Uncovering the influence of sleep in recovery, training and team-sport competition

by

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DOCTORATE OF PHILOSOPHY

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ABSTRACT

There is an emerging consensus that sleep is an important part of the post-exercise recovery process for athletes. Evidence suggests that a lack of sleep, or sleep of poor quality, can negatively influence markers of physical, physiological, and perceptual recovery that may impact the subsequent training and performance outcomes of athletes. Moreover, recent findings suggest that increasing total sleep time can improve performance, yet comprehensive evidence is lacking. This has seen an increased focus on the investigation of the sleep behaviours of athlete populations; however, this research often does not consider many important contextual factors, such as the physical sleep environment, competition factors including location, travel and timing, and training-related factors like periodisation and training load exposure. Furthermore, little is known about the physical and physiological influences of sleep on the post-exercise recovery process, and information regarding the amount of sleep that is required to maximise recovery and athletic performance is lacking.

The aim of the first study in this thesis was to investigate the influence of physical sleep environment during a pre-season training camp on the sleep behaviours of professional Australian Rules footballers. The results of Study 1 (Chapter 4) describe the sleep behaviours of professional Australian Rules footballers between the home environment and a pre-season camp environment, both during the pre-season training period. Australian Rules footballers went to bed and woke earlier when on camp, spending longer in bed without a significant increase in sleep duration, caused by significantly increased wake after sleep onset. Relative changes to time in bed and wake after sleep onset on camp had a strong negative correlation with absolute home values, suggesting those who spend longer time in bed at home are more likely to experience reduced time in bed in the camp environment. Although there was no significant change in total session rating of perceived exertion (s-RPE) training load, when accounting for daily variations of within-player s-RPE load, both increased and decreased s-RPE load had weak correlations with changes in total sleep time in the home environment. Comparatively, in the camp environment, decreases in s-RPE load displayed a moderate positive relationship with total sleep time, whereas increases in s-RPE load displayed moderate negative correlation with total sleep time. However, daily ambient temperature was ~5°C hotter during the camp environment, compared to the normal home environment, which may have

influenced results. A change in physical sleep environment, without external influences such as circadian phase-shifting, altered training schedules or increased total training load reduces the quality of sleep and effects the attainment of increased duration of sleep, despite spending longer periods of time in bed. Furthermore, the individual variation in response to a change in environment stresses the importance of assessing sleep on a case-by-case basis, especially if assessment leads to the provision of interventions designed at improving the sleep of athletes during time spent in unfamiliar physical sleeping environments.

The aim of the second study in this thesis was to investigate the role that individual contextual factors (age and chronotype) and environmental factors (competitive matches, competition level, and competition location) have on the sleep behaviours across the pre-season and in-season periods in professional Australian Rules footballers. Study 2 (Chapter 5) found that the individual-specific factor chronotype influences the sleep behaviours of Australian Rules footballers. Furthermore, players went to bed and woke later, resulting in increased time in bed and total sleep time, during the in-season compared to the pre-season. On the night before a match, and the two nights following a match, players spent longer in bed and obtained more sleep compared to the pre-season. In contrast, on match nights players spent less time in bed and obtained less sleep, compared to the night before and the two nights following a match; but obtained similar sleep durations on match nights to during the pre-season. No differences in sleep behaviours were observed between matches played at home or away; however, time in bed and sleep duration were reduced following National-level competition, compared to State-level competition. Collectively, these results suggest that individual chronotype needs to be considered in the evaluation of athlete sleep behaviours, and that sleep behaviours vary between season phases, nights surrounding competition, and between competitive levels.

The aim of the third study in this thesis was to determine the influence of changes in load variables during both the pre-season and in-season across 1-, 7-, 14-, 21- and 28-day periods and their relationships with objectively measured sleep behaviours in Australian Rules footballers. Study 3 (Chapter 6) found that same-day increases in volume (total distance and s-RPE) and intensity (relative total distance, high-speed running and very high-speed running) have negative associations with sleep behaviours during both the pre-season and in-season. Cumulative 7-day loads during the pre-season have minimal associations with sleep behaviours, whereas sleep duration was negatively associated with higher 7-day cumulative loads during the in-season period. Increased load measures detrimentally influence sleep behaviours over 14-day, 21-day and 28-day cumulative periods during the in-season. These results suggest that heightened short- and long-term exposure to increased loads have a negative effect on the sleep behaviours of Australian Rules footballers. Therefore, consideration of both the acute and cumulative demands of training and competition should be made in the context of monitoring of Australian Rules footballers sleep.

The aim of the fourth study in this thesis was to determine the effect of a single night of sleep extension on physiological, physical, and perceptual recovery. Study 4 (Chapter 7) found that whilst the novel high-intensity intermittent exercise session induced similar post-exercise responses to that of team-sport competition, a single night of increased sleep duration (sleep extension) did not influence markers of neuromuscular, autonomic, perceptual, and hormonal function and status on the morning following a session of high-intensity interval exercise under laboratory-controlled conditions. Longer periods of sleep-intervention may be required to have a beneficial effect on markers of recovery and function following exercise.

Finally, the aim of the fifth study in this thesis was to determine the effects of multiple days of post-exercise sleep extension (where a total of 10 h per day for 3 days was obtained) on the status of physiological, physical, and perceptual recovery and physical performance. Study 5 (Chapter 8) found that 2-hour afternoon naps (following 8 h of sleep each night) improves the recovery rate of neuromuscular function. Furthermore, both overnight sleep extension (10 h) and afternoon naps improved the recovery of sprint performance following a session of high-intensity interval eercise that was followed by a night comprised of a 6-hour sleep. Overnight sleep extension appears to enhance recovery of perceptual wellbeing measures after, compared to afternoon naps. These results suggest that both overnight extension and afternoon naps have a postive influence on post-exercise recovery. However, caution should be exercised, as afternoon naps may increase sleep onset latency and wake after sleep onset, and reduce sleep efficiency of subsequent night sleep when performed on consecutive days.

STUDENT DECLARATION

I, Nathan Wylie Pitchford, declare that the PhD thesis entitled "Uncovering the influence of sleep in recovery, training and team-sport competition" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: 16/02/2019

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"Run in to the fire"

Luke Beveridge, Head Coach – Western Bulldogs

This experience has been rewarding beyond my expectations, and wildest dreams. It has been so rewarding, not only for the experiences and achievements, but for the skills and self-belief it has given me to know that anything is possible. The PhD process is not an easy one, and I would not have completed it without help from a range of people.

