index (PSQI) were collected via Google Forms (Google LLC, Mountain View, CA, USA) at the conclusion of data collection to assess various aspects of sleep behaviour across the data collection period. The ASBQ is an 18-item sleep questionnaire which contains questions about sleep habits and behaviours thought to be areas of concern amongst athlete populations (Driller, Mah, & Halson, 2018). The survey asks participants how frequently they engaged (never, rarely, sometimes, frequently, always) in specific behaviours that have been considered maladaptive over the past month. The response to each question is weighted on a scale of 1-5 (never = 1, rarely = 2, sometimes = 3, frequently = 4, always = 5), and all questions are summed to produce an ASBQ global score. Global scores range from 18-90, with a higher score indicating poor sleep behaviours. The PSQI is a 19-item self-rated questionnaire intended to assess sleep disturbances and quality over the past month (Buysse et al., 1989). The questionnaire is separated into 7 components (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications and daytime dysfunction) and each component is weighed on a scale of 0-3. A higher score indicates a poor habit or behaviour in that component. All components are summed to produce a PSQI global score. Global scores range from 0-21, with a higher score indicating worse sleep behaviours.

Sleep Regularity Index

The sleep regularity index (SRI) is a metric that assesses night-to-night shifts in sleep and wake cycles by accounting for changes in sleep onset and wake times. The SRI assesses the likelihood that an individual's sleep-wake cycle matches from one day to the next, which was then aggregated over the study period to provide a total SRI score. An SRI score of 100 indicates that the sleep-wake cycle was identical between one day and the next. Conversely, an SRI score of 0 indicates no overlap between sleep-wake cycles from one day to the next. SRI values of each athlete were determined using binary sleep-wake data. Each sleep onset and wake time was derived from wrist actigraphy and converted into UNIX time, representing the time and day. Each UNIX time was coded as either '1' for sleep time or '0' for wake time. SRI calculations were conducted using the R program (Rstudio) using the *sleepreg* package (Windred et al., 2021).

As described by Windred et al. (24), SRI scores were calculated using the following equation:

$$SRI = -100 + 200\left(1 - \frac{1}{N_v}\sum_{i=1}^{N}|s_i - s_{i+C}|\right)$$

Sleep-wake state is represented by $s_i = 1$ for wake, $s_i = 0$ for sleep, and $s_i = NA$ represents excluded epochs. Number of valid epoch-by-epoch comparisons is represented by N_v, which includes all comparisons where $s_i \neq NA$ and $s_{i+c} \neq NA$. Where $s_i = NA$ or $s_{i+c} = NA$, $|s_i - s_{i+c}| = 0$. Subscript i represents each epoch from recording start to 24h prior to recording end, such that at:

$i = 1,\ t_1 = 0$

$i = 2,\ t_2 = E$

$i = 3,\ t_3 = 2E$

$i = C,\ t_C = E(C - 1) = 24$

$i = N,\ t_N = E(N - 1) = t_{max} - 24$

Time is represented by t_i , epoch length is represented by E , recording length is represented by t_{max} , and number of epochs within one 24-h interval is represented by C. All time values are in hours.

Following the calculation of each individual's SRI score, each athlete was classified as either regular (n = 11) or irregular (n = 12) sleepers. Specifically, athletes were classified as Regular sleepers if they were above the median (> 76.4) of the cohort based on their SRI scores, while participants who were below the median (<76.4) based on their SRI score, were considered Irregular sleepers.

Statistical Analyses

All descriptive statistics are reported as means ± SD unless otherwise stated. Statistical analysis was performed using Statistical Package for Social Sciences V27.0 (IBM Corporation; Chicago, IL, USA) with statistical significance set at $p \leq 0.05$ for all analyses. Data of sleep regularity, sleep measures, wellness assessment, and sleep questionnaires were pooled, and Pearson's correlations (r) were used to determine if any relationships were present between sleep, markers of wellness, and sleep questionnaire global scores. Correlations were interpreted using thresholds of r <0.1, *trivial*; 0.1-0.3, *small*; 0.3-0.5, *moderate*; 0.5-0.7, *large*; 0.7-0.9, *very large*; and 0.9-1.0, *almost perfect*. A comparison between regular and irregular sleepers was made for sleep indices, wellness scores, and global sleep questionnaire scores using in dependent samples *t*-tests. There were no outliers in the data as assessed by inspection of a boxplot. Each variable was normally distributed as assessed by Shapiro-Wilk's test (p >0.05). Effect-size statistics were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, and 0.8 for *small, moderate,* and *large*, respectively. An effect size of -0.2>0<0.2 was considered *trivial,* and the effect was deemed *unclear* if the 95% confidence interval overlapped the thresholds for both positive and negative effects (Cohen, 1988).

Results

Descriptive analysis of sleep regularity scores across the cohort revealed that the highest SRI score was 86.1, with the cohort median being 76.4, and the lowest SRI value being 61.0. Furthermore, Pearson's correlation analysis revealed a *moderate* correlation between SRI and average (r = 0.40; Figure 5) and total sleep duration (r = 0.43), while all other measures of sleep and wellness showed *small* to *trivial* correlations with SRI.

Independent sample t-tests revealed a significant difference in average sleep duration per night (*p* = 0.03) and total sleep duration over the 3-week period (*p* = 0.02) in favour of the Regular sleeping group, as shown in Table 8. The results showed that Regular sleepers achieved ~ 24 minutes longer sleep duration on average per night and ~ 9 hours more total sleep across the 3-week period. No significant differences (*p* > 0.05) were observed between Regular and Irregular sleepers for sleep latency, wake episodes, WASO, and sleep efficiency. The effect size analysis revealed that Regular sleepers displayed *moderately* (*d* ±95% CI = 0.71 ±0.83) fewer wake episodes per night and a *moderately* higher (*d* = 0.69 ±0.85) sleep efficiency compared with Irregular sleepers.

Table 8. Differences in sleep indices assessed via wrist actigraphy (mean ± SD) between Regular (n = 11) and Irregular (n = 12) sleepers in elite Rugby Union athletes, including *p*-values and effect size comparison (with 95% confidence intervals) between groups.

Measure	**Mean ± SD**		***p-value***	**Effect size (*d* ±95% CI)**
	Regular	**Irregular**		
Average Sleep Time per night (h:min)	7:42 ± 0:29	7:18 ± 0:20	**0.03***	0.89 ±0.85 ***large***
Total Sleep Duration over 3 weeks (h:min)	169:28 ± 10:48	160:07 ± 7:19	**0.02***	0.97 ±0.85 ***large***
Average Time in Bed per night (h:min)	9:09 ± 0:16	8:28 ± 0:25	<0.01	1.84 ±0.89 ***large***
Average Sleep Onset Time (time of day)	22:37 + 0:47	23:18 + 0:56	0.08	0.75 +0.86 *unclear*
Average Wake Time (time of day)	7:11 + 0:29	6:58 + 0:42	0.26	0.46 +0.85 *unclear*
Sleep Latency (min)	28.9 ± 16.8	32.9 ± 11.2	0.50	0.27 ±0.85 *unclear*
Wake Episodes per night	2.9 ± 1.0	3.8 ± 1.3	0.09	0.71 ±0.83

(no.)				***moderate***
Wake after sleep onset (h:min)	0:28 ± 0:12	0:36 ± 0:15	0.17	0.57 ±0.83 *unclear*
Sleep Efficiency (%)	85.2 ± 3.6	83.1 ± 2.2	0.09	0.69 ±0.85 ***moderate***

*indicates a significant difference between groups ($p < 0.05$)

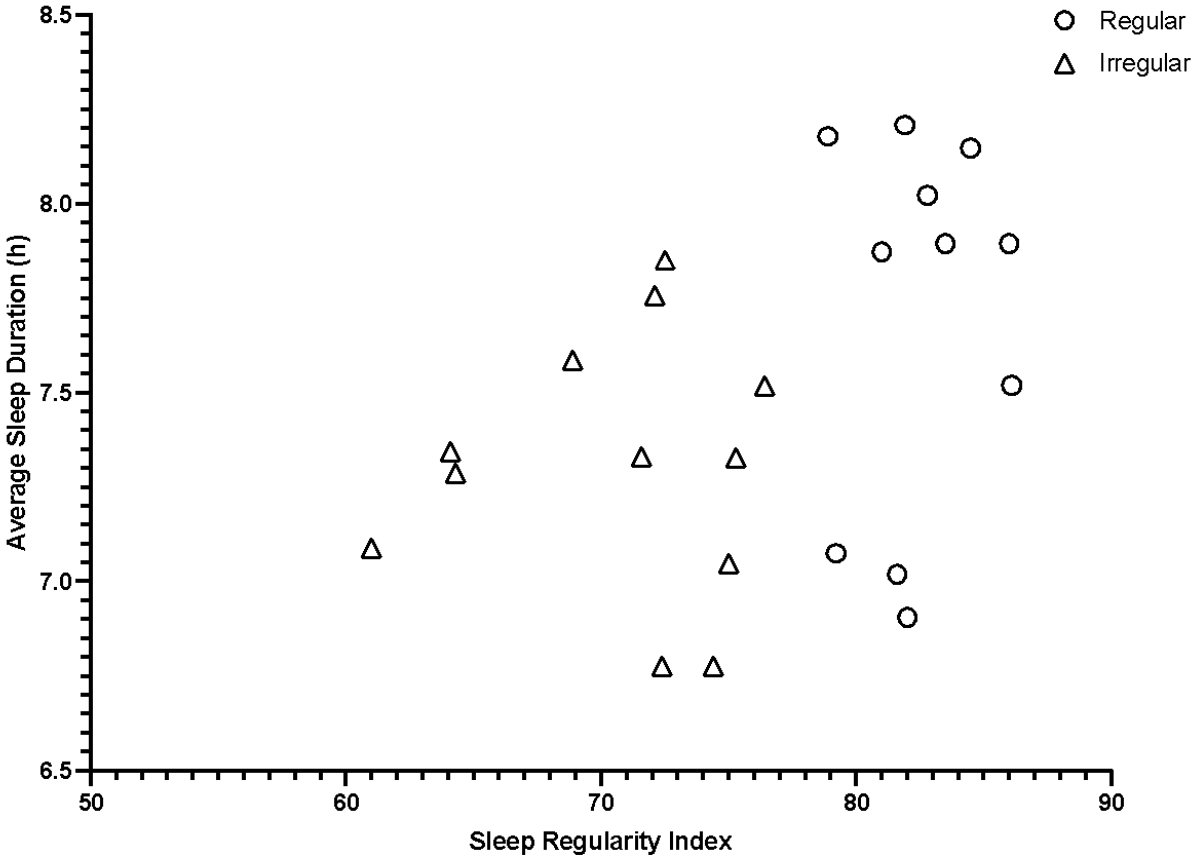


Figure 5. The relationship between sleep regularity index score and average sleep duration for all participants split into Regular (n = 11) and Irregular (n = 12) sleepers in elite Rugby Union athletes.

The results of the independent sample *t*-tests revealed no significant differences ($p > 0.05$) between Regular and Irregular sleepers for any of the wellness measures (fatigue, muscle soreness, stress, sleep quality, and overall wellness), as shown in Table 9. Additionally, no significant differences ($p > 0.05$) were observed between Regular and Irregular sleepers for global scores derived from the ASBQ ($p = 0.65$) and the PSQI ($p = 0.88$). However, inspection of individual questions of the ASBQ revealed significant differences ($p < 0.05$) with Irregular sleepers reporting higher (poorer) scores for Q5, "*I go to bed at different times each night (more than ± 1 hour variation)*" and Q12, "*I wake to go to the bathroom more than once per night*".

Table 9. Differences in wellness measures as assessed by a wellness questionnaire (mean ± SD) for the Regular (n = 11) and Irregular (n = 12) sleepers in elite Rugby Union athletes, including p-values and effect size comparison (with 95% confidence intervals) between groups. AU = arbitrary units.

	Mean ± SD		***p-value***	**Effect Size (*d* ±95% CI)**
	Regular	**Irregular**		
Fatigue score (AU)	4.1 ± 0.5	4.1 ± 0.7	0.96	0.02 ±0.84 *unclear*
Muscle Soreness (AU)	3.8 ± 0.8	3.8 ± 0.9	0.81	0.10 ±0.83 *unclear*
Stress (AU)	4.7 ± 0.9	4.4 ± 0.8	0.37	0.36 ±0.84 *unclear*
Sleep Quality (Self-reported)	4.3 ± 0.9	4.2 ± 0.8	0.82	0.09 ±0.83 *unclear*
Overall Wellness (AU)	17.0 ± 2.3	16.7 ± 3.0	0.75	0.13 ±0.83 *unclear*
ASBQ (AU)	41.1 ± 4.0	42.0 ± 5.4	0.65	0.18 ±0.83 *unclear*
PSQI (AU)	5.2 ± 1.6	5.4 ± 2.7	0.88	0.06 ±0.83 *unclear*

Discussion

The current investigation aimed to compare measures of sleep and well-being across a pre-season phase of training in elite male professional Rugby Union athletes who displayed regular sleep onset and offset times against those who displayed irregular sleep onset and offset times. Key findings highlighted that maintaining a more regular sleep onset and offset time across a pre-season period resulted in ~ 24 minutes longer sleep duration on average per night, and ~ 9 hours more total sleep across the three-week period compared to athletes who displayed irregular sleep patterns. Increased sleep duration appears to be important for improving reaction time, stress hormone suppression (Swinbourne *et al*., 2018), aerobic performance, and body composition (Teece *et al*., 2021) in the pre-season in elite Rugby Union athletes. Therefore, the finding that maintaining regular sleep onset and offset routines may be associated with increased sleep duration is a novel and important finding for team sport athletes attempting to maximise their performance and physiological adaptations. Furthermore, although not statistically significant, we observed that the more regular sleepers showed *moderately* lower wake episodes per night and *moderately* higher sleep efficiency when compared with their counterparts who were considered irregular sleepers.

To the authors' knowledge, this study is the first to show a relationship between SRI and total sleep time in professional Rugby Union athletes. Since SRI is a relatively new metric of sleep consistency, there are limited studies reporting this within athlete populations. The findings of the current investigation of the regular group displaying increased sleep duration are in contrast with previous studies investigating SRI. Indeed, Halson *et al.* (2022) investigated SRI among a cohort of 203 elite team sport athletes across four sports and found that SRI had no impact on total sleep time. It is important to note that the investigation by Halson and colleagues (2022) required athletes to have their sleep monitored for a minimum of seven nights to be included in the study. Therefore, the relatively shorter monitoring period (average of ~10 nights) combined with the heterogenous sample (multiple sports) may have influenced the ability to discover differences in sleep duration between regular and irregular sleepers. Our median SRI score (76.4) was also notably lower than the score of 85.1 reported by Halson *et al.* (2022)., perhaps due to the same reasons stated above. Furthermore, Phillips *et al.* (2017) investigated the SRI in an age-matched university cohort across a 30-day period and found no differences in average sleep duration between regular and irregular sleepers (7:27 and 7:16 h:min, respectively). Although it is unclear why Phillips and colleagues (2017) did not observe any differences in total sleep time between regular and irregular sleepers, the research team suggested that due to the number of students living on campus, they displayed polyphasic sleep schedules and therefore may have maintained sleep durations irrespective of their SRI. It is important to note that within the current investigation, while the data was not collected, it is possible that the athletes did not have the opportunity to nap during the day given their training schedules, and therefore sleep duration was achieved only through night-time sleep, which may in part explain the differences observed between the current investigation and Phillips *et al.* (2017).

While speculative, the positive effects observed for the duration of sleep may be due to better regularity in sleep onset and offset times supporting the entrainment of circadian rhythms (Soehner, Kennedy, & Monk, 2011). Circadian rhythms have been shown to affect body temperature (Ayala et al., 2021), melatonin secretion, and sleep propensity (Cajochen, Kräuchi, & Wirz-Justice, 2003), which are all important drivers of sleep (Fuller, Gooley, & Saper, 2006). Prior research suggests that high sleep and wake time variability may lead to circadian rhythm disturbances (Videnovic *et al.*, 2014). Circadian rhythm disruptions result in sleep disturbances caused by advancing or preventing sleep, including insomnia, and decreased sleep duration (Bei, Wiley *et al.*, 2016; Bei, Seeman *et al.*, 2016). Conversely, regularity in sleep timing may support circadian rhythms in remaining oriented to an individual's daily environment and routine (Soehner, Kennedy, & Monk, 2011). It is plausible that maintaining regularity in sleep onset and offset times may assist in optimising circadian rhythms, subsequently influencing sleep duration, as seen in the current investigation.

Whilst not statistically significant, we observed a *moderate* increase in sleep efficiency in favour of regular sleepers. Similar findings have been observed by Halson *et al.* (2022), who found that regular sleepers displayed significantly greater sleep efficiency than irregular sleepers. Halson *et al.* (2022) reported that bedtime (the time at which the individual attempted to start sleep), a consistent sleep onset time (the time at which an individual first fell asleep), and sleep offset time were important factors that contributed to improved sleep efficiency among athletes. Furthermore, the number of wake episodes per night may have influenced sleep efficiency in the current investigation. We observed that irregular sleepers displayed more wake episodes than regular sleepers, as demonstrated by a *moderate* effect size difference between groups. This more frequent waking coincided with higher reporting of waking up greater than once per night to go to the bathroom compared to regular sleepers. In fact, since sleep efficiency is calculated as a ratio of total sleep time divided by time in bed, a loss of sleep time due to increased wake episodes will decrease sleep efficiency and may, in part, explain the results of the current investigation. Interestingly, aside from the SRI in the current study, regular sleepers self-reported less frequently going to bed at different times each night in Q5 of the ASBQ, suggesting that athletes may already know how consistent their routines are without undergoing sleep monitoring. Therefore, practitioners may be able to ascertain sleep regularity via subjective responses, without the need for objective monitoring.

Given the applied nature of the present study and the difficulties of conducting research on professional athletes, we acknowledge several limitations. First, this study was designed to create minimal impact on the training and performance of each athlete, meaning that we could only employ an observational study design with retrospective analysis. Furthermore, SRI only accounts for night-time sleep duration, and therefore daytime naps (data not collected) were not included in the total sleep duration, which may have influenced the total sleep duration and pressure individuals experienced over a 24-hour period. Additionally, the current investigation was over a three-week period, and therefore, it only assessed SRI during a relatively short period of an athlete's overall season. It should be considered that this study was conducted within a period where no competition was present; therefore, it may have missed important factors such as travel and match day influences that can affect sleep onset and wake time variability during a competition season (Driller & Cupples, 2019). Lastly, this investigation was performed on male Rugby Union athletes, as this was the only professional rugby cohort available to the researchers. Whether the same findings can be generalised to elite female rugby athletes is yet to be explored. Future research should investigate an in-season training phase to assess the impact of various other factors on SRI and sleep metrics and include professional female Rugby Union athletes to determine whether the same relationships between SRI and sleep metrics apply to them.

Conclusion

The current investigation is the first to show a relationship between sleep regularity index and sleep metrics in an elite male Rugby Union environment during a pre-season phase of training. The results suggest that maintaining a more consistent sleep onset and offset time is associated with improved sleep duration and trends towards higher sleep efficiency and less wake episodes per night (both associated with *moderate* effect sizes compared to irregular sleepers). This study provides further evidence for including sleep-wake routines as a key component of sleep monitoring and educational sessions with athletes during periods in which the quality and quantity of sleep can often be compromised.

CHAPTER SEVEN

Nap to perform? Match-day napping on perceived match performance in professional Rugby Union athletes.

Chapter Seven
Teece AR, Beaven, C. M., Huynh, M., Argus, C. K., Gill, N. D., & Driller, M. W. (2022). Nap to perform? Match-day napping on perceived match performance in professional Rugby Union athletes. *International Journal of Sports Science & Coaching*, *18*(2), 462-469. https://doi.org/10.1177/17479541221084

Prelude: Based on the findings from studies one to three, this study aimed to investigate the prevalence and impact of daytime napping which is a method of extending total sleep duration on match day where players need to be performing at their peak.

Abstract

Background: Daytime napping on match-day is a strategy used by athletes to alleviate sleep debt or to avoid boredom. However, the utilisation of pre-match napping and its effect on self-rated performance has not been evaluated in professional Rugby athletes.

Methods: Over a 17-match season, 30 professional Rugby Union athletes (mean±SD: 23±3 y) completed a weekly questionnaire on their daytime napping practices on match day. Questions included whether they took a nap, the duration of nap, their mood state upon waking and, their perceived performance during the subsequent match. Additionally, three team coaches evaluated the match performance of each participant. Finally, each participant was asked a questionnaire focusing on their napping preferences and individual habits of match-day napping at the conclusion of the season.

Results: Pre-match naps were used by 86% of athletes, with an average nap duration of 32±19 min. A significantly greater number of naps were taken during away matches compared to home matches (60% vs. 40%, $p < 0.01$). Of the athletes who napped, 86% chose to nap less than 4 h before kick-off. Furthermore, 87% of athletes who napped on match day reported believing naps helped their match performance. Additionally, the odds of an athlete rating their performance as "good" was increased 6.7 times if they napped and won the match.

Conclusion: This study highlights that match-day naps are commonly used amongst professional Rugby Union athletes. The results suggest that taking naps before away matches may support self-rated performance amongst Rugby Union athletes.

Introduction

Sleep has been suggested to be one of the best recovery tools available to athletes and has been shown to support physical and mental performance (Walsh *et al*., 2020). Conversely, mild sleep loss or sleep restriction (less than 7 h sleep) has been shown to impair alertness, energy levels and physical performance (Walsh *et al*., 2020; Dattilo *et al*., 2011; Cook *et al*., 2012). Despite the importance of sleep on performance, researchers have reported that poor sleep is common in team sport athletes in training and pre-competition environments, resulting in sleep debt (Lastella *et al*., 2015; Driller *et al*., 2022). Daytime naps are a commonly used strategy in an attempt to recover from sleep debt present amongst team sport athletes (Lastella *et a*l., 2021). Previously, naps have been defined as a period of sleep less than 50% of an individual's nocturnal sleep (Dinges, 1987). Naps have been shown to improve physical, mental performance and reduce the negative effects of daytime sleepiness in athlete populations (Waterhouse *et al*., 2007; Blanchfield *et al*., 2018). However, to date, there is limited knowledge on the prevalence of daytime napping on match days in elite team-sport athletes.

Sleep duration in athletes appears to be affected the night before a competition, with team sport athletes displaying a shorter sleep duration than individual athletes (7 h 36 min vs. 7 h 48 min, respectively) (Juliff *et al*., 2015; Lastella, Lovell, & Sargent, 2014). In professional Rugby League athletes, Caia and colleagues (2018) reported an average sleep duration of 6 h and 56 min, lower than the recommended 7–9 h of sleep per night for the general population. In a BJSM review, the prevalence of poor sleep has been reported to be high amongst team-sport athletes, with athletes showing habitual sleep durations of < 7 h.1 According to Lastella and colleagues (2014), 68% of athletes experience poorer sleep than usual the night before a competition resulting in an average sleep duration of < 6 h. The reduction in sleep the night before a competition may have a negative effect upon performance via causing reductions in mood states (Lastella, Lovell, & Sargent, 2014), reaction time and alertness (Elmenhorst *et al*., 2008) on competition days and therefore has been proposed as a potential reason why athletes utilize napping on competition day in an effort to reduce the effect of sleep debt and sleepiness from the previous night (Nédélec *et al*., 2015).

Taking naps are common practice amongst athletic populations within training environments (Thorton *et al*., 2017; Lovato & Lack, 2010). The recuperative value of naps is suggested to depend upon the duration and timing of naps throughout the day (Winget, DeRoshia, & Holley, 1985). To maximise the benefits of napping, it is recommended that naps occur between 13:00–16:00 h due to a dip in circadian rhythm, also referred to as the post-lunch dip (Winget, DeRoshia, & Holley, 1985). This post-lunch dip is associated with reductions in alertness and attention between these times which may affect performance (Akerstedt & Folkard, 1997; Daaloul, Souissi, & Davenne, 2019). A review by Lastella *et al.* (2021), reported that naps taken during the post-lunch dip may be beneficial for improving physical, cognitive, and psychological performance in athletes with durations of 20–90 min likely to have the greatest improvement for performance outcomes. A study conducted by Daaloul and colleagues (2019), demonstrated that a 30-min nap post-lunch nap in 13 national level athletes increased alertness, improved reaction time, and increased time to exhaustion on a sport-specific test. Similar findings were reported by Waterhouse *et al.* (2007), who reported that a 30-min post-lunch nap improved 2-m and 20-m sprint performance, alertness, and short-term memory when sleep was restricted the night before.

Furthermore, naps are commonly used amongst rugby athletes, especially during periods of high training load and during periods of travel (Smithies *et al*., 2021; Dunican *et al*., 2018). Thornton *et al.* (2017) reported that 83% of Rugby League athletes took naps during a two-week pre-season camp with an average duration of 30 min and 32 min in the morning and afternoon, respectively. Additionally, Smithies *et al.* (2021) reported that in professional Rugby Union athletes, 86% of athletes napped during high travel periods, which included long-haul travel throughout the season. These authors highlighted that the prevalence of napping was high when sleep duration the previous night was low. Additionally, research by Dunican *et al*. (2018) suggests that Rugby Union athletes may display poor overall sleep behaviours as well as a high prevalence of obstructive sleep apnoea, periodic leg movement and excessive daytime sleepiness.

Whilst several studies have investigated the effects of napping on performance within training environments, to our knowledge, there is limited research investigating the effects of pre-match napping on subsequent performance on the day of competition in elite team sport athletes. O'Donnell and colleagues (2018) investigated pre-match napping on measures of performance and reported a significantly greater peak jump velocity during a countermovement jump test in favour of a short (20 min) condition. Whilst this netball study highlighted that a short pre-competition nap may be beneficial for performance, the reasons for utilizing match-day naps, including prevalence and preference of match-day napping is still unclear amongst elite athlete populations. Therefore, the current investigation firstly aimed to identify the utilization and reasons behind why match-day naps are used amongst a cohort of professional Rugby Union athletes. A secondary aim of this investigation was to expand on previous findings to assess if match-day naps have an effect on coach and player subjective performance ratings recorded at home and away matches in Rugby Union athletes.

Methods

Participants

A total of 30 professional Rugby Union athletes (mean ± SD; age; 24 ± 2 y) and three professional Rugby Union coaches (24 ± 4 y coaching experience) volunteered to participate in the current study. The study took place over one season during the Super Rugby competition, which is the premier professional Rugby Union club competition in the southern hemisphere that included 15 teams from New Zealand, Australia, South Africa, Argentina, and Japan. All participants were of Super Rugby standard and played a minimum of three matches throughout the season. Additionally, participants provided written consent before taking part in this study. Ethical approval was obtained through the institution's Human Research Ethics Committee.

Study Design

The present study used a longitudinal, observational design. The data was collected over a 19-week Super Rugby competitive season which consisted of 17 matches (11 played in New Zealand, 3 played in Australia, 1 played in South Africa, and 2 played in Argentina) played weekly with two bye weeks. On the day of each match, the athletes were told to prepare for the match as they usually would. Athletes were given two windows of individual preparation time which consisted of a 4-hour morning preparation window following breakfast (0900-1400 h) and a shorter 1-hour 15-minute afternoon preparation window following a pre-match meal (1600-1715 h) as depicted in Figure 6 in which athletes allocated time for naps. If a nap was taken in either window, athletes were asked to keep track of duration. Additionally, participants were asked to write down their levels of alertness on a 5-point Likert type scale (1=poor, 3=normal, 5=excellent) upon waking up from any naps taken with higher scores representing greater alertness. A Likert scale of 1-5 was chosen as participants were familiar with such a scale from their wellness questionnaires completed frequently. At the conclusion of the second window, athletes completed typical match day preparation leading up to match time. For the purpose of this study, a nap was defined as any period of sleep that occurred outside the normal night-time sleep period on competition day.