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ABBREVIATIONS

TST = total sleep time

TIB = time in bed

WASO = wake after sleep onset

SEF = sleep efficiency

SOL = sleep onset latency

SF = sleep fragmentation

SCN = Suprachiasmatic nucleus

PSG = polysomnography

EEG = electroencephalography

ECG = electrocardiography

EOG = electrooculography

EMG = electromyography

REM = rapid eye movement

nREM = non-rapid eye movement

MEQ = Morningness-Eveningness Questionnaire

POMS = profile of mood states

EXT = sleep extension

NAP = nap

BL = baseline

CON = control

SR = sleep restriction

DEP = sleep deprivation

PS = pre-season

IS = in-season

ARF = Australian Rules football

AFL = Australian Football League

VFL = Victorian Football League

NRL = National Rugby League

N = night

MN-1 = night before a match

MN = match night

R1 = one night after a match

R2 = second night after a match

$\dot{V}O_2max$ = maximal volume of oxygen consumption

$v\dot{V}O_2max$ = velocity at maximal volume of oxygen consumption

TD = total distance

$m \cdot min^{-1}$ = meters per minute

HSR = high-speed running

VHSR = very high-speed running

RPE = rating of percieved exertion

s-RPE = session-RPE

CWI = cold-water immersion

PkTq = peak torque

MVC = maximal voluntary contraction

VA = voluntary activation

CMJ = countermovement jump

ConcTime = concentric time

NMF = neuromuscular function

YoYo IR1 = YoYo Intermittment Recovery Test Level One

HIIE = high-intensity interval exercise

HR = heart-rate

RHR =resting heart-rate

HRV = heart-rate variability

HRex = maximum heart-rate during exercise

HRr = heart-rate recovery

CHO = carbohydrate

PRO = protein

GH = growth hormone

GHRH = growth hormone releasing hormone

IGF-1 = insulin-like growth factor-1

IL-6 = interleukin-6

h:mm = time in hours and minutes

hh:mm = time of day in hours and minutes

UTC = Coordinated Universal Time

bpm = beats per minute

y = years

h = hours

min = minutes

s = seconds

ms = milliseconds

km = kilometres

m = metres

cm = centimetres

mm = millimetres

$km \cdot h^{-1}$ = kilometers per hour

$m \cdot s^{-1}$ = metres per second

$mL \cdot kg^{-1}$ = millimetres per kilogram

Nm = Newton metres

AU = arbituary units

°C = degrees Celcius

RH = relative humidity

% = percentage

SD = standard deviation

TEE = typical error of the estimate

ANOVA = analysis of variance

p = probability of statistical significance

r = correlation coefficient

d = Cohen's effect size

CI = confidence interval

< = less than

> = greater than

PUBLICATIONS

The following work has been presented at scientific meetings and/or published in peer-reviewed journals in support of this thesis:

1. **Pitchford NW**, Robertson SJ, Sargent C, Cordy J, Bishop DJ, Bartlett JD. “A change in training environment alters sleep quality but not quantity in elite Australian Rules football players.” *International Journal of Sports Physiology and Performance*; 2017; 12(1):75-80. This work was also presented as an Oral Presentation at Sports Medicine Australia Conference, Queensland Australia 2015. “A pre-season training camp alters sleep behaviour and quality but not quantity in elite Australian Rules football players.”
2. Bartlett JD, Thornton HR, Fullagar HHK & **Pitchford NW**. “A Comparison of Sleep Characteristics During Weekly In-Season Competition vs Pre-Season Training in Australian Rules Footballers.” This work was presented as an Oral Presentation at the 21st Annual Congress of the European College of Sport Science, Vienna Austria 2016.
3. Oral Presentation – **Pitchford NW**, Bishop DJ, Robertson SJ, Thornton HR & Bartlett JD. " Training load and sleep: The importance of monitoring in team-sport athletes." This work was presented as an Oral Presentation given at the Smartabase Users Conference, Queensland Australia 2017.
4. Oral Presentation – **Pitchford NW**, Bishop DJ & Bartlett JD. " Resting to Recover: Influence of sleep extension on recovery following high-intensity exercise." This work was presented as an Oral Presentation at the 22nd Annual Congress of the European College of Sport Science, Essen Germany 2017.
5. Poster Presentation – Lee M, Bishop DJ, Bartlett JD & **Pitchford NW**. "Does more sleep enhance recovery? Influence of post-exercise sleep extension on physiological, neuromuscular, and perceptual recovery." This work was presented as a Poster at the Exercise and Sport Science Australia – Research to Practice Conference, Brisbane, Australia 2018.

PUBLICATIONS ARISING DURING CANDIDATURE

The following outputs have been presented at scientific meetings and/or completed during the PhD, but are outside the scope of this thesis:

Journal Publications:

1. Onay Z, Vincent G, Scanlan A, Elsworthy N, **Pitchford NW** & Lastella M. "Wakeup call: a review of the current literature on sleep and decision making in sporting officials." *Clocks & Sleep*; Under Review.
2. Lee NA, Fell JF, **Pitchford NW**, Hall AH, Leveritt MD & Kitic CM. "Combined carbohydrate and protein ingestion during Australian Rules football matches and training does not reduce fatigue or accelerate recovery throughout a week-long tournament." *Journal of Strength and Conditioning Research*; 2018; 32(2): 344-355.
3. Juhari F, Ritchie D, O'Connor F, **Pitchford NW**, Weston M, Thornton HR & Bartlett JD. "The quantification of within week session duration, intensity and distribution across a season in Australian Football." *International Journal of Sports Physiology and Performance*; 2017; 13(7): 940-946.
4. Bartlett JD, O'Connor F, **Pitchford NW**, Torres-Ronda L & Robertson SJ. "Relationships between internal and external training load in team sport athletes: Evidence for an individualised approach." *International Journal of Sports Physiology and Performance*; 2017; 12(2): 230-234.
5. Thornton HR, Duthie GM, **Pitchford NW**, Delaney JA, Benton DT & Dascombe BJ. "Effects of a 2-Week High-Intensity Training Camp on Sleep Activity of Professional Rugby League Athletes." *International Journal of Sport Physiology and Performance*; 2017; 12(7): 928-933.

Conference Proceedings and Thesis Contributions:

6. Oral Presentation – **Pitchford NW**, Kitic CM, Vincent G & Lastella M. "Sleep characteristics and behaviours in amateur football referees." Submitted for Oral Presentation at the World Congress of Science in Football, Melbourne, Australia 2019.
7. Oral Presentation – **Pitchford NW**, Kitic CM, Vincent G & Lastella M. "Differences between training and match activity profiles of amateur football referees." Submitted for Oral Presentation at the World Congress of Science in Football, Melbourne, Australia 2019.

8. Honours Thesis – Sadri A, supervised by Petersen A, co-supervised by Bartlett JD & **Pitchford NW**. "Effect of Resistance Training in the Heat on Sleep." Accepted to the Bachelor of Applied Science (Honours) – Human Movement, Victoria University, Australia 2018.
9. Poster Presentation – Whelan GA, Karageorgiou J, Bahnisch J, **Pitchford NW**, Kitic CM & Fell JW "Reducing the Impact of Time Zone Changes on Disturbed Sleep and Game Performance." Australian Strength and Conditioning Association – National Conference, Melbourne, Australia 2016.
10. Poster Presentation – Thornton HR, Duthie GM, **Pitchford NW**, Delaney JA, Benton DT & Dascombe BJ "Influence of Acute Training Demands on Sleep During a Rugby League Training Camp." Australian Strength and Conditioning Association – National Conference, Melbourne, Australia 2016.
11. Poster Presentation – **Pitchford NW** & Bartlett JD "Impact of Being a First-Year Draftee on Training Load, Wellness and Sleep in Elite Australian Rules Football." Exercise and Sport Science Australia – Research to Practice Conference, Melbourne, Australia 2016.