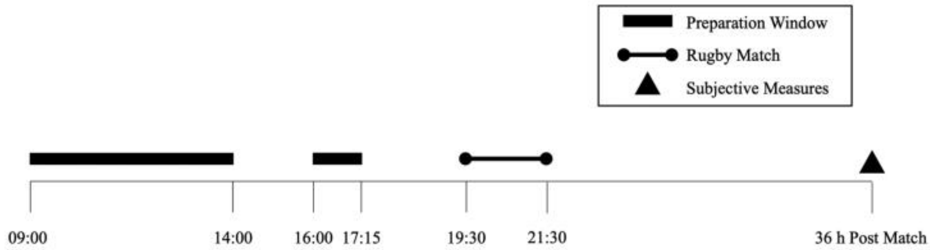


Figure 6. Study timeline

Measures

Measures were obtained within 36 hours following the conclusion of the match each week and were collected in person by the lead researcher. Each participant was asked a questionnaire which consisted of four questions, including the following: Did you nap on match day? (yes or no), how long did you nap for? (reported in minutes), how alert did you feel upon waking? (1=poor, 3=normal, 5=excellent), and how do you rate your match performance? (1=unsatisfactory, 3=normal, 5=outstanding). Additionally, the three coaches evaluated each participant's match performance (1=unsatisfactory, 3=normal 5=outstanding) within 36 hours of the completion of the match, as used previously (O'Donnell, Beaven, and Driller, 2018). For each participant, match performance was evaluated by two coaches: 1) the head coach and 2) the position-specific coach (backs or forwards coach). All coaches were blinded to the other coaches' ratings and the athletes' napping conditions. In addition to the questionnaire, the research team noted the result of the match (win or loss), the time of the match (local and home), and the country/time zone in which the match took place.

After the season, each participant was required to fill out a questionnaire that was specifically designed to gather perspectives on their individual napping habits. The questionnaire consisted of 5 questions which included frequency of napping on match day throughout the season (always, sometimes, never), preferred length of a nap (reported in minutes), which individual preparation window they preferred to nap (greater than 5 hours before match time or less than 5 hours before match time), perception of improved performance when they decided to nap throughout the season (better, undecided, worse). Lastly, participants were asked to list their reasons for choosing to nap, or not to nap, on match day.

Statistical Analyses

Descriptive statistics were performed using the Statistical Package for Social Sciences (V.27.0, SPSS Inc., Chicago, IL, USA). R program (R core Team, 2020) was used with the Ime4 package (Bates *et al*., 2015) to perform multilevel generalised linear (GLMM) analyses of perceived performance (as rated by the players and coaches) on napping status with statistical significance set a $p < 0.05$ for all analysis. Descriptive statistics (counts and percentages) were computed for the different rating measures to determine the feasibility of modelling them as outcome variables. Subjects did not respond in a uniform manner across the different options (e.g., none of the players provided a rating of 1, and very few provided ratings of 5). As such, the responses were dichotomized into "poor to average" (ratings of 1 to 3) and "good" (ratings of 4 and 5) responses to allow for optimized modelling procedures. An initial inspection of these new ratings indicated a difference in performance across rounds. A multilevel logistic model, with 'Player ID' and 'Round Number' as random effects was performed to determine relationships between response variables and perceived match performance. Finally, Spearman's correlational analysis (using the original 5 category response variable) was conducted to examine the relationship between player performance ratings and coach ratings (both head coach and position-specific coach). Spearman's correlation is more appropriate than Pearson's correlation when the variables are not measured on a continuous scale (in this case: ordinal).

Results

Descriptive analysis revealed that 26 of 30 athletes reported taking a nap on match-day at least once throughout the study, resulting in a total of 199 naps from 319 responses with 11 players on average taking naps on match-day each round. A significantly greater number of naps ($p < 0.01$) were reported before away matches (n=119, 60%), compared to naps that were recorded before home matches (n=80, 40%) (Figure 7). Nap duration averaged 0:32 ± 0:19 min with no significant difference ($p > 0.05$) for the duration of naps between home and away matches. When players took naps, 68% reported waking up feeling better than normal with an average feeling upon waking score of 3.6 ± 0.7 AU.

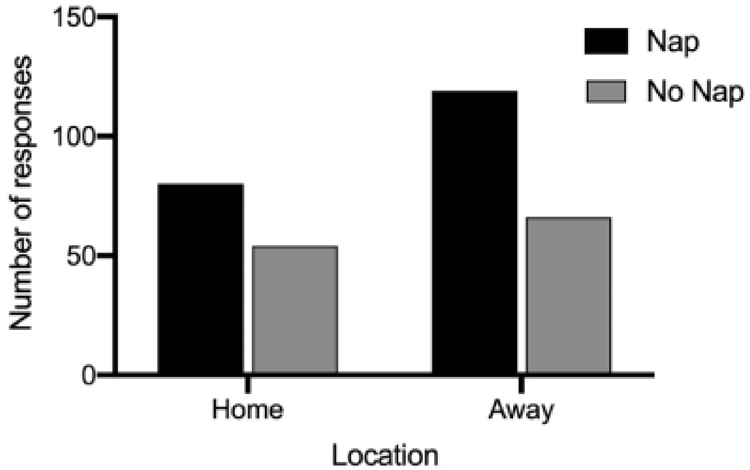


Figure 7. Prevalence of athletes who napped or did not nap at home and away locations

Analysis of the post season questionnaire revealed six main reasons for utilizing match-day napping amongst professional Rugby Union athletes, as seen in Table 10. Preferred nap duration ranged from 15 – 120 minutes with 83% of athletes reporting a preferred duration between 20-45 minutes, 10% reported a preferred nap duration of 45-60 minutes and 7% preferring greater than 60 minutes nap duration. Furthermore, it was revealed that 86% of athletes who nap on match-day choose to nap between 16:00-17:15 h less than 5 hours before kick-off, with only 14% choosing to nap more than 5 hours before the start of the match. Furthermore, it was revealed that 87% of athletes who napped on match-day, perceived that utilizing match-day napping was beneficial to their performance. Additionally, 14% of athletes reported choosing not to nap on match-day, citing feeling groggy after naps and sleeping in on match-days as reasons for not utilising naps on match-day.

Table 10. Reasons cited by professional Rugby Union athletes as to why they utilize pre-match napping.

	%	Number of responses
Increase energy	85%	22
Increase performance	62%	16
Increase alertness	50%	13
Alleviate sleep debt or jet-lag	46%	12
Boredom	31%	8
Attenuate nerves	15%	4

Data shown for 26 of the 30 participants who napped throughout the study period.

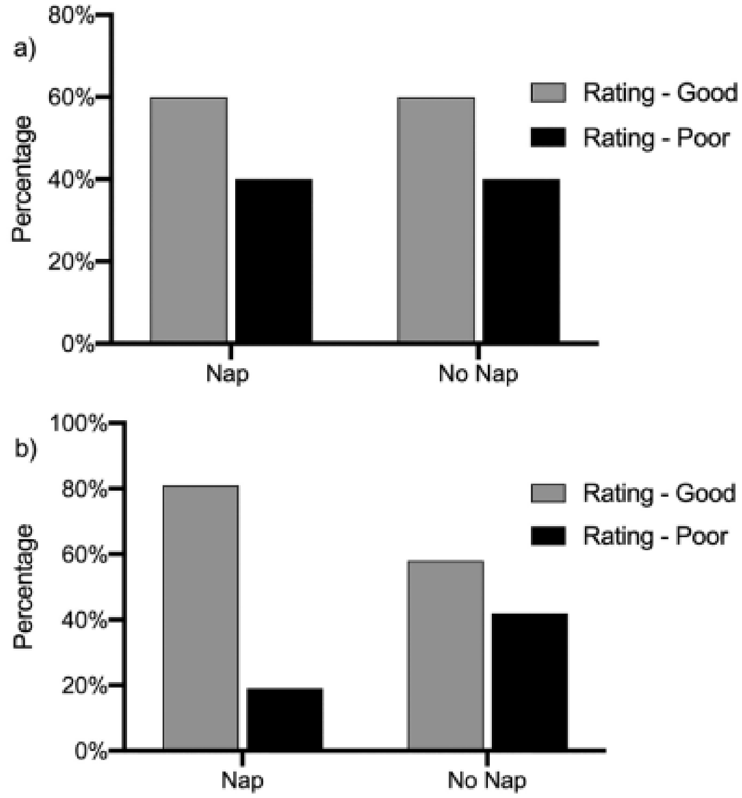


Figure 8. Comparison of self-rated match performance of athletes who napped or did not nap before matches before (a) home matches and (b) away matches as reported by athletes

Analysis of performance ratings revealed that the proportion of players who rated their performance as “good”, whilst playing an away match, was 81% for napping players versus 58% for non-napping players. By comparison, the proportion of players who rated their performance as good, whilst playing a home match, was similar across napping (60%) and non-napping players (60%) as seen in Figure 8. The multilevel logistic model did not identify napping as a significant predictor for “good” self-performance rating whilst controlling for the other covariates; however, there was a significant interaction between napping and match outcome. Specifically, the odds of a player rating their performance as “good” increased by 6.7 times ($p < 0.01$, 95% CI [2.10, 21.47]) if they napped and had won the match, after controlling for location. By comparison, the odds of a player rating their performance as “good” decreased by 0.27 times (p = 0.02, 95% CI [0.09, 0.86]) if they had napped and were playing on home ground, after controlling for match outcome.

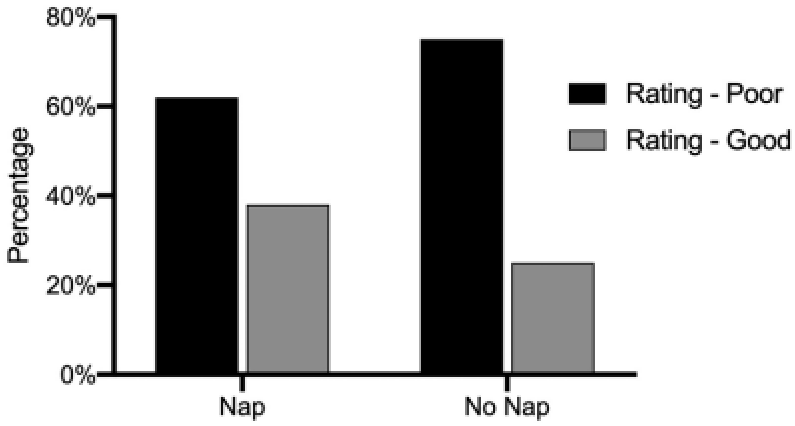


Figure 9. Proportion of "good" (ratings 4–5) and "poor" (ratings 1-3) performance ratings between nap and no nap conditions for players self-rating of match performance.

The results from the Spearman's correlation indicated that there was a weak (albeit significant) positive correlation between player and head coach ratings, (*Spearman's rho* = 0.29, $p < .001$), as well as between player and position coach rating, (*Spearman's rho* = 0.24, $p < .001$). On the other hand, the correlation between the two coach ratings revealed a strong positive correlation (*Spearman's rho* = 0.74, $p < .001$). There were no significant relationships observed between napping and either the head coach or position-specific coaches' ratings of match performance ($p > 0.05$) (Table 11) (Figures 9-11).

Table 11. Descriptive statistics for outcome performance measures (1=unsatisfactory, 3=normal, 5=outstanding)

		Nap: No		Nap: Yes	
		n	%	n	%
Player Performance Rating	1	--	--	--	--
	2	10	8.47%	23	11.73%
	3	78	66.10%	101	51.53%
	4	29	24.58%	69	35.20%
	5	1	0.85%	3	1.53%
Head Coach Rating	1	--	--	--	--
	2	7	6.60%	10	5.75%
	3	73	68.87%	112	64.37%
	4	25	23.58%	51	29.31%
	5	1	0.94%	1	0.57%
Position-specific Coach Rating	1	1	0.94%	--	--
	2	10	9.43%	10	5.75%
	3	62	58.49%	103	59.20%
	4	27	25.47%	57	32.76%
	5	6	5.66%	4	2.30%

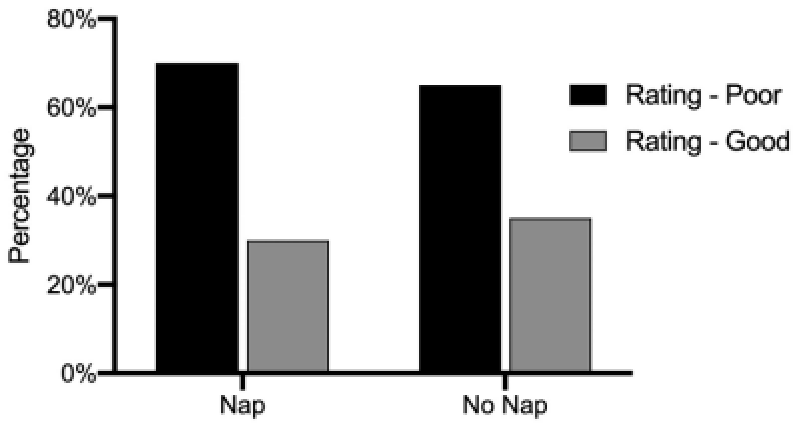


Figure 10. Proportion of "good" (ratings 4–5) and "poor" (ratings 1-3) performance ratings between nap and no nap conditions for players self-rating of match performance.

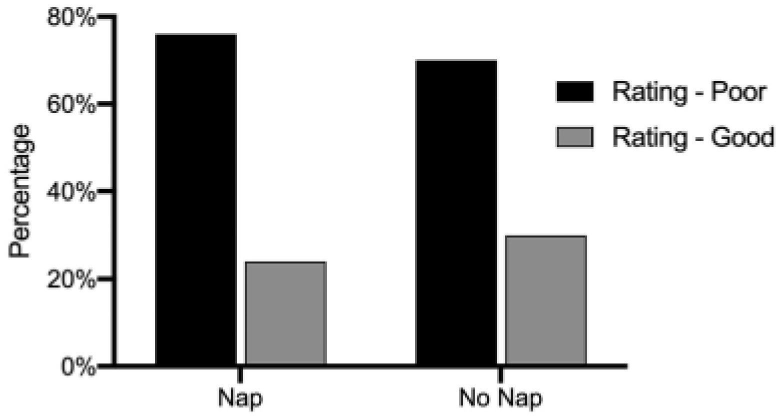


Figure 11. Proportion of "good" (ratings 4–5) and "poor" (ratings 1-3) performance ratings between nap and no nap conditions from position-specific coach's ratings of match performance.

Discussion

This study aimed to investigate the current utilisation of match-day napping amongst professional Rugby Union athletes across a season and assess whether pre-match napping has an effect on coach and player subjective match performance ratings. The key findings highlighted that pre-match naps are commonly used amongst professional Rugby Union athletes with increases in energy and performance cited as important reasons for utilising naps on match day. Furthermore, the results highlighted that professional Rugby Union athletes partake in a greater number of naps before an away match when compared to a home match. Finally, the results highlighted that when athletes napped before an away match, a larger proportion of athletes rate their performance as "good" compared to those who did not nap.

The results from the current study highlight that pre-match napping is commonly utilised amongst professional Rugby Union athletes. We observed that 86% of athletes reported taking a nap on at least one match day throughout the season and on average 11 of 23 (47%) athletes each round chose to nap on match-day, which is similar to the previously reported 7 of 14 (50%) athletes on average within elite netball athletes on match day (O'Donnell and colleagues, 2018). Furthermore, the average duration of naps on match-day within the current investigation was 32 minutes, which lies within the 20–45 minute preferred nap duration reported by 83% of athletes within the current investigation with an average nap duration of 41.5 minutes previously reported on match-day by O'Donnell and colleagues (2018) in elite netball athletes. Thus, it appears that when athletes are given periods of time on match-day in which naps can take place they display relatively similar nap durations. It is unclear why athletes across the two studies display relatively similar nap durations on match day; however, in the current investigation nap duration may have been constrained by the time of day in which the majority of naps took place on match-day. In the present investigation we observed that 86% of athletes that took naps on match day chose to nap during the 1h 15 min afternoon preparation window. The afternoon preparation window was the last opportunity athletes got to organise themselves before leaving for the match venue. Therefore, it is likely that the athletes during this window only had a constrained time period in which to nap, which may explain the short duration of naps observed.

The results from the current investigation showed that Rugby Union athletes have numerous key reasons cited for utilising napping on match-day. The most reported reason for napping was to increase energy which is a commonly reported benefit of using napping (Lastella *et al.*, 2021). Taking a nap to increase energy may also be a response to a prolonged match-day present amongst professional Rugby Union athletes due to the requirements of matches scheduled in the evenings. The second most reported reason for utilising naps on match-day amongst Rugby Union athletes was to increase performance. To further support this finding when asked after the season if they felt napping improved their performance throughout the season, 68% of athletes who napped throughout the season reported feeling that their performance was improved by napping on match-day. This finding is novel and suggests that professional Rugby Union athletes perceive that match-day naps may benefit match performance.

Interestingly however, our results are somewhat in contrast to previous research, which has suggested that naps are used to counteract daytime sleepiness associated with sleep restriction, disorders or disturbances, and training schedules common within elite athletes (Lastella *et al*., 2021; Caia *et al*., 2018; Smithies *et al*., 2021). Results from the current investigation found that alleviating effects of sleep debt or jet lag was only the fourth highest cited reason for professional Rugby Union athletes napping on match-day, with less than 50% of athletes reporting this as a reason for napping. Previous research by both Shearer *et al.* (2015) and Dunican *et al.* (2019) has reported that elite Rugby Union athletes obtain sufficient amounts of sleep the night before a match, and indeed, this may explain the finding within the current investigation. Athletes may have gained adequate amounts of sleep the night before match-day, reducing the need to use naps on match-day to alleviate sleep debt. However, it must be noted the previous research by Shearer and colleagues only included home matches and to our knowledge sleep the night before away matches is yet to be evaluated in Rugby union athletes (Shearer *et al*. 2015).

It should be noted that 46% of athletes still cited alleviating sleep debt and jet lag as a reason for napping. Prior research in female volleyball players has highlighted that subjectively assessed sleep may be compromised before away matches (Erlacher *et al*., 2009), which may explain why we observed an increase in match-day napping before away matches compared to home matches. The current investigation is the first to show an increased prevalence of naps taken on match-day depending upon the match's location. A study by Thornton *et al.* (2017) reported a similar pattern of an increased number of naps during a pre-season camp when athletes were sleeping away from home in a cohort of elite Rugby League athletes. Thornton and colleagues (2017) suggested that the increased number of naps observed was a response to jeopardised night-time sleep observed during the camp period. Indeed, sleep may be jeopardised amongst Rugby Union athletes when away from home. Numerous factors associated with away matches, including jet lag (Waterhouse *et al*., 2007), travel fatigue (Janse van Rensburg et al., 2021), and changes in the sleeping environment and situation (Caddick *et al*., 2018) have been shown to negatively affect sleep which explains an increase in napping before away matches.

Whilst the current investigation focuses napping on match-day in Rugby Union athletes, it is important to note that a small proportion (14%) of athletes reported not using naps on match-days. Indeed, athletes cited sleeping in on match-day as a key reason for not utilising naps on match-day. Prior research has highlighted that extending sleep in athlete populations can have a positive effect on physical, cognitive, and mental performance including improved sprint performance, reaction time, and levels of daytime sleepiness (Swinbourne *et al*., 2018; Mah *et al*., 2011). Therefore, extending sleep on match-day may be a viable way to improve performance for an athlete who chooses not to nap on match-day. However, the efficacy of sleep extension on performance needs to be further studied on match-day.

When we examined the effects of match-day napping on perceived match performance, we observed that when athletes utilised pre-match naps prior to away matches, 81% of athletes rated their performance as "good". Conversely, only 58% of athletes rated their performance as "good" when not utilizing naps before away matches. Due to the observational nature of this study, it is difficult to say why this occurred. However, we observed that 68% of athletes who napped reported waking up feeling better than normal following a nap. Therefore, whilst not directly linked, one plausible explanation, may be due to an improvement in mood in athletes that napped. Indeed, a recent meta-analysis reported that pre-performance mood may be predictive of performance outcome (Beedie, Terry, & Lane, 2000). Previous research by Polman and colleagues (2007), has reported that a depressed mood resulted in lower self-rated performance during away matches and suggested a link between mood and self-rated performance amongst professional Rugby League athletes. Furthermore, daytime naps have been shown to improve mood states amongst athlete populations, therefore napping may support self-rated performance. Future research should investigate the effects of napping on pre-match mood and subsequent self-rated performance in professional athletes.

Interestingly, an interaction was observed between match outcome, napping and performance ratings. When athletes napped prior to a match in which the team won, they were nearly seven times more likely to rate their performance within the match as "good". The presence of outcome bias can explain this finding in part. Outcome bias occurs when knowledge of the outcome affects an evaluation of how well an individual or team performed a task (Baron & Hershey, 1988). However, interestingly mood may play a part in the current findings. Prior research has suggested that a win results in a positive change in mood (Polman *et al*., 2007), additionally as stated previously, a positive change in mood has been suggested to result in better ratings of self-performance.

Several limitations within the current investigation need clarification in future research. As the present investigation was a field-based study, there were numerous variables we were unable to control for, which may have impacted the overall results of the study. Studies conducted within professional athletes are required to be as minimally invasive to players and staff, particularly on match-day. Whilst the use of objective sleep and performance measures would have provided more in-depth information on the quality and duration of naps, sleep leading up to match day, and impact naps had on performance. This study aimed to produce an ecologically valid piece of research in an applied setting of elite sports and therefore implementing objective measure was not practical. Given the observational nature of this study, future research incorporating objective measures of napping and performance is warranted. Furthermore, future studies investigating match-day napping should consider factors that may contribute to a higher instance of match-day napping in the week preceding the match, which may include family situations (young family vs. single), sleep duration, sleep quality and sleep disorders. We also acknowledge that it would have been preferable to collect napping data on the same day as competition, rather than 36 h post-match, however, given the game-day requirements and not wanting to interrupt pre- and post-match schedules, this was the most convenient time to collect the data. Additionally, we recognise that perceptions and self-reporting of the athletes were relied on to assess whether they actually fell asleep and acknowledge that we were unable to confirm napping via polysomnography or other objective measures.

Practical Recommendations

Napping preferences and habits are highly individual. Therefore, practitioners working with athletes should seek to investigate the individual preferences of athletes regarding their napping habits, in order to optimise recovery and performance. Furthermore, on game-day, coaching and athletic staff should consider allowing time for athletes to nap pre-match specifically before away matches.

Conclusion

The current study has shown that napping on match-day is common amongst professional Rugby Union athletes. On average athletes napped for 32 minutes with the large majority of athletes preferring to take naps between 16:00-17:15, less than 4 h before kick-off. Furthermore, increasing energy and performance were the most cited reasons for athletes utilising naps on match-day. Additionally, we observed that the number of match-day naps increased prior to away matches compared to home matches, which may be due to impaired sleep associated with travel and away matches. Finally, the results highlighted a link between napping and self-rated performance, which may be due to an increase in mood as a result of napping, which has been shown to improve self-rated performance.

CHAPTER EIGHT

Daytime naps improve afternoon power and perceptual measures in elite Rugby Union athletes – a randomized cross-over trial.

Chapter Eight

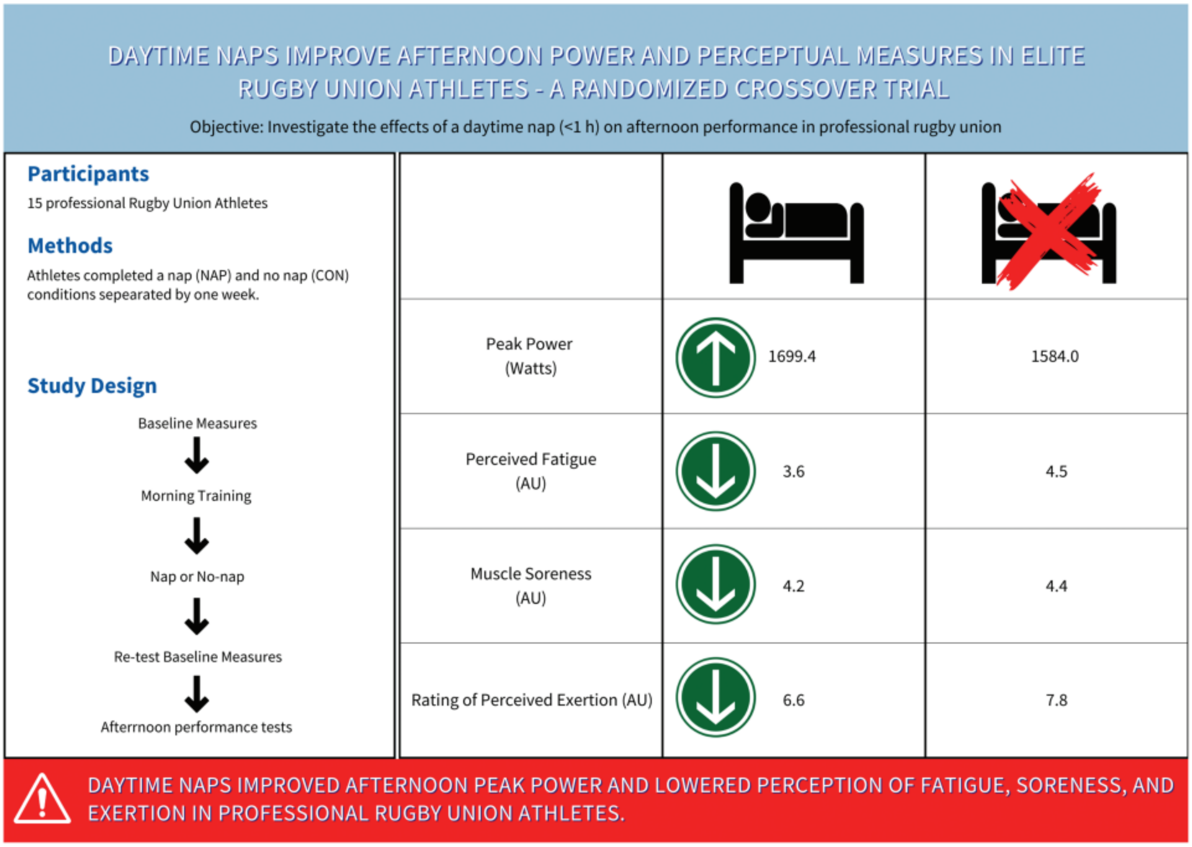
Teece, A.R, Beaven, C. M., Gill, N., & Driller, M. (2023). Daytime naps improve afternoon power and perceptual measures in elite Rugby Union athletes. *Sleep*, *46*(12), zsad133. https://doi.org/10.1093/sleep/zsad133

Prelude: Based on the findings from Studies Three we identified that longer sleep durations were associated with improved physical performance. In this study we aimed to investigate whether sleep extension using a daytime nap acutely improves physical performance in elite Rugby Union athletes.