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CHAPTER 1 – INTRODUCTION

Relationships between sleep and exercise have long been a topic of interest in sport science and psychology (Baekeland and Lasky, 1966; Martin, 1981; Martin and Gaddis, 1981; Martin and Haney, 1982; Martin and Chen, 1984; Martin, 1986; Martin et al., 1986; Martin, 1988). This interest has developed the knowledge that sleep loss leads to impaired health, wellbeing, and both cognitive and physical performance outcomes, which may impair athletic performance and recovery (Knutson et al., 2007; Leproult et al., 2014; Mougin et al., 1991; Patel, 2009; Walker, 2008). Total sleep deprivation (DEP) impairs both sprint and endurance performance, and leads to impaired neuromuscular function and muscle force production (Souissi et al., 2003; Skein et al., 2013; Skein et al., 2011). However, exposure to reduced sleep durations compared to habitual amounts, more commonly known as sleep restriction, is more relevant as athletes are unlikley to experience complete sleep deprivation, given the importance athletes place on sleep (Venter, 2014). Reducing sleep duration to 3 h and 4 h, compared to 7 h, alters the physiological responses and impairs force and power production during exercise (Mougin et al., 1991; Souissi et al., 2008; Souissi et al., 2013). Sleep restriction may also result in a loss of muscle mass and dysregulation of inflammatory, hormonal, immunological functions and sympathetic nervous system activity (Spiegel et al., 1999; Nedeltcheva et al., 2010; Obal and Krueger, 2004; Santos et al., 2007; Vgontzas et al., 2004), which may negatively effect post-exercise recovery. Given that athletes have been observed to display worse sleep quality than non-athletic populations (Leeder et al., 2012), investigation of sleep behaviours are of high relevance to athlete populations, to ensure that not only are athletic performance and recovery enhanced, but health and wellbeing too.

Athletes have high recovery requirements, due to the demanding nature of both training and competition, forms of high-intensity intermittent exercise (HIIE), which have similar effects on markers of physical and physiological function to that of sleep loss. High-intensity exercise impairs immune function, increases inflammatory signalling and causes muscle damage (Croft et al., 2009; Fragala et al., 2015; Nieman, 1997; Neubauer et al., 2014), whilst also leading to impairments of neuromuscular function, muscle force production and autonomic nervous system function (Bailey et al., 2007; Rowell et al., 2016; Skein et al., 2013; Thorlund et al., 2008; Johnston et al., 2013; Plews et al., 2013; Thorpe et al., 2015; Buchheit et al., 2015; Buchheit et al., 2013b). High-intensity exercise also impairs subjective ratings of perceived wellness and the perceived effort of completing a subsequent bout of submaximal exercise

(Saw et al., 2015; Mann et al., 2015), as well as increased ratings of perceived muscle soreness and fatigue (McLean et al., 2010; Bailey et al., 2007). However, unlike the transient nature of impairments in markers of recovery following single exposures to reduced sleep durations, impaired physical and physiological functions can be observed from immediately after to 96 hours following HIIE (Bailey et al., 2007; Rowell et al., 2016; Skein et al., 2013; Thorlund et al., 2008; Johnston et al., 2013; McLean et al., 2010; Neubauer et al., 2014). Sleep loss following HIIE may have substantial effect on post-exercise recovery status; therefore, efforts to prevent an additive effect of these factors is warranted in team-sport athletes. The role that sleep plays as a potential method to facilitate post-exercise recovery will be addressed in this thesis.

Team-sport athletes, specifically Australian Rules footballers, compete in matches that are characterised by submaximal activity interspersed with sprinting, agility demands and physical contact that result in substantial physical loads (Coutts et al., 2010; Kempton et al., 2014). To meet the speed, strength and power, agility, and aerobic fitness demands of matches (Reilly and Gilbourne, 2003), team-sport athletes undertake extensive training that mimics or exceeds the match demands, and varies in a cyclic periodised manner, both within and between the pre-season training and in-season competition phases (Ritchie et al., 2016). The training and load demands placed upon athletes, in both the volume and intensity domains, can have a substantial influence on sleep. Increased daily training intensity increases sleep duration and sleep efficiency in rugby league players (Thornton et al., 2017a), whereas increased training intensity leads to improved sleep efficiency when summated across the preceding 3-day and 7-day periods (Thornton et al., 2017a). Increased training volume averaged across 6- to 21-day periods lead to reduced average sleep duration, efficiency and quality (Jürimäe et al., 2002; Jürimäe et al., 2004; Thornton et al., 2017b; Hausswirth et al., 2014). However, investigations typicaly only include data from the pre-season training period, present mean training and sleep behaviour data, and restrict calculations of cumulative load demands to a maximum of 7 days. Hence, further research is required to elucidate how day-to-day or cumulative changes in load effect daily sleep behaviours. Therefore, to address recent calls for greater understanding of the role that load has on sleep behaviours in athletes (Watson, 2017), this thesis will expand on further work by investigating the role that load plays across periods form 1-day to 28-days in length on the sleep behaviours of team-sport athletes during both the pre-season and in-season phases.

Athletes rate sleep as the most important recovery modality available (Venter, 2014). However, athletes also experience both individual- and environment-specific factors that may reduce sleep quality and quantity, leading to disadvantageous training and performance outcomes. Individual-specific factors such as age and chronotype, can influence both the sleep and performance outcomes of athletes. In general, athletes display a greater propensity for morning-type and intermediate-type chronotypes than evening-type chronotypes compared to non-athletic populations (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016) and team-sport athletes display a greater proportion of later chronotypes compared to individual sports (Lastella et al., 2016). Furthermore, older athletes display a shift from later evening-type chronotypes during adolescents towards earlier morning-type chronotypes with age (Adan et al., 2012; Hagenauer and Lee, 2012), which has been observed as shifts to earlier bed times, sleep onset times, and wake times in older athletes, compared to their younger counterparts (Caia et al., 2017a). Despite knowledge on the effects of age and chronotype in both non-athletic and athletic populations (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016; Adan et al., 2012), these factors are rarely considered in the evaluation of athlete sleep behaviours, which will be addressed in this thesis.