Abstract

Daytime naps are used by elite athletes in both training and match-day settings. Currently, there are limited interventional studies on the efficacy of napping on physical performance in elite team-sport athletes. Therefore, the objective was to investigate the effect of a daytime nap (< 1 hour) on afternoon performance of peak power, reaction time, self-reported wellness, and aerobic performance in professional Rugby Union athletes. A randomized cross-over design was carried out among 15 professional Rugby Union athletes. Athletes performed nap (NAP) and no nap (CON) conditions on two occasions, separated by 1 week. Baseline testing of reaction time, self-reported wellness, and a 6-second peak power test on a cycle ergometer were completed in the morning, followed by 2 × 45-minute training sessions, after which athletes completed the NAP or CON condition at 1200 hours. Following the nap period, baseline measures were retested in addition to a 30-minute fixed-intensity interval cycle and a 4-minute maximal effort cycling test. A significant group × time interaction was determined for 6-second peak power output (+157.6 W, $p < 0.01$, $d = 1.53$), perceived fatigue (−0.2 AU, $p = 0.01$, $d = 0.37$), and muscle soreness (−0.1 AU, $p = 0.04$, $d = 0.75$) in favour of the NAP condition. A significantly lower perceived exertion rating (−1.2 AU, $p < 0.01$, $d = 1.72$) was recorded for the fixed-intensity session in favour of NAP. This study highlights that utilizing daytime naps between training sessions on the same day improved afternoon peak power and lowered perceptions of fatigue, soreness, and exertion during afternoon training in professional Rugby Union athletes.

Graphical abstract



Statement of significance

This study explored the impact of a daytime nap on afternoon performance and perceptual measures of well-being in elite Rugby Union athletes. Findings highlighted that utilizing a daytime nap of less than 1 hour improved 6-second peak power performance, lowered athletes' perception of exertion, levels of fatigue, and general muscle soreness in the afternoon compared to when athletes did not take a daytime nap. The findings suggest that using a daytime nap may support recovery between training sessions on the same day and may provide positive effects on afternoon performance amongst elite Rugby Union athletes.

Introduction

Insufficient sleep duration has been demonstrated to impact performance, causing decrements in physical performance (Kirschen, Jones, & Hale, 2018), negatively affecting mood (Sargent et al., 2014), and decreasing cognitive function (Taheri & Arabameri, 2012). Therefore, strategies that can increase total daily sleep may allow for the maintenance of training loads. Extending nighttime sleep has been shown to increase performance, support optimal hormonal responses and adaptation in 25 professional Rugby Union athletes (Swinbourne *et al*., 2018). However, exploring alternative methods to increase total daily sleep is necessary when nighttime sleep cannot be extended due to scheduling constraints. One such method previously used to extend the total daily sleep duration is the use of daytime napping.

Napping has been defined as a period of sleep less than 50% of an individual's average nocturnal sleep duration (Dinges *et al*., 1987). Daaloul *et al.* (2019), investigated the effects of daytime napping to improve performance in elite-level Karate athletes, athletes performed a 30-minute post-lunch nap or post-lunch rest period (no nap) at 13:00 following either a full night's sleep (>7 hours) or a night of partial sleep deprivation (4 hours). The 30-minute nap enhanced cognitive outcomes following either a full night of sleep or a night of partial sleep deprivation. Furthermore, it was reported that a 30-minute nap had a positive effect on physical and cognitive deteriorations in performance caused by either sleep loss or by fatigue-induced training. Similarly, O'Donnell, Beaven, and Driller 2018, revealed that a nap of less than 20 minutes enhanced neuromuscular performance. Improvements in countermovement jump peak velocity were observed in favour of the 20-minute nap compared to no nap or a nap longer than 20 minutes in elite Netball athletes.

The use of napping in elite athlete populations has been widespread (Lastella et al., 2021), and Thornton *et al.* (2017) reported across a 2-week preseason period, 156 naps were taken within a cohort of 31 professional Rugby League athletes in both home and away environments. Previous work from our laboratory (Teece et al., 2022) highlighted that 86% of professional Rugby Union athletes reported napping on a match day throughout the season. Given the widespread use of napping as a strategy in rugby athletes, it seems that this is a population living with sleep debt. Supporting this suggestion, Dunican *et al.* (2019) previously reported that professional rugby athletes obtain an average of 6 hours 30 minutes of sleep per night, which is below the recommended amount of sleep suggested in the general population of 7–9 hours (Watson et al., 2015). A lack of sleep in rugby athletes has resulted in symptoms of excessive daytime sleepiness (Dunican *et al*., 2019) and decreased performance (Fullagar *et al*., 2015). Extending nighttime sleep may not be possible for professional rugby athletes because of early training (Dunican, Higgin *et al*., 2019), playing schedules, and travel requirements (Smithies *et al*., 2021) and, therefore, may be a reason for the prevalence of daytime naps in this population.

There is a paucity of experimental research investigating the effects of daytime naps following morning training on subsequent performance in elite team-sport athletes. Therefore, the objective of this study was to examine the impact of a 1-hour daytime nap on afternoon performance of peak power, reaction time, self-reported wellness, and aerobic performance in a cohort of professional Rugby Union athletes.

Methods

Participants

A total of 23 participants were recruited between April 2019 and July 2019 for the present investigation. To be eligible to participate, athletes were required to be free of illness and injury at the time of data collection, six athletes were excluded from the study due to injury. Additionally, athletes needed to be able to perform both study conditionings over 2 consecutive weeks, which excluded another two from the study (Figure 12). Therefore, a sample of 15 professional Rugby Union athletes who competed in the Super Rugby competition (see Table 12 for participant characteristics) participated in the current study, which was conducted in the athletes' normal training environment. Although 39 athletes were contracted during the time of data collection due to player availability and weekly playing schedules, available participants were limited to 23 athletes, which was therefore the entire population available during the data collection period. Before beginning data collection, the athletes gave their informed consent and ethical approval was granted by the University of Waikato Human Research Ethics Committee in March 2019 (HREC 2019#17).

Table 12. Participant Characteristics

Variable	Descriptive statistics	Values
Age (y)	Mean ± SD	21 ± 2
Body mass (kg)	Mean ± SD	105.7 ± 11.6
Height (CM)	Mean ± SD	186.8 ± 5.4

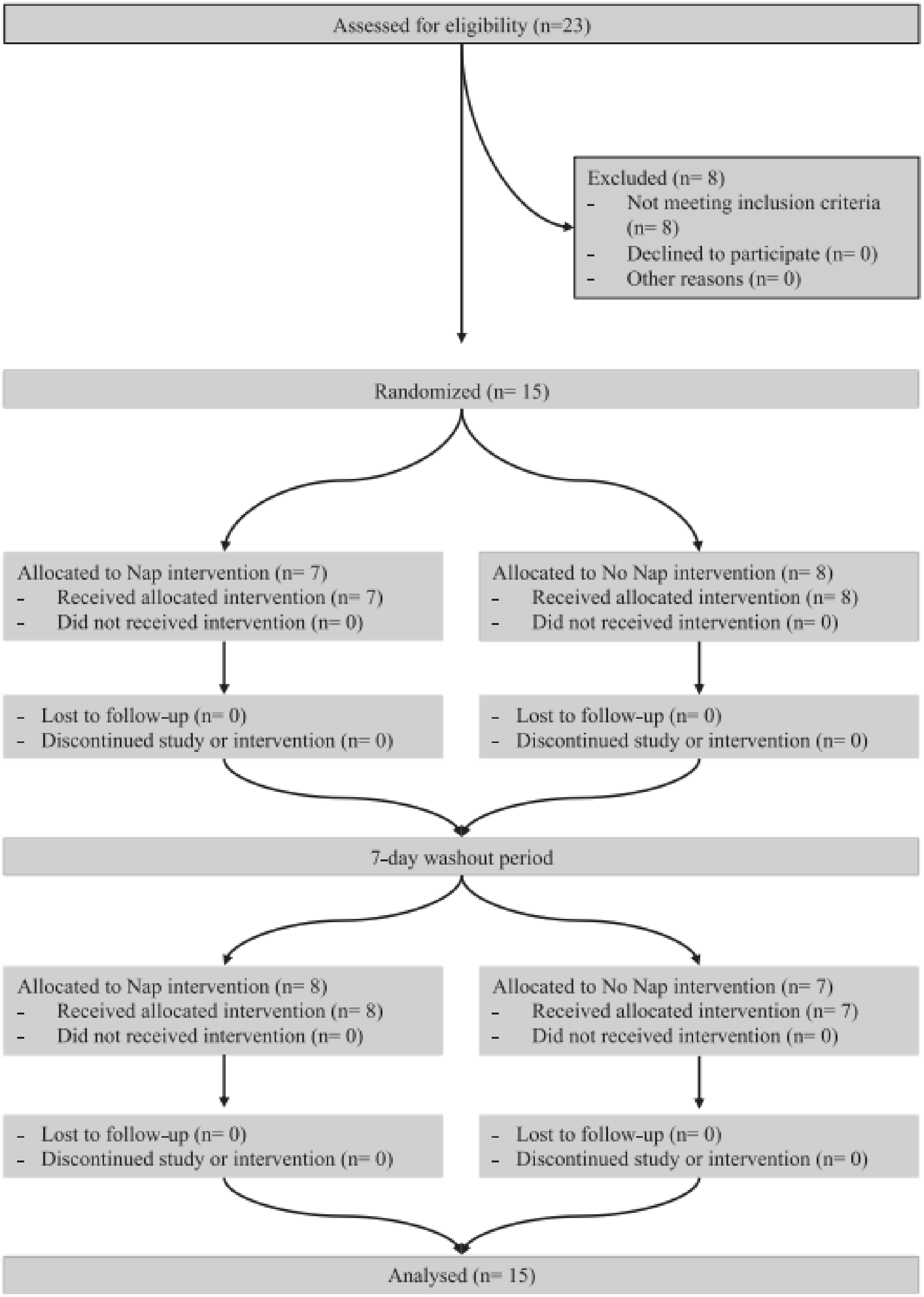


Figure 12. Participant flow diagram

Research design

The study utilized a randomized, counterbalanced, crossover design, as described in Figure 1. Participants were recruited and randomly assigned, according to a computer-generated allocation to a condition by the lead investigator. Participants were assigned to nap condition on testing day one followed by no nap condition on testing day two or non-nap on testing Day 1 followed by nap on testing Day 2. Each treatment was separated by a 1-week washout period. All training volumes were controlled by the strength and conditioning staff to ensure minimal effects of fatigue between and on the trial days. There were no changes in the protocols after the first participant started the study. A familiarisation trial took place prior to the first day of data collection, and all athletes were familiar with all tests and surveys performed. The day before data collection, athletes received a wrist actigraph (ReadiBand, Fatigue Science, Vancouver, BC, Canada.) which they were required to wear the night before data collection to collect sleep measures. On data collection days, athletes were required to undertake baseline measures (self-reported wellness, choice reaction time, and 6-second peak power followed by two typical training activities of 45-minute duration (resistance training and running conditioning: see below for details). Morning training was followed by an hour period in which athletes were to have lunch, athletes were prohibited from having caffeine or any other stimulants at any stage during data collection days. At 1200 hours, athletes were randomly assigned to nap (NAP) or no nap (CON) conditions. A 30-minute period separated the NAP and CON from afternoon tests, which included a warm-up consisting of 10 minutes of self-selected intensity cycling and dynamic stretching (hamstrings and quadriceps, hip flexors and extensors, calf, and ankle mobility). This 30-minute period post-nap before afternoon testing was included to allow for and minimize sleep inertia based on previous research (Lastella *et al*., 2021). Afternoon testing started with retesting of baseline measures and then consisted of a 30-minute fixed-intensity interval session and a 4-minute maximal effort time trial. Between trials, athletes were instructed to maintain their typical sleep habits (Figure 13).

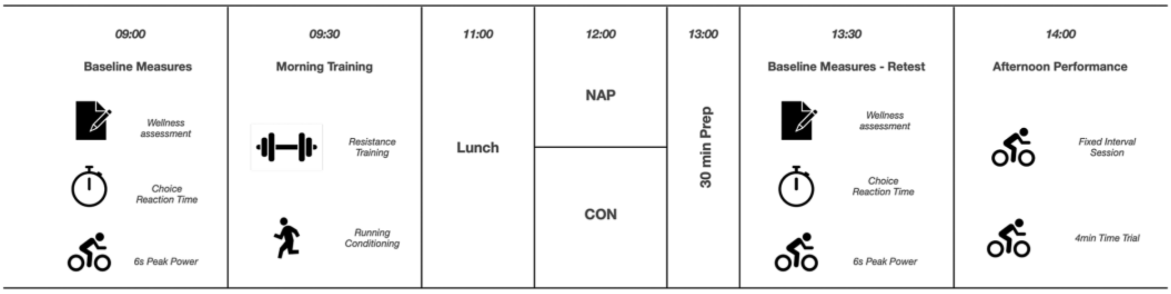


Figure 13. Experimental Protocol.

Nap trial (NAP)

The nap trial involved athletes attending a dedicated sleep room for a period of 1 hour at 1200 hours. The room was dark and temperature-controlled at 18°C, athletes were provided with eye masks, earplugs, and beds in which to sleep. Athletes were not allowed to bring phones or other technology (e.g. smartwatches) into the sleep room. Athletes were required to stay in the sleep room for the entire hour period and were required to relax in the sleep room for the hour if they could not get to sleep. Following the 1-hour nap period, athletes were asked if they napped (yes or no) and were to report their self-estimated nap duration. During the same 1-hour period, the CON condition was instructed not to sleep and not to consume caffeine or any other stimulants. Athletes were otherwise allowed to do as they usually would between morning and afternoon training sessions, including having access to phones and other technology, such as games and music in the team lounge.

Sleep monitoring

Quantitative sleep measures were collected the night before data collection to ensure sleep the night before each testing day was similar. Sleep measures were collected via wrist actigraphy (ReadiBand, Fatigue Science, Vancouver, BC, Canada). Athletes were required to wear the wrist actigraph on either wrist the night before data collection (Driller, O'Donnell, and Tavares, 2017) and athletes were asked to maintain their regular sleep routine. At the beginning of each data collection day, the data were wirelessly downloaded to an iPad and then analysed using the manufacturer's online software. The raw activity data were translated into sleep–wake indices, including total sleep time, sleep efficiency (SE%), and sleep latency. The Readiband has been validated against polysomnography (PSG) and has been deemed to be acceptable with approximately 90% agreement in total sleep duration compared to PSG (Dunican *et al*., 2018). Furthermore, the inter-device reliability of the Readiband has been shown to have high levels of agreement (Driller, McQuillan, and O'Donnell, 2016).

Self-reported wellness

A wellness questionnaire based on the previous work of Hooper and Mackinnon (1995) was completed in the morning and afternoon for both nap and CON conditions. The questionnaire comprised of three questions related to fatigue, general muscle soreness, and alertness. All questions were rated on a scale of 1–7 Likert-type scale where 1 represented a good/desirable score (e.g. very fresh) and 7 represented a poor score (e.g. very fatigued). Research from our laboratory has highlighted that the wellness questionnaire displays acceptable day-to-day reliability with an ICC of 0.73 and a TE of 1.63%.

Reaction time test

Measures of reaction time were collected at 2-time points (morning and afternoon) for each trial. Reaction time was assessed via a choice reaction time test conducted using the Psych Lab 101 application for iPad (Neurobehavioral Systems, San Francisco, USA). The use of mobile devices to assess choice reaction time has been shown to be a valid and reliable way of assessing choice reaction, as described by Burke *et al.* (2017). The choice reaction test required athletes to react to two different stimuli as quickly as possible and touch the corresponding side of the screen. If the athlete saw a red box, they were required to touch the left-hand side of the screen as quickly as possible. If they saw a blue box appear, they were required to touch the right-hand side of the screen. The athletes were required to complete the test, which consisted of 40 trials of each stimulus. The choice reaction test took approximately 3 minutes in total to complete. At the completion of the test average reaction time was recorded by the research team for analysis.

Peak power assessment

Peak power was assessed in the morning and afternoon of both conditions using the 6-second peak power test on a Wattbike cycle ergometer (Wattbike Ltd, Nottingham, UK). The 6-second peak power test was performed as an assessment of lower-body neuromuscular power. On the initial trial, saddle and handlebar height positions were set up according to athletes' preferences and were replicated thereafter. Resistance settings for the test were determined according to the recommendations by the Wattbike software based on the athlete's body mass. The 6-second peak power test was initiated following a 5-second countdown which was followed by a verbal command of "Go." The test employed a seated stationary start, with the athletes self-selecting the leg which initiated the first downstroke. Athletes were instructed to remain in a seated position and produce maximal effort for the 6-second duration. Peak and relative peak power (W and $W \cdot kg^{-1}$) were recorded for analysis. The test–retest reliability of the 6-second peak power assessment has previously been reported by Wehbe *et al.* (2015), who reported an ICC of 0.96 and CV of 3.0%.

Resistance training

Athletes completed a resistance training program which was designed by the team's strength and conditioning staff. The program was designed to increase maximal strength and power, including three upper-body and three lower-body exercises. The resistance program took approximately 45 minutes to complete, and the same resistance training session was completed for both conditions. At the completion of the resistance training session, athletes were required to report a rating of perceived effort (RPE). Borg's modified 1–10 scale (Borg, 1982) was used to assess each athlete's perception of exertion from each training session.

Conditioning session

Following resistance training, athletes were required to undertake a running conditioning session designed by the team's strength and conditioning coaches. The session had components of repeated speed, maximal aerobic speed, and high-intensity interval running. The running conditioning session took approximately 45 minutes to complete, and the same session was completed on the same standard-sized Rugby Union field on both occasions. For each session, locomotion activity was measured using an 18 Hz GPS unit to ensure trials were the same each week (Apex Pro Series Pod, STATSports, Belfast, UK). Units were worn on the upper back to decrease variability, and each athlete used the same GPS unit for both conditions. Heart rate (HR) monitors (Polar Electro Oy, Kempele, Finland) were worn by all athletes, with average, and maximal HR recorded by researchers for analysis. Finally, each athlete reported a rating of perceived exertion after the conditioning session. RPE was assessed using Borg's modified 1–10 scale.

Fixed-intensity interval cycling test

Athletes undertook a fixed interval cycling test in the afternoon on a Wattbike ergometer on both occasions. The fixed-intensity session was included in the experimental design to ensure that fatigue levels were similar before the 4-minute time trial while also assessing the physiological and perceptual responses to standardized exercise following the NAP and CON trials. Athletes were required to complete a 30-minute interval session which consisted of a 2-

minute intensity interval at 2.5 W·kg^{-1} immediately followed by a 3-minute recovery interval at 1.5 W·kg^{-1}. Athletes completed both intensity and recovery intervals 6 times in total. Resistance settings were self-selected by the athletes to maintain the prescribed power outputs. Athletes wore HR monitors with average and maximal HR collected for analysis. Additionally, average power output (W) and RPE were collected at the completion of the test and were used for analysis.

Four-minute time trial

A 4-minute time trial was performed on a Wattbike cycle ergometer on both occasions to assess afternoon maximal aerobic performance. Athletes self-selected their resistance settings before the commencement of the time trial. The time trial commenced from a stationary start, with athletes selecting the foot which initiated the first downward stroke. The time trial began following a 5-second countdown followed by a verbal confirmation of "Go." Athletes were instructed to perform maximally throughout the 4-minute test. Throughout the test, athletes were given verbal encouragement and indicators of time remaining however, athletes were blinded from all performance outcomes. HR was consistently monitored throughout the 4-minute period, with average and maximal HR recorded at the 4-minute mark for analysis. The 4-minute time trial has been shown to have strong inter-day reliability, with Driller *et al.* (2014) reporting an ICC of 0.94, a TEM of 8.8 Watts, and a CV of 2.3%.

Statistical analyses

All descriptive statistics are reported as means ± standard deviation unless otherwise stated. Statistical analysis was performed on 15 participants using the Statistical Package for Social Sciences (V.27.0, SPSS Inc., Chicago, IL, USA), with statistical significance set at $p < 0.05$ for all analyses. A two-way repeated-measures ANOVA, with 2 (condition: NAP, CON) × 2 (time: PRE, POST) factors, was performed to determine the differences in wellness assessments, reaction time, and peak power. Analysis of the studentized residuals showed normality, as assessed by the Shapiro– Wilk test of normality and no outliers were present, as assessed by no studentized residuals greater than ± 3 standard deviations. The main effects were run to identify where statistically significant differences existed and if there were differences between conditions at the POST time point. Additionally, paired-sample t-tests were used to compare HR and RPE in the fixed intensity cycling test, power output in the 4-minute time trial, sleep indices, GPS, and HR data between the NAP and CON for morning training. Effect-size statistics were calculated using Cohen's d and interpreted using thresholds of 0.2, 0.5, and 0.8 for small, moderate, and large, respectively (Cohen, 1988). An effect size of <0.2 was considered trivial, and the effect was deemed unclear if the 95% confidence interval overlapped the thresholds for both small (d = 0.2) positive and negative effects.

Results

Analysis of sleep indices the night before each trial (CON and NAP) revealed no differences 0.05) between conditions for any sleep measures, including total sleep time (p = 0.95), sleep efficiency (p = 0.73), and sleep latency (p = 0.92) (Table 13). When morning training data was analysed, the morning resistance training elicited similar RPE's (5.3 ± 0.8 vs. 5.3 ± 0.7, p = 1.0) for the CON and NAP conditions.

Table 13. Data (mean ± SD) for comparison of total sleep time, sleep efficiency and sleep latency as assessed via wrist actigraphy between the NAP and CON conditions from the night before data collection, including p-values and effects size comparison between conditions

Measure	Condition	Mean ± SD	*p*-Value	ES (*d*) ±90% CI
Total Sleep Time (h:mm)	NAP	7:25 ± 0:41	0.95	0.03 ±0.89, *unclear*
	CON	7:23 ± 0:44		
Sleep Efficiency (%)	NAP	90.0 ± 3.2	0.73	0.20 ±1.04, *unclear*
	CON	89.1 ± 3.8		
Sleep Latency (min)	NAP	11.1 ± 4.0	0.92	0.06 ±1.13, *unclear*
	CON	10.8 ± 3.9		

Additionally, the running conditioning elicited a similar running distance (3019 ± 56 m vs. 3037 ± 80 m, $p = 0.58$), mean HR (156 ± 7 beats·min−1 vs. 154 ± 6 beats·min-1, $p = 0.10$) and RPE (8.3 ± 0.6 vs. 8.3 ± 0.7, $p = 1.00$) for CON and NAP conditions indicating that the morning exercise was completed at a similar physical intensity for each trial. Analysis of athletes' responses to the 1-hour nap period revealed all athletes reported being able to successfully nap, with an average self-perceived nap duration of 35 ± 10 minutes.

Peak power

Results from the 2-way repeated measure ANOVA revealed a statistically significant group × time interaction for absolute peak power, $F(1,14) = 21.46$, $p < 0.01$ (Figure 14) and relative peak power, $F(1,14) = 24.04$, $p < 0.01$. The NAP condition was associated with improvements in absolute and relative peak power (Table 14). The POST time point was associated with significantly higher absolute peak power ($p < 0.01$), a mean difference of 157.6 (W) and relative peak power ($p < 0.01$), a mean difference of 1.1 ($W \cdot kg^{-1}$) compared to CON (Figure 15).

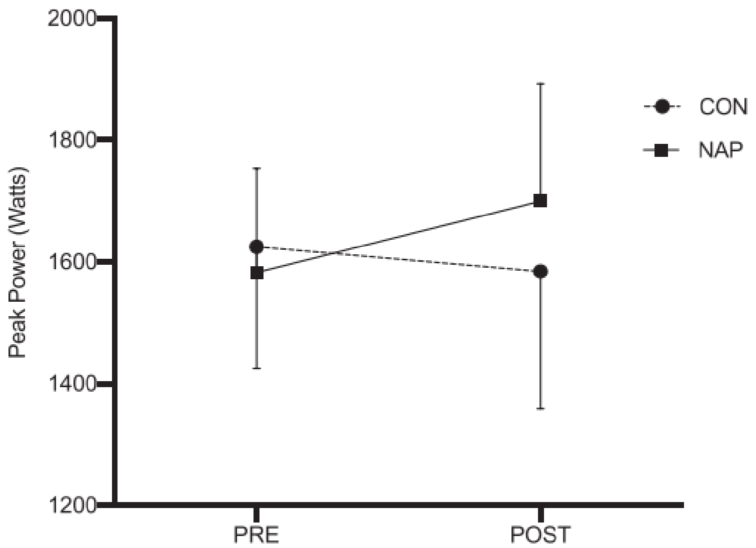


Figure 14. Mean 6 seconds peak power (W) from PRE (morning) to POST (afternoon) timepoints for the NAP and CON trials. Error bars represent standard deviations. * significant group × time interaction.

Table 14. Data (mean ± SD) for comparison between NAP and CON conditions for morning and afternoon peak power in the 6 s cycle test and reaction time, including *p*-value and effect size comparison between conditions for both time points (PRE = morning, POST = afternoon).

					Group x Time interaction	
		PRE	POST	Change	*p*-value	ES (*d*) ±90% CI
Absolute Peak Power (W)	NAP	1582.5 ± 170.9	1699.4 ± 193.3 ^	116.8 ± 28.6 #	<0.01	0.72 ±0.27,
	CON	1624.8 ± 200.2	1584.0 ± 225.5	-40.8 ± 24.6		*moderate*
Relative Peak Power ($W{\cdot}kg^{-1}$)	NAP	15.0 ± 1.2	16.1 ± 1.6 ^	1.1 ± 0.2 #	<0.01	0.80 ±0.29,
	CON	15.4 ± 1.3	15.0 ± 1.8	-0.4 ± 0.2		*Large*
Reaction Time (ms)	NAP	353.6 ± 16.9	346.5 ± 19.7	-7.1 ± 4.6	0.51	0.21 ±0.56,
	CON	351.8 ± 19.1	349.1 ± 20.9	-2.7 ± 4.5		*unclear*

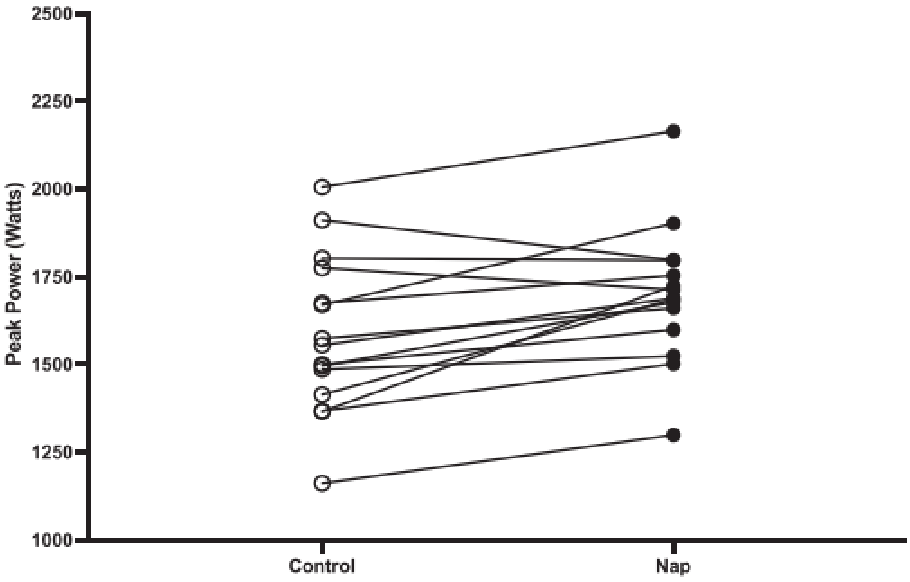


Figure 15. Individual scores of 6 seconds peak power (W) at the POST.