Environment-specific factors also influence the sleep behaviours of athletes. Scheduling restrictions, such as early-morning training or recovery commitments reduce sleep opportunity and subsequent sleep duration in athletes (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b). Athletes sleep less on nights prior to training days compared to rest days (Sargent et al., 2014b; Sargent et al., 2014a; Kölling et al., 2016), and sleep more on weekends than weekdays, due to altered training commitments (Dumortier et al., 2018). Investigations have also shown that sleep duration is reduced on the night of competition in Australian Rules football, soccer, and rugby players (Lalor et al., 2017; Richmond et al., 2004; Shearer et al., 2015), which may impair recovery and subsequent physical performance (Oliver et al., 2009; Souissi et al., 2013; Souissi et al., 2008; Fowler et al., 2015). However, studies have been done in the presence of next-day early-morning training or recovery commitments (Lalor et al., 2017; Caia et al., 2017b) or when athletes were required to travel recently before (Fowler et al., 2015) immediately following matches (Richmond et al., 2004), which influences the interpretation of athlete sleep behaviours (Richmond et al., 2004). Although Caia et al. (2017a) showed that elite-level rugby league players displayed less intra-individual variation and greater sleep durations, compared to their sub-elite counterparts, environment-specific factors relating to competitive level have received limited attention. Hence, this thesis will investigate the influence of competitive level on the sleep behaviours of Australian Rules footballers.

Improving sleep duration and quality is the aim for most sleep interventions and attempts to improve the sleep-related behaviours, better known as sleep hygiene, and subsequent sleep duration and quality of athletes are promising. Following sleep hygiene guidelines, such as the removal of electronic devices, avoiding excessive light exposure 30 min prior to bed, and sleeping in a cool and quiet environment, leads to improved sleep duration (Caia et al., 2018a; Duffield et al., 2014; O'Donnell and Driller, 2017; Fullagar et al., 2016a), but not physical performance or recovery following soccer competition (Fullagar et al., 2016a). However, whilst these improvements appear to be effective over short periods of time, they appear to be transient in nature (Caia et al., 2018a; O'Donnell and Driller, 2017). Therefore, deliberate attempts to increase sleep duration through increased time in bed may also be advantageous. Increasing time in bed, or sleep extension, by 1.5 to 2 h reduces perceive exertion during exercise, improves mood states, benefits physiological function, and improves physical performance indicators such as reaction times, sprint performance and skill execution (Arnal et al., 2016; Mah et al., 2011; Dement, 2005; Famodu et al., 2017; Horne et al., 2008; Leproult et al., 2014; Schwartz and Simon, 2015). Opportunities for increased night-time sleep duration, however, may be limited.

Naps may serve as a suitable intervention to increase total daily sleep duration and provide a more practical solution for those who cannot obtain increased overnight sleep. Napping for 20 min to 2 h reduces feelings of daytime sleepiness, and improves reaction times neuromuscular function (Dinges et al., 1987; O’Donnell et al., 2018). Furthermore, implementing naps following a night of sleep loss is of particular relevance to team-sport athletes who suffer reduced sleep following matches (Fullagar et al., 2016b; Richmond et al., 2004). Indeed, following overnight sleep restricted to durations of 2 to 4 h in bed, a short 20 to 30 min nap can improve sprint performance and neuromuscular function, and attenuate the sleep restriction-induced increases in inflammation (Waterhouse et al., 2007; Faraut et al., 2015; O’Donnell et al., 2018). Overall, both overnight sleep extension and naps improve physical performance and function; however, their effects in the context of post-exercise recovery are unknown. As team-sport athletes experience reduced sleep following matches (Fullagar et al., 2016b; Richmond et al., 2004), which also lead to impaired physical and physiological function (Bailey et al., 2007; Rowell et al., 2016; Skein et al., 2013; Thorlund et al., 2008; Johnston et al., 2013; McLean et al., 2010; Neubauer et al., 2014); sleep extension, either by night or by nap, presents as a viable option to aid post-exercise recovery.

This thesis will provide additional information pertaining to the sleep behaviours of Australian Rules footballers and investigate the influence that sleep extension has on markers of recovery following high-intensity interval exercise, similar to that of team-sport competition. Specifically, this thesis will consider both individual- and environmental-specific contextual factors that are likely to influence the sleep behaviours of team-sport athletes and how they vary across the pre-season and in-season phases. The accompanying investigations of sleep extension in this thesis will supplement the studies in Australian Rules footballers by providing information regarding the efficacy of sleep increasing interventions, using both overnight extension and using afternoon naps, which are applicable for professional athletes who may experience sleep loss.

CHAPTER 2 – REVIEW OF LITERATURE.

2.1 Sleep

Sleep is a functional state, defined as an altered state of consciousness and altered behaviour, reduced movement, and limited sensory responses, in a reoccurring 24-hour pattern (Walters, 2002; Gordijn and Beersma, 2007). Although complete agreement regarding the purpose of sleep has not been reached, the over-arching benefits of sleep are its ability to restore the body and brain following a period of wake, and to subsequently facilitate adaptation to the stresses placed on those structures during the preceding wakefulness (Gordijn and Beersma, 2007). Restoration of the body can be seen in the natural peak of growth hormone secretion and protein synthesis during periods of sleep (Van Cauter and Copinschi, 2000); brain restoration and functional improvements are indicated by improvements in memory, learning, motor skill development, as well as the maintenance of mood states, during sleep (Curcio et al., 2006). Adequate sleep duration, or at least the avoidance of a short sleep duration (i.e. < 4 h a night), has also been shown to maintain key metabolic and hormonal functions that reduce the risk of chronic disease states such as diabetes mellitus and cardiovascular disease (Anothaisintawee et al., 2016; Chontong et al., 2016; Meier-Ewert et al., 2004). Together, sleep plays a key role in the operation, maintenance, and development of a range of key processes and functions relevant to physical and mental function, performance, and recovery.

According to the two-process model of sleep regulation, sleep is controlled by the interaction between homeostatic (process S) and circadian (process C) processes (Borb and Achermann, 1999), which have important interactions with environmental factors (Stiller and Postolache, 2005). Process S refers to the gradual accumulation of sleep pressure during wakefulness, which is subsequently dissipated during sleep (Borbély, 1982), whereas Process C is indicative of a rhythmic nature of sleep propensity, that rises and falls throughout the 24-hour day, as well as the cyclic distribution of sleep stages during the sleep period (Borbély, 1982). The circadian nature of sleep propensity is synchronised with changes in body temperature and hormonal secretions, which are heavily influenced by environmental light exposure and ambient temperature changes (Adan et al., 2012). These processes and influencers are managed by a structure within the brain called the suprachiasmatic nucleus (SCN; Schibler and Sassone-Corsi (2002).

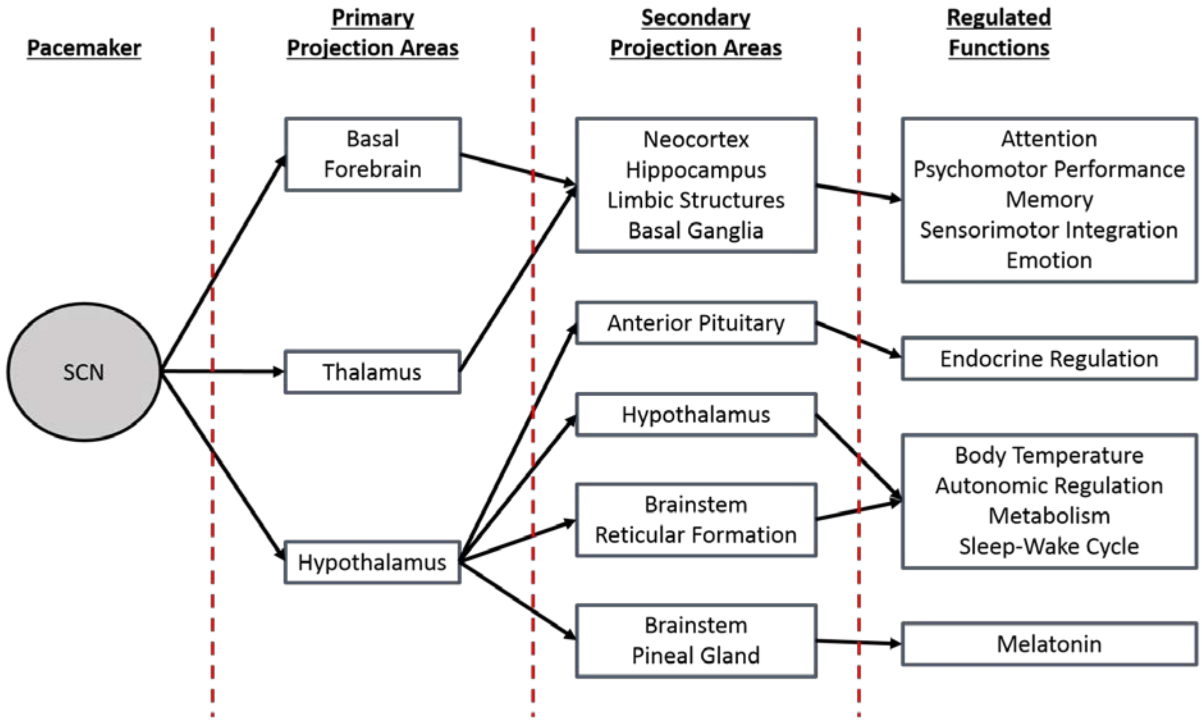


Figure 2.1. Regulatory process of sleep and the functional impact the control areas have. Recreated from Stiller and Postolache (2005)

Sleep can be broken down into two distinct types: non-rapid eye movement (nREM) and rapid eye movement (REM) sleep (Lee-Chiong, 2006). Each sleep episode itself is composed of repeated cycles lasting ~90 min, each starting with stage 1 nREM sleep and progressing through to REM sleep (Lee-Chiong, 2006). nREM sleep is further classified into three distinct sleep stages of progressive "depth" and serves to regulate metabolic functions and to aid physical recuperation (Dattilo et al., 2011; Lastella et al., 2014c). Upon rest, humans first progress to stage 1 nREM sleep, which last ~10 min, where humans are still responsive to the external environment and easily aroused (Walters, 2002). Flowing into stage 2 nREM sleep, humans become much less responsive to light and noise stimuli and display much more restful behaviours (Walters, 2002). Stage 3 nREM sleep then follows, which is more commonly referred to as slow-wave sleep (SWS) or deep sleep. This stage plays a critical role in hormonal regulation, and in particular the release of growth hormone (GH); 50% of daily GH secretion occurs during the first half of the sleep period (Van Cauter and Copinschi, 2000; Gronfier et al., 1996). Following SWS, the sleep cycle drops briefly back in to stage 2 nREM sleep, before then progressing to REM sleep. REM sleep has many important roles in the maintenance of human function, including, but not limited to, cognitive function, decision making, reaction times, and the learning of newly acquired information (Karni et al., 1994). REM sleep is also the stage where most dreams occur (Flanagan, 2001). As the sleep period continues, the proportion of SWS decreases and REM sleep increases, which can vary depending on sleep-related behaviours and environmental factors (Buguet, 2007; Libert et al., 1988; Sexton-Radek and Hartley, 2013), which have important implications for post-sleep cognitive and physiological status and performance. An overview of the sleep process can be seen in Figure 2.2.

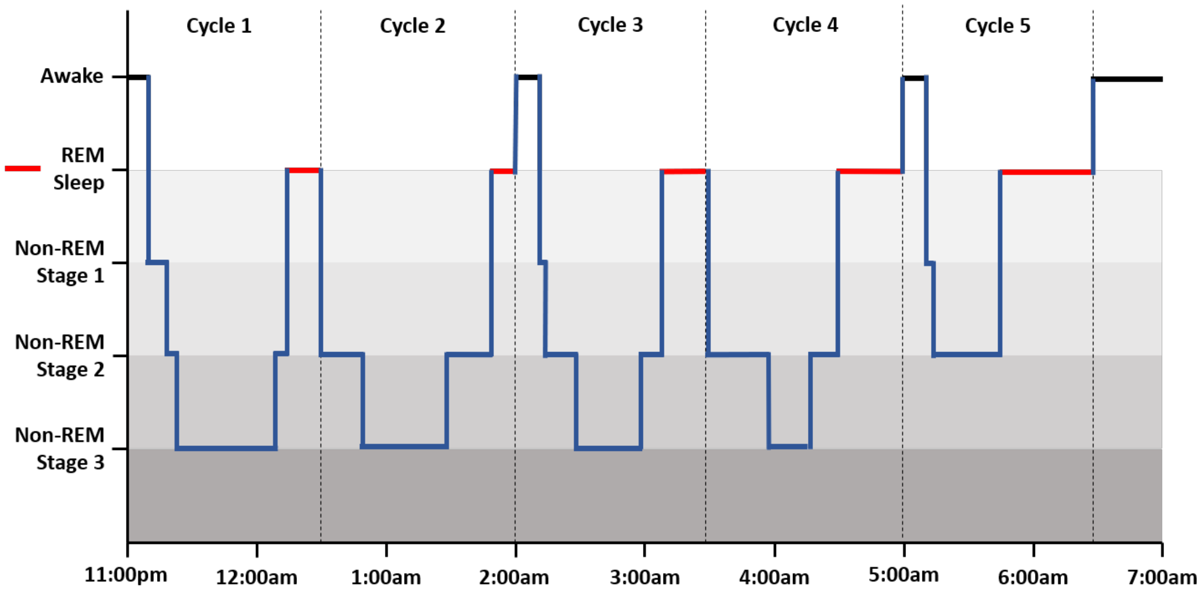


Figure 2.2. Schematic representation of the cyclic pattern of sleep stages during the nocturnal sleep bout. Recreated from Carskadon and Dement (2005).

Sleep quantity and quality can be measured using both objective and subjective measures. Sleep quantity is measured as total sleep time (TST) and time spent in bed (TIB), whereas sleep quality is often determined by factors such as sleep onset latency (SOL, time to sleep onset), wake after sleep onset (WASO, product of both the number and length of awakenings during sleep), sleep efficiency (SEF, percentage of time in bed spent asleep), and sleep fragmentation (SF, an indexed number representing small arousals and movements during sleep). Sleep is best quantified using the gold-standard of objective sleep measurement - Polysomnography or PSG. Polysomnography, which involves the measurement of electroencephalography (EEG), electrocardiography (ECG), electrooculography (EOG), and electromyography (EMG), is highly accurate, but also obtrusive, and involves specialised equipment and trained staff. Sleep quantity in total, and per sleep stage, is calculated based on the number of epochs (typically 30 s in duration) that are scored as being stage 1, stage 2, SWS and REM sleep, or awake.

Investigation of the sleep behaviours of athletes has grown substantially in recent years (Figure 2.3). To facilitate this, versatile measurement processes have become popular. The lessinvasive actigraphy technique determines sleep or restfulness through the absence of movement using data derived from accelerometers, most commonly attached to the wrist (Leeder et al., 2012), and through the use of mathematical algorithms (Sadeh, 2011). Actigraphy is more practical for both the general population and elite athletes, as it requires minimal training, and can be utilised over extended periods of time (Jean-Louis et al., 1998; Weiss et al., 2010). Actigraphy-based measurement of sleep display high sensitivity (>97 %) and has been validated against PSG (*r* >0.80) (Cole et al., 1992; Mullaney et al., 1980; de Souza et al., 2003), and is listed as a suitable tool for the assessment of sleep over prolonged periods of time by the American Academy of Sleep Medicine (Morgenthaler et al., 2007). Subjective measures of sleep, often taken using a sleep diary for the duration of assessment, are commonly paired with the results from objective measures. Diaries incorporate noting the time of bed and wake time from bed, ratings of pre-sleep arousal levels, presence of awakenings during the night, and an overall rating of sleep quality. When combined, objective and subjective measures allow researchers and practitioners to more accurately quantify sleep quality and quantity (Sadeh, 2011), as well as provide insight into the impact of pre-sleep behaviours on subsequent sleep habits and vice versa.

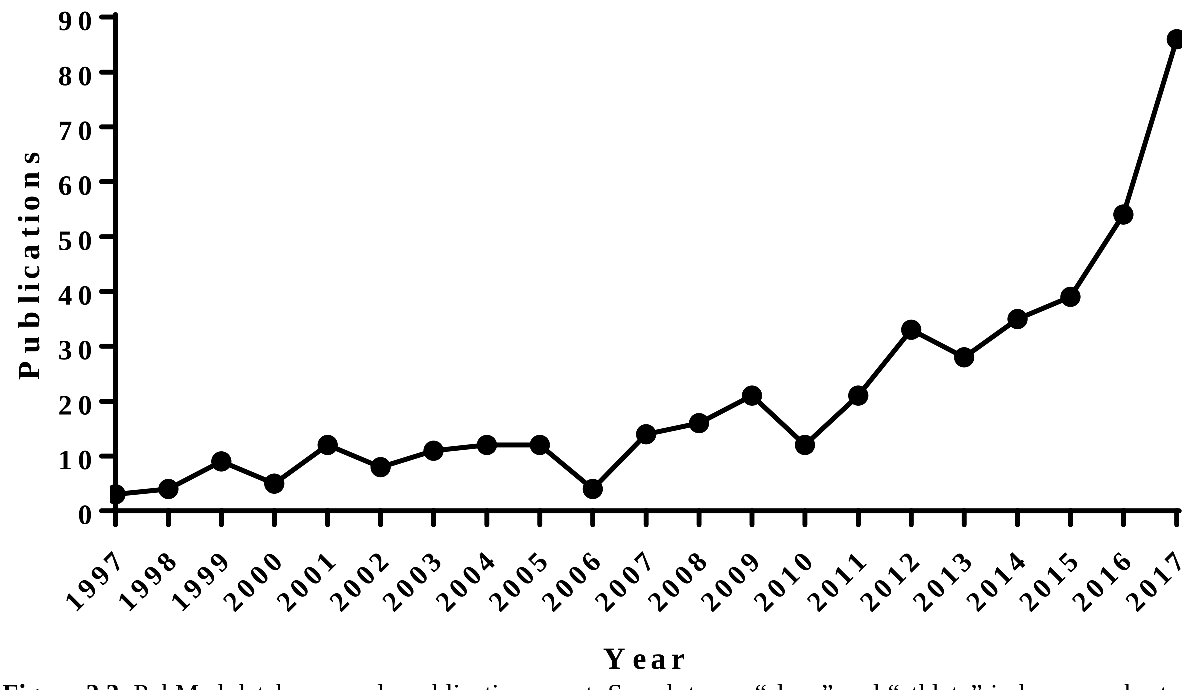


Figure 2.3. PubMed database yearly publication count. Search terms “sleep” and “athlete” in human cohorts in the past 20 years, from 2018.

Professional athletes are also exposed to high physiological demands and cognitive loads to achieve optimal performance in their given sports. Given the clear importance of sleep for human physiological and cognitive function, in this review I will summarise our current understanding of sleep as it relates to athletic populations. Specifically, I will provide a summary of the literature regarding the sleep behaviours of athletes and how sleep is influenced by varying contextual factors specific to athlete populations. The role of sleep for recovery and performance will then be evaluated, before proposing a body of work aimed at improving our understanding of the sleep of athletes, the influence of previously unconsidered contextual factors, and the role that sleep interventions can play in enhancing athlete recovery and performance.

2.2 Sleep in Athletic Populations

Team-sport athletes are often exposed to situations where sleep opportunities can be limited, such as following travel, after night games, during periods of intensified training, or during training camps (Fullagar et al., 2015b; Fullagar et al., 2016b). Lost or poor sleep may negatively influence athlete preparation, performance, and recovery - which may hinder an athlete’s ability to undertake regular quality training sessions and lead to further impairments in performance. Furthermore, the influence of individual (e.g. chronotype, age, sex) and environmental (e.g. training and competition schedules, daily workloads, season phase, sleeping environment) factors may also affect sleep and negatively affect recovery and subsequent performance. Therefore, the vastly different physiological and psychological stresses imposed on athletes, in comparison to non-athletes, may negatively impact on the sleep requirements and behaviours of athletes.

2.2.1 Habitual Sleep of Elite Athletes

Longitudinal analysis suggests that athletes obtain a similar amount of total sleep time compared to non-athletic populations, despite spending more time in bed trying to sleep (Leeder et al., 2012; Halson, 2014; Mah et al., 2011; Sargent et al., 2014b). Although similarities in sleep duration are apparent, sleep quality, efficiency, onset latency, and movements during sleep, have been reported to be worse in athletes compared to non-athletes (Leeder et al., 2012). Differences also exist in sleep behaviours between sports, especially in the comparison of individual and team-sport athletes. Compared to individual-sport athletes, team-sport athletes have significantly shorter sleep onset latency, longer time in bed, longer sleep duration, and less time awake after sleep onset. There is also evidence to support differences in the sleep behaviours of athletes from different team-sport environments. Lastella et al. (2014e) found that Australian Rules footballers spend more time in bed, obtain less sleep, have more time awake after sleep onset, and spend more time moving during sleep, than both individual-sport athletes and team-sports athletes from sports such as basketball, soccer and rugby. However, compared to team-sport athletes, sleep efficiency and subjective sleep quality was lower, and there was a higher prevalence of daytime sleepiness in individual-sport athletes (Antic et al., 2013). The appreciation that team-sport and individual-sport athletes have differing sleep habits and requirements than both each other and non-athletic populations is a crucial step in the development of appropriate investigative methods for sleep and its importance in recovery and performance. Furthermore, the understanding that Australian Rules footballers display different habitual sleep tendencies and training schedules to other team-sport athletes is also important in the understanding and application of sleep-based recommendations and interventions on both a team- and individual-athlete level.

The sleep patterns of elite athletes can also be influenced by fluctuations in contextual factors that are specific to both the individual (e.g. chronotype, age, sex) and the environment they are in (e.g., training and competition schedules, daily workloads, season phase, sleeping environment). Restrictive training schedules, involving early-morning training or recovery commitments, can have a negative effect on sleep opportunity and subsequent sleep duration in athletes (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b). Two studies of elite athletes from several different sports found that athletes go to bed earlier, wake up earlier, spend less time in bed, and obtain less sleep on nights prior to training days compared to rest days (Sargent et al., 2014b; Sargent et al., 2014a). Furthermore, Kölling et al. (2016) found that elite rowers wake up later and obtain more sleep on non-training days and that rowers modified their sleep behaviours depending on the start time of morning training sessions, and elite gymnasts sleep more on weekends than weekdays due to altered training commitments (Dumortier et al., 2018). Previous investigations of the sleep behaviours of team-sport athletes following competition have been done under restrictive conditions involving immediate post-match travel following away matches (Richmond et al., 2004) or in the presence of regular early-morning recovery commitments (Lalor et al., 2017; Caia et al., 2017b). Therefore, evidence suggests that emphasis must be placed on the consideration of how training schedules can impact on the sleep of elite athletes and there is presently a lack of information regarding the sleep behaviours of team-sport athletes when restrictive training schedules are minimised.

Morningness-eveningness, or more commonly known as chronotype, is the preference to arrange daily schedules or undertake daily activities at certain times during the 24-h day; this includes social outings, diurnal activities, and sleep habits (Roenneberg et al., 2003). This favouritism for differences in daily structure can be identified by a range of biological measures (e.g. sleep-wake cycle, body temperature, and hormonal secretions), but it can also be determined using questionnaires, such as the Horne-Ostberg Morningness-Eveningness Questionnaire (MEQ; Horne and Ostberg (1976)). Adolescents tend to display a stronger propensity for later or more-evening chronotypes (Hagenauer and Lee, 2012), which may increase the daily variation in sleep behaviours (Carskadon, 2011; Danielsson et al., 2016; Wolfson and Carskadon, 2003). Also, as humans age, a shift towards earlier chronotypes is observed (review see Adan et al. (2012)). This pattern of chronotype adjustment is true also of athletic populations. Athletes from both individual and team-sport populations display a greater propensity for morning-type and intermediate-type chronotypes than evening-type chronotypes compared to non-athletic populations (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016). However, within athlete populations, team-based sports display a greater proportion of later chronotypes compared to individual sports (Lastella et al., 2016). Age may also influence this phenomena, as older (25.5 ± 3.7 years) rugby league athletes display significantly earlier bed times, sleep onset times, and wake times compared to their younger colleagues (18.8 ± 0.9 years) (Caia et al., 2017a). These differences may be explained by aforementioned chronotype-shifts observed in adolescent athletes (Hagenauer and Lee, 2012); however, morningness-eveningness was not directly assessed by Caia et al. (2017a). Despite the existing literature on the effects of age and chronotype in both non-athletic and athletic populations (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016; Adan et al., 2012), few investigations considered their role in the evaluation of athlete sleep behaviours.

The variation in maximal oxygen consumption ($\dot{V}O_2max$) from morning (6:00 – 8:30am) to evening (3:30 – 6:00pm) indicates that evening-types indeed show higher $\dot{V}O_2max$ values in the evening, whereas morning-types show little variation in $\dot{V}O_2max$ between morning and evening testing (Hill et al., 1988). However, Kunorozva et al. (2014) showed that morning-type athletes perceive the same session of high-intensity exercise, performed at different times throughout the day, to be harder during evening sessions (6:00pm and 10:00pm) than during morning and afternoon sessions (6:00am, 10:00am and 2:00pm). In team-sport athletes, soccer players display no differences in sleep behaviours when both morning-type and evening-type players completed exercise in the morning (8:00am). However, when exercise was performed in the evening (8:00pm), total sleep time and sleep efficiency were reduced in morning-types, compared to evening-types (Vitale et al., 2017). Given the influence that chronotype has on exercise responses and athlete's preference for daily structure, further investigation is warranted to better understand the impact of restrictive pre-arranged training schedules, and other contextual factors, such as; age, training and competition schedules, daily workloads, season phase, sleeping environment have on the sleep behaviours of team-sport athletes.

2.2.2 The Relationship between Exercise Training and Sleep.

Research indicates that regular physical activity improves the habitual sleep quality of non-athletic populations (Youngstedt, 2005), which then has a flow-on effect to the avoidance of overtraining (Halson, 2008). Despite the positive effects of exercise on sleep, the intensity, duration and type of exercise through both training and competition may have differing effects on the habitual sleep of athletes. High training and competition volume may increase pro-inflammatory cytokines, causing a rise in core body temperature and cortisol secretion, resulting in increased wakefulness (Cunniffe et al., 2010). High-intensity exercise close to bed time increases sleep onset latency, reduces total sleep time, lowers sleep efficiency, and increases core temperature (Tc) compared to no exercise, but not when compared to moderate-intensity exercise in active young men (Oda and Shirakawa, 2014). In contrast, Myllymäki et al. (2012) have shown that variations in duration (30 min, 60 min and 90 min) and intensity (45 %, 60 % and 75 % of maximal heart rate) of exercise had no effect on sleep quality or sleep duration when undertaken ~5 h prior to bed. However, given that ultra-endurance racing has been shown to increase wakefulness and reduce REM sleep (Driver et al., 1994), the exercise intensity and duration used by Myllymäki et al. (2012) may have been insufficient to elicit changes in sleep. Collectively, evidence suggests that the timing, intensity, and duration of exercise may have differing effects on the subsequent sleep of athletes.

2.2.3 Training Load and Sleep

Given the acute influence of exercise and training on subsequent sleep behaviours in healthy but non-athletic populations, it stands to reason that the sleep behaviours of athletes would be affected by extended periods of high physical loads. High-intensity individual-sport activity (badminton) has been shown to increase the need for restorative sleep compared to lower-intensity activities (ten-pin bowling) in adolescent athletes (Suppiah et al., 2015). Further analysis using repeated PSG, combined with longitudinal subjective sleep analysis, indicates that increases in training volume of young female swimmers during the general preparation phase (9.0 ± 1.5 km/day) and the specific preparation phase (10.1 ± 1.9 km/day), compared to the taper phase (2.4 ± 0.5 km/day), significantly reduces SWS as a percentage of total sleep time, without considerable changes in total sleep time (Taylor et al., 1997). Periods of increased training volume (+30%), which can lead to functional overreaching, result in decreased sleep duration and sleep efficiency in triathletes (Hausswirth et al., 2014), whereas larger increases in training volume (+100%) in rowers reduces subjective ratings of sleep quality (Jürimäe et al., 2002; Jürimäe et al., 2004). Furthermore, evidence also shows that when a period of over-training is followed by a tapering of training volume (-50%), sleep duration is returned to baseline levels (Hausswirth et al., 2014), supporting a negative relationship between training volume and sleep duration in athletic populations. However, this does not provide a clear picture of the effect that training intensity, without a change in modality, may have on the sleep behaviours of team-sport athletes.

In comparison to individual endurance sports, team-sport athletes rely heavily on a combination of physical attributes, which include speed, strength and power, agility, and aerobic fitness (Reilly and Gilbourne, 2003), and are subjected to cyclical periodisation models that produce cyclical variations in frequency, intensity, duration and mode of exercise both within and between yearly training phases (Ritchie et al., 2016). Previous evidence shows that daily training demands of rugby league players have an intricate relationship with sleep behaviours, potentially due to the disparate physiological loads between high-volume and high-intensity training sessions. Increased acceleration/deacceleration demands improve sleep duration and sleep efficiency, whereas increased total distance covered reduces sleep duration (Thornton et al., 2017a; Thornton et al., 2017b). Improved sleep efficiency was also observed when the acceleration-deacceleration demands were summated across 3-day and 7-day periods, and high-speed running distance resulted in reduced sleep efficiency when summed across 3-day and 7-day periods (Thornton et al., 2017a). However, the previous investigations by Thornton and associates (Thornton et al., 2017a; Thornton et al., 2017b) were done during the pre-season training period and incorporated cumulative training demands only lasting up to 1 week. Hence, there appears to be a lack of available literature investigating the sleep responses to increased physical demands during the in-season phase. As a growing number of practitioners are monitoring the physical demands placed upon team-sport athletes over periods up to 4 weeks in duration (Gabbett, 2018), greater understanding of the impact that exposure to changes in both volume and intensity of training and competition between season phases, as well as the added influence of environmental and individual contextual factors, have on the sleep behaviours of elite athletes may help improve evidence-based recovery practises of elite team-sports athletes.

2.2.4 Effects of Competition on Sleep

Competition performance is the defining product of athletic preparation. Maintaining sleep behaviours, and sustaining sleep quality and quantity, are considered to be important components for maximising preparation and performance. In support of this, Brazilian athletes who rated their pre-competition sleep as poor displayed reduced likelihood of success during competition the next day (Brandt et al., 2017). In samples of both Australian and German athletes, ~65% of athletes experience sleep that is worse than normal on the night preceding competition, with individual sport athletes more likely to report pre-competition sleep disturbances (Erlacher et al., 2011; Juliff et al., 2014). Indeed, in elite cyclists, a 2-day competition period results in significantly reduced total sleep time and earlier sleep onset and wake times compared to baseline nights (Lastella et al., 2014d), whereas a 21-day grand-tour results in a gradual decline in sleep duration throughout (Lastella et al., 2014c). Gymnasts also display reduced total sleep time on the night preceding competitive events (Dumortier et al., 2018; Silva and Paiva, 2016), which is also related to impaired next-day performance (Silva and Paiva, 2016). In team-sport athletes, however, increased pre-competition sleep duration and sleep efficiency have been reported in Australian Rules footballers (Lalor et al., 2017; Richmond et al., 2004), suggesting disparity in sleep behaviours surrounding competition between individual and team-sport athletes.

Whereas individual-sport athletes display reductions in sleep duration and quality on the night preceding competition, team-sport athletes exhibit both reduced sleep duration and rate subjective sleep quality poorer following matches (Fullagar et al., 2015b; Richmond et al., 2004; Shearer et al., 2015; Lalor et al., 2017). Richmond et al. (2004) and Lalor et al. (2017) reported that sleep duration on the night preceding a match is significantly longer, whereas sleep duration following match-play is significantly reduced compared to baseline nights. However, despite Richmond et al. (2004) observing no changes in sleep efficiency, awakenings during sleep, or subjective ratings of sleep quality, Lalor et al. (2017) found improved sleep efficiency and less awakenings on the night of competition compared to baseline. This is supported by investigations in soccer (Fullagar et al., 2015b) and rugby (Shearer et al., 2015), which found that sleep duration was significantly less following match-play compared to baseline sleep nights.

Although competition negatively impacts on the sleep of ARF players (Richmond et al., 2004) and rugby players (Shearer et al., 2015), these results are limited to being observational as they do not offer insight in to possible reasons for sleep disruption. Furthermore, evidence in soccer players suggests that night matches, but not day matches, result in substantial influences in sleep duration and behaviour, compared to the sleep obtained following training days (Carriço et al., 2018; Fullagar et al., 2016b). Hence, although the detrimental effects of restrictive scheduling, age and chronotype have been previously discussed, evidence suggests that other factors such as pain (Samuels, 2008; Skein et al., 2013), increased post-game arousal (Meyer et al., 2014), consumption of ergogenic aids such as caffeine (Miller et al., 2014; Dunican et al., 2018) and late-night start-times (Halson, 2014; Fullagar et al., 2016b; Lalor et al., 2017; Carriço et al., 2018), may negatively impact sleep following competition. Compared to day matches (those concluding before 6:00 pm), night matches (starting after 6:00 pm) substantially reduce sleep duration in professional soccer players (Fullagar et al., 2016b; Carriço et al., 2018), and evening matches (starting at 7:10pm) result in lower sleep efficiency and increased sleep onset latency compared to earlier matches (starting at 1:40pm, 2:10pm and 4:40pm) in Australian Rules footballers (Lalor et al., 2017). However, the earlier match start-times displayed increased sleep efficiency and reduced wakefulness compared to habitual sleep durations (Lalor et al., 2017), which may suggest that during the pre-season period, when habitual sleep assessments are completed, Australian Rules footballers display similar sleep behaviours to that of evening matches.

When taken together, current literature demonstrates the detrimental effects of competition on the sleep of team-sport athletes following competition. However, the presence of influencing factors and the flow-on effects to recovery are unknown, as current investigations do not consider potential influencers such as chronotype, unfamiliar sleeping environments, season phase, and cumulative training and competition loads. Therefore, further investigations of the effects of competition on sleep should consider time-of-day, travel, individual and environmental factors due to their potential influence on sleep behaviours of team-sport athletes.

2.3 Sleep and Recovery

Sleep is widely considered to be a crucial component of the recovery process for athletes, with domestic, national- and international-level athletes from hockey, netball, rugby, and soccer populations all rating sleep as the most important recovery modality available (Venter, 2014). Despite this, it is often neglected during the recovery process (Venter, 2014; Walters, 2002). Poor sleep quality or quantity can have detrimental effects on recovery, which may negatively affect subsequent performance during training or competition. High-intensity interval exercise (HIIE) can also lead to a range of functional and physiological impairments, factors that need to be restored to facilitate subsequent exercise performance. The combined detrimental effects