Reaction time

Results from the 2-way repeated measure ANOVA revealed no significant group × time interaction for reaction time, F(1,14) = 0.45, p = 0.51 (Table 14). Afternoon performance Analysis of the fixed intensity cycle session revealed no significant (p > 0.05) differences for mean power output (191.6 ± 30.5 W vs. 194.5 ± 24.9 W, p = 0.65) or average HR (150 ± 8 vs. 152 ± 10 beats min−1, p = 0.37) between CON and NAP conditions. However, a significant difference ($p < 0.01$, $d = 1.75$) was observed in RPE scores between conditions, with the NAP condition reporting a lower RPE (6.6 ± 0.7 AU) than the CON condition (7.8 ± 0.6 AU). Analysis of the 4-minute time trial showed no differences between NAP and CON for relative or mean power output or average HR (Table 15).

Table 15. Data (mean ± SD) for comparison of mean power, relative power, average heart rate and rating of perceived exertion results from the 4-minute time trial between NAP and CON conditions, including p-value and effect size comparison between conditions

Measure	**Condition**	**Mean ± SD**	***p*-Value**	**ES (*d*) ±90% CI**
Mean power (W)	NAP	316.8 ± 46.8	0.39	0.09 ±0.24, *trivial*
	CON	312.6 ± 41.3		
Relative Power ($W{\cdot}kg^{-1}$)	NAP	3.0 ± 0.4	0.82	0.11 ±0.26, *trivial*
	CON	2.9 ± 0.3		
Average Heart Rate ($beats{\cdot}min^{-1}$)	NAP	163 ± 10	0.93	0.00 ±0.30, *unclear*
	CON	163 ± 9		

Self-reported measures

Results from the 2-way repeated measure ANOVA revealed a significant group × time interaction for fatigue, $F(1,14) = 5.38$, $p = 0.03$ and general muscle soreness, $F(1,14) = 4.67$, $p = 0.04$, but not for alertness, $F(1,14) = 3.33$, $p = 0.08$. A main effect of time was observed for fatigue and general muscle soreness. The NAP condition displayed significantly lower fatigue scores compared to the CON condition at the POST time point ($p = 0.01$). Conversely, the CON condition displayed significantly lower general muscle soreness scores at the PRE time point compared to the NAP condition ($p = 0.03$). Additionally, a small effect was observed for changes in fatigue and moderate effects were observed for changes in general muscle soreness and alertness, both in favour of the NAP condition (Table 16).

Table 16. Data (mean ± SD) for comparison between NAP and CON conditions for morning and afternoon fatigue, general muscle soreness, and alertness, including p-value and effect size comparison between conditions for both time points (PRE = morning, POST = afternoon).

					Group x Time interaction	
		PRE	POST	Change	*p*-value	ES (*d*) ±90% CI
Fatigue (AU)	NAP	3.8 ± 0.7	3.6 ± 1.5 *	-0.2 ± 1.4#	0.03	0.48 ±0.37, *small*
	CON	4.0 ± 1.0	4.5 ± 1.0	0.5 ± 1.2		
General Muscle Soreness (AU)	NAP	4.3 ± 1.0	4.2 ± 0.8	-0.1 ± 0.9	0.04	0.75 ±0.61, *moderate*
	CON	3.7 ± 0.9 ^	4.4 ± 1.4	0.7 ± 1.6		
Alertness (AU)	NAP	3.7 ± 0.8	3.4 ± 1.5	-0.3 ± 1.8	0.08	0.66 ±0.64, *moderate*
	CON	3.4 ± 1.1	4.0 ± 1.1	0.6 ± 1.6		

# Indicates a significant difference between PRE and POST measures (p<0.05), ^ Indicates a significant difference between NAP and CON (p<0.05) at the PRE time point. * Indicates a significant difference between NAP and CON (p<0.05) at the POST time point.

Discussion

The aim of the current study was to examine the effects of a short daytime nap following morning training on afternoon performance in a cohort of professional Rugby Union athletes. Utilizing a daytime nap of less than 1 hour (average of ~35 minutes) improved afternoon peak 6-second cycling power, lowered afternoon perception of exertion during exercise, and improved afternoon levels of fatigue and general muscle soreness. Therefore, a short daytime nap following morning training may support aspects of physical and perceptual recovery in the afternoon amongst professional Rugby Union athletes and may be a useful strategy to implement in these settings.

While this study is the first to evaluate the effects of a daytime nap on afternoon performance in professional Rugby Union athletes, previous research has evaluated the effects of short daytime naps on physical performance in other cohorts. O'Donnell *et al.* (2018) showed that a 20-minute nap mid-afternoon improved countermovement jump peak velocity amongst elite netball athletes on match days. Additionally, Daaloul *et al.* (2019) reported that a 20-minute nap following sport-specific training that induced fatigue improved squat jump and countermovement jump performance amongst elite-level karate athletes. Our findings support the beneficial effects of a short nap on physical performance, with athletes displaying increased peak and absolute peak power following a short ~35-minute nap. It is likely that the mechanism behind the increase in peak and relative power observed following the nap is multifactorial. Although speculative, one possible mechanism is that elevated cortisol levels that have been observed following a daytime nap (Vgontzas *et al*., 2007) may have been associated with better neuromuscular performance (Passelergue, Robert, &. Lac, 1995; Crewther *et al*., 2009). Indeed, the 6-second cycling test relies heavily upon high neuromuscular function for optimal performance (Douglas, Roos, & Martin, 2021). Neuromuscular fatigue has been shown to impair force capabilities, including strength and power (Alba-Jiménez, Moreno-Doutres, & Peña, 2022), altered movement strategies (Kennedy & Drake, 2017), and how team sport athletes produce high-intensity activities (Mooney *et al*., 2013). Force capabilities and locomotive movement are important aspects of performance in training and competition among Rugby Union athletes (Crewther *et al*., 2009). Therefore, the findings of a nap supporting neuromuscular performance may be important for afternoon training performance in athlete populations.

An additional benefit of daytime naps previously reported is that naps may reduce the perception of effort during exercise. Blanchfield *et al*. (2018) reported that after a 20-minute nap, athletes cited a lower sense of effort via assessment of RPE following a time-to-exhaustion exercise protocol in trained endurance runners. Our results align with previous findings, with athletes reporting lower RPEs for the fixed-intensity cycling session following the NAP condition. The differences observed in RPE may be due to differing levels of physical fatigue between the nap and no-nap conditions. Previous research has proposed that RPE scores during constant exercise are a direct function of workload (Myles, 1985), suggesting that fatigue is a possible stimulus for increases in RPE scores during exercise. Therefore, the finding from the current investigation may indicate that the nap provided improved physical recovery from the morning training session, resulting in lower ratings of exertion in the afternoon.

Measures of fatigue, sleepiness, and alertness have been reported to improve after a daytime nap (Tietzel & Lack, 2001). We observed that the nap condition displayed significantly lower levels of Self-reported fatigue and a moderate reduction in general muscle soreness in the afternoon compared to the no-nap condition, which may support the suggestion that a short daytime nap supports physical recovery. Previous research agrees with the findings from the current investigation; Bourkhris *et al.* (2020) reported that a 40-minute daytime nap resulted in decreased Self-reported fatigue and delayed onset muscle soreness compared to not taking a nap. The finding that a daytime nap reduces fatigue and muscle soreness observed in the current investigation is of importance amongst team sport athletes. Indeed, fatigue has been suggested to impact decision-making amongst athlete populations (Halson, 2014). Effective and accurate decision-making is important for skill execution and has been suggested as fundamental for success in rugby performance (Sherwood, Smith, & Masters, 2019). Furthermore, general muscle soreness has been suggested to negatively impact neuromuscular performance (Byrne, Twist, & Eston, 2004),] and be linked to measures of decreased performance in rugby (McLean *et al*., 2010). Therefore, it may be suggested that reducing muscle soreness may be important for sporting performance in rugby athletes. Subsequently, these findings are of high relevance and importance amongst professional athlete populations who train more than once per day.

One possible explanation for the current findings of fatigue and general muscle soreness may be linked to levels of cytokines such as interleukin-6 (IL-6) following the nap. Increased levels of IL-6 have been observed following physical exercise (Steensberg *et al*., 2000) and have been associated with muscle damage (Bruunsgaard *et al*., 1997), and heightened sensations of fatigue (Robson-Ansley *et al*., 2004). Additionally, levels of IL-6 have been shown to be suppressed following a daytime nap (Vgontzas *et al*., 2007). Another plausible factor that needs to be considered is that the daytime nap may relieve sleep pressure and adenosine buildup in the brain, which increases throughout wake periods (Porkka-Heiskanen, 1999). Sleep pressure has been shown to increase in the afternoon (Monk, 2005; Bes, Jobert, & Schulz, 2009) and has been associated with reductions in alertness and increased fatigue (Askaripoor *et al*., 2019). Furthermore, adenosine buildup inhibits neurotransmitters within the brain, causing an increase in sleepiness and negatively affecting alertness and fatigue (van Dongen & Dinges, 2000).

No differences were observed between conditions for reaction time or Self-reported alertness. The lack of change in alertness and reaction time is contrary to previous results by Daaloul *et al.* (2019), who demonstrated improvements in alertness and cognitive performance following a 30-minute daytime nap. The findings in the current investigation may partly be explained by a degree of sleep inertia present following the nap. Sleep inertia has been shown to impair Self-reported alertness and cognitive performance, including reaction time following awakening (Achermann *et al*., 1995). Additionally, it has been shown that sleep inertia can impair alertness and cognitive performance for up to 2 hours after waking (Jewett *et al*., 1999). Indeed, within the current investigation, we allowed 30 minutes between waking and reaction time testing; while this may have been enough time to overcome sleep inertia, it is possible that sleep inertia was still present 30 minutes post-nap. Furthermore, performance tests are more sensitive to fatigue when longer in duration (Romyn *et al*., 2022). The reaction time test took approximately 3 minutes to complete compared to 6 seconds for peak power which may suggest that reaction time was more impacted by potential fatigue present from any remaining sleep inertia.

Given the applied nature of the present study and the difficulty of conducting research on professional athletes, it must be noted that within the current investigation complete case analysis was able to be conducted on 15 athletes meaning that all 15 athletes who started to study completed both conditions which is a strength of the investigation. However, there are several limitations that we must acknowledge within the current investigation. The nap duration and confirmation of being able to nap during the 1 hour were self-reported by athletes, which relied on athletes to assess whether they actually fell asleep, and we were unable to confirm napping via polysomnography (PSG) or any other objective measures. We felt that PSG was not a practically viable option in this setting, as it would take too long to set up in an already short timeframe. We also felt that it would be too unnatural and uncomfortable to use during a relatively short napping period. Alternatively, we considered the use of actigraphy, however, this method has been shown to have some issues in detecting naps in populations where sleep periods contain significant movement (Galland *et al*., 2014), which has been shown to be an issue amongst Rugby Union athletes (Dunican *et al.,* 2018). We also acknowledge that sleep inertia following a nap is highly individual (Ritchie *et al*., 2017) and that the 30-minute duration between napping and post-testing measures may not have been enough time for some athletes to wake up and feel alert. However, the time frames used in the current study were designed to replicate the real-world schedule that these athletes follow.

It should be mentioned that due to some performance metrics requiring athletes to exert maximally, we cannot discount that this may be influenced by athletes not being blind to which condition they are undertaking, and therefore the nap may have produced some placebo effect as a result. Furthermore, an addition to strengthen the current study design would have been to collect information about athletes' habitual napping and sleep behaviours. This data would enable comparisons between nap duration between habitual and non-habitual nap takers and evaluate if habitual nap takers performed better in the study. Additionally, collecting habitual sleep duration would have highlighted if any athlete was under any form of sleep debt prior to testing days. Given the positive effects of a nap observed in the current investigation, future research should investigate the chronic application of daytime napping in elite sporting populations and evaluate whether daily napping over longer time frames (e.g. 4+ weeks) would be beneficial to physiological adaptations and performance.

Conclusion

The current study investigated the impact of a daytime nap on afternoon performance and Self-reported measures in professional Rugby Union athletes. A short nap of around 35 minutes, resulted in an increase in afternoon peak power production, reduced Self-reported fatigue, less general muscle soreness, and lowered perceived exertion during afternoon training compared to not taking a nap between sessions. The findings from the current study suggest that napping may support recovery between training sessions on the same day and may provide positive effects on afternoon performance amongst professional Rugby Union athletes. Therefore, we are confident that it is unlikely that any harm would be caused to the athletes by implementing napping into their schedule. Given the potential improvements identified in this study, we would encourage practitioners to implement napping into their daily and weekly schedules. Coaches and performance staff should consider allowing time between training sessions on the same day to provide athletes with an opportunity to take a daytime nap to help improve afternoon training performance.

CHAPTER NINE

Summary, Practical Applications, Limitations and Future Research.

Thesis Summary

This thesis was comprised of six studies which were designed to address the primary aims of investigating sleep behaviours and the relationship between sleep and physical performance in an elite rugby union population.

Study One was the first to compare sleep behaviours across competitive tiers in Rugby Union athletes using previously validated sleep questionnaires in the ASBQ and PSQI. The large sample size and stratification by competition level provided valuable insights into the habits and behaviours that influence sleep across academy, semi-professional and professional athletes. Professional athletes displayed longer sleep duration compared to semi-professional and academy level athletes. Additionally, results highlighted that differences exist between levels of competition for specific sleep behaviours. Of further note, mean PSQI global scores exceeded the poor sleep threshold of five across all levels. Moreover, whilst the mean scores position each level of competition marginally above the threshold the standard deviations highlight that a proportion of athletes are likely to be experiencing very poor sleep beyond what the group average indicates. Such poor sleep is likely to have clinical implication and is worthy of further investigation.

Study Two investigated the difference in sleep habits and behaviours between elite male and female Rugby Union athletes. Male athletes displayed better self-reported sleep quality and quantity than female athletes Furthermore the findings highlighted that male and female not only face difference in quality and quantity of sleep but also face distinct challenges with specific behaviours or habits affecting their sleep as well. It appears the differences observed between elite male and female athletes may be due to differing levels of professionalism, differences in timings of trainings which may also account for the reduction of sleep quantity observed amongst the female population.

Study Two highlighted that male athletes displayed better self-reported sleep quality and quantity than female athletes; however, the present study highlighted that male and female elite Rugby Union athletes face specific challenges that differ. It appears that the differences observed between male and female elite Rugby Union athletes may be due to differing levels of professionalism or differences in training or competition schedules.

Study Three investigated the relationship between sleep duration and changes in physical performance throughout a pre-season period in an elite Rugby Union environment. The results highlighted that longer sleep duration during pre-season periods of training may assist in enhancing physical qualities including aerobic capacity and body composition which are of particular importance and relevance to elite Rugby union athletes who are consistently striving to get bigger, faster, and stronger and therefore sleep may be an important tool to assist in achieving this goal.

Study Four investigated the effects of sleep routine and sleep regularities association with sleep metrics. The results highlighted that when stratified into two groups; regular sleepers (SRI >76.4) and irregular sleepers (SRI <76.4) that regular sleepers showed significantly longer sleep duration per night. Furthermore, regular sleepers may have displayed improved sleep efficiency and less wake episodes when compared to irregular sleepers. These novel results suggest that minimising variability in sleep onset and offset times is an important factor of sleep quality and quantity amongst elite Rugby Union athletes. These data hold clear implications and should be an area of focus for sleep hygiene practices and education within team sport environments.

Study Five investigated the prevalence and perceived impact of pre-match napping across a competitive season. The results highlighted that 86% of players utilised pre-match naps throughout the season with a significant more taken when games were player away compared to home. Of note, the data shown that 87% of athletes who napped on game day believed it helped their match performance and that coaches rated performance more highly. The most common reason reported for taking naps was to increase energy. The findings highlight that match day napping is commonly used in elite Rugby Union environments. Indeed, napping may be an accessible and practical way in which to increase perceived performance before matches.

Study Six examined the effects of a daytime nap of approximately 35 minutes on subsequent afternoon physical performance following a morning training session. Athletes who napped demonstrated a significant increase in afternoon six-second peak power output (+157.6 W), alongside reductions in muscle soreness, perceived fatigue, and ratings of perceived exertion during a fixed-intensity session compared to those who did not nap. These findings confirm that daytime napping is an effective strategy for enhancing acute recovery between same-day training sessions in elite athletes and offer a potential explanation for the perceptual performance benefits reported by athletes in Study Five.

Collectively the six studies included within this thesis address meaningful gaps in the literature regarding sleep in Rugby Union. The studies provide novel data and further the knowledge and understanding of sleep practices amongst Rugby Union athletes with the potential to improve recovery and performance across a range of high-level athletes. With the physical demands of Rugby Union continuing to increase and the drive to gain physical development the importance of sleep as a recovery and performance tool cannot be emphasised enough. The findings from this thesis highlights that there are numerous challenges that can impact sleep in Rugby Union athletes but also demonstrates the importance that both quality and quantity of sleep for Rugby Union athletes. Furthermore, the results provide coaches, medical staff and athletes with practical, evidence-based strategies in which to address sleep challenges and potentially improve sleep specific to their environment.

Practical Applications

The following section will outline the practical applications based on the findings and outcomes of the six studies this practical application section will aim to provide target education focuses and highlight what best practice may look like within Rugby Union environments.

Study One

- Education for academy level athletes should focus on improving sleep environments via methods such as temperature, noise, and light. Additionally, education should be targeted at reducing the incidence of using light emitting technology in the hour prior to bed.
- Education for semi-professional athletes should be centred around techniques to reduce problems with falling asleep due to though or worry whilst in bed. Additionally, the importance of a good sleep environment should be part of target education for this group.
- Education targeted at professional athletes should focus on methods to minimise the effects of sleep-in foreign environments. Furthermore, targeted education might focus on how best to relax prior to sleep to minimize muscle tension that can lead to nighttime disturbances.
- Across all levels of Rugby Union there needs to be targeted education on the importance of gaining sufficient quality and quantity of sleep as this can be improved across all levels.

Study Two

- Education specific to elite female athletes should be focused on maximizing their ability to downregulate at night before and whilst in bed. Due to greater thought or worry whilst in bed as well as being required to train late at night (after 7:00 p.m.) more frequently. Education may focus on bedtime routines or other downregulation techniques such as breathing and meditation.
- Elite male athletes in addition to the above need targeted education on the impact that alcohol consumption prior to bed can have upon quality of the sleep achieved following consumption

Study Three

- The findings from Study Three can be used to highlight the importance of prioritising increased sleep duration and that it may help to facilitate the physiological adaptations that are sought during pre-season. This can be used to highlight that sleep is a critical recovery tool for athletes.
- Practically, athletes should be encouraged to optimise their sleep in these periods. The use of a sleep alarm, setting both a target sleep and wake time, is a simple and implementable strategy to support athletes in optimizing their sleep. Furthermore, this will also allow athletes to start to set a bedtime routine which is important for both quality and quantity of sleep.
- Coaching and management staff should also be conscious of the impact that frequently changing training and competition schedules can have on athlete sleep. Where possible schedules should be kept consistent which allows athletes to maintain a stable sleep and wake routine thereby assisting to maximise their recovery between training and competition.

Study Four

- Study Four highlighted the importance of maintaining a consistent sleep-wake patterns and that is has a meaningful impact upon sleep duration and therefore in turn may impact physical adaptations. Whilst education of this is important to athletes, the other practical application of this research is that coaches and management need to be conscious of the impact in which adjusting training schedules may have on this and therefore should try to limit its impact upon individuals sleep and wake times.

Study Five

- Study Five from a practical point of view highlighted that athletes take naps on match-day and may assist in improving the perception of performance amongst athletes. Therefore, coaches should consider preserving time within a match-day schedule to allow for naps to occur. Indeed, this may mean providing downtime within their day for this to occur.

Study Six

- Study Six highlighted that daytime naps can attenuate performance decrements during afternoon training. Time within schedules should be attributed to naps specifically on double training days, however for this to be a viable option for athletes, clubs and organisations must invest in providing sleep rooms in which players can use. This research can be used to highlight the importance of, and therefore the need for, sleep rooms within professional environments.

Limitations

The findings and outcomes presented in this thesis have direct and practical implications for understanding how sleep contributes to recovery and physical performance in elite Rugby Union or similar sports. While each study acknowledged specific limitations, the overall limitations of the research are outlined below:

- Ecological validity: Actigraphy was used to assess sleep metrics and sleep questionnaires were used to assess subjective sleep metrics. Although polysomnography (PSG) is the gold standard and may have provided more accurate data, its use was not practical nor feasible due to the constraints of not changing sleep environments, the number of participants involved, and the need to maintain ecological validity within this thesis. Therefore, it was not feasible to use within the thesis.
- Consideration for confounding variables: It must be noted that it was not possible to account for all confounding variables that would be present within the observational studies, it was not possible to control for differences in training loads, training schedules, or external factors such as work commitments. This was due to collecting data from a large number of athletes across different levels, locations, and teams. Furthermore, given the applied nature of the thesis and the elite environments in which it was conducted, several studies were designed to minimise disruption to athletes, teams, and individual schedules. In some instances, this also meant that training compliance outside the club environment, as well as other factors influencing physical performance and recovery, could not be enforced.

- Physical testing: Physical testing was conducted in line with standard practices in professional Rugby Union environments and, at times, could not be adapted to better suit research purposes. For example, outdoor tests such as the Bronco shuttle test were subject to uncontrollable environmental conditions. Furthermore, the choices of tests were at time limited to those already present within the environment as adding additional test would add greater burden on the players.
- With specific regards to Study Three it is important to note that whilst the is a link with increased sleep duration and improvements in physical attributes we advise caution around interpretation of these findings as the findings do not equate to causation. Indeed, an intervention study would need to be conducted to be able to confirm cause and affect between the two variables.

Future Research Directions

Based on the outcomes, findings, and results presented in this thesis, a range of future research avenues are warranted. In particular, further work should explore strategies to improve sleep in elite Rugby Union athletes, with the aim of enhancing recovery, physical performance, and training adaptations.

- Future research should be focused around the impacts of implementing specific sleep hygiene education and the impacts upon different levels of competition in Rugby Union athletes for example. sleep hygiene strategies, particularly the effects of optimising the sleep environment (e.g., light, temperature, noise) and reducing pre-bedtime screen exposure
- Further investigation into should be done within the area of subjective sleep in Rugby union athletes. The research should delve further into differences between athletes with sub-group analysis such as sleep behaviours of parents vs non-parents.
- A valuable extension of the current work would be a controlled interventional study manipulating sleep duration across a full pre-season. Such a design could establish causal relationships between different levels of sleep (e.g., habitual vs. extended) and changes in key performance markers such as strength, speed, and recovery capacity.
- Understanding individual variation in sleep needs and circadian rhythms is critical for tailoring training and recovery schedules. Future studies should account for factors such as athlete chronotype, travel schedules, and morning vs. evening training preferences to assess how biological timing influences sleep quality and subsequent performance.

- Sleep banking in the lead up to heavy training or competition phases is another area of interest as there are examples from other contexts such as shift work, that has showed promise.
- Another important area for exploration is the bidirectional relationship between recovery strategies and sleep. Interventions such as breathwork, mindfulness, or other parasympathetic-stimulating techniques may improve sleep onset and quality. Investigating the physiological mechanisms linking these modalities to sleep improvements could help optimise recovery protocols in high-performance settings.
- Although acute napping has demonstrated short-term performance benefits, the long-term effects of habitual daytime napping remain unclear. Future research should examine whether regular napping contributes to cumulative performance gains or adaptation effects in elite athletes.
- Specific and individualised timing and duration of napping strategies on game and training days, along with the consideration of player preferences, should also be investigated to inform optimal outcomes. Further to this, the incidence of daytime napping when matches are played during the day requires investigation to see if the prevalence reduces due to there being less time from waking and the start of the match.

Closing Remarks

The series of studies presented in this thesis provide a better understanding of habitual and acute sleep behaviours influencing readiness, performance and recovery in elite Rugby union athletes. Whilst it was evident that Rugby Union athletes experience poor sleep habits and behaviours, they are also exposed to numerous factors such as muscle damage, night-time games, stress from media scrutiny, and inter-time zone travel that can affect sleep. It was evident that gaining increased sleep, maintaining a sleep routine, and implementing daytime napping can improve physical performance and nighttime sleep quality and afternoon physical performance in Rugby Union athletes. Results from this thesis increase our understanding of sleep and physical performance in elite Rugby Union athletes in both training and competition environments. The novel work disseminated through six published journal articles highlight the importance of sleep on physical performance, adaptation and recovery and demonstrate that sleep should be given greater emphasis within elite Rugby Union and collision team sport environments.

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APPENDICES

Appendix A: Co-authorship Forms from Chapter Three to Chapter Eight

THE UNIVERSITY OF WAIKATO
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Co-Authorship Form

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Chapter Three - Teece AR, Beaven, C. M., Argus, C. K., Gill, N. D; Driller, M. W. (2023). Characterization of differences in sleep behaviors between academy, semi-professional and professional levels of competition in rugby union athletes. International Journal of Sports Science & Coaching, 18(6), 2091-2096. https://doi.org/10.1177/17479541221127516

Nature of contribution by PhD candidate	Research conceptualisation, development of study design, data collection and analysis, manuscript preparation and journal submission
Extent of contribution by PhD candidate (%)	80%

CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervised the research process, feedback on data analysis and drafting of paper prior to submission and publishing
Martyn Beaven	Provided feedback on the research process, feedback on drafting of paper and reviewed prior to publication
Christos Argus	Supervised research process, supported data collection, feedback on drafting of paper and reviewed prior to publication
Nicholas Gill	Provded feedback on drafting of paper and reviewed prior to publication

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- that the candidate wrote all or the majority of the text.

Name	Signature	Date
Matthew Driller	[illegible]	10/9/25
Martyn Beaven	[illegible]	9/9/25
Christos Argus	CArgus	10/9/25
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Chapter 4 - Teece AR, Beaven, C. M., Argus, C. K., Gill, N., & Driller, M. W. (2023). Comparing perceived sleep quality, practices, and behaviors of male and female elite Rugby Union athletes with the use of sleep questionnaires. Sleep Science, 16(3), e271-e277. https://doi.org/10.1055/s-0043-1772788

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Chapter 5 - Teece, AR, Argus, C. K., Gill, N. D., Beaven, C. M., Dunican, I. C., & Driller, M. W. (2021). Sleep and performance during a preseason in elite Rugby Union athletes. International Journal of Environmental Research & Public Health, 18(9), 4612. https://doi.org/10.3390/ijerph18094612.

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Chapter 6 - Teece AR, Beaven, C. M., Suppiah, H., Argus, C. K., Gill, N., & Driller, M. (2024). Routine, routine, routine: Sleep regularity and its association with sleep metrics in professional rugby union athletes. Sports Medicine - Open, 10(51). https://doi.org/10.1186/s40798-024-00709-5

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Teece, A.R, Beaven, C. M., Gill, N., & Driller, M. (2023). Daytime naps improve afternoon power and perceptual measures in elite rugby union athletes. Sleep, 46(12), zsad133. https://doi.org/10.1093/sleep/zsad133

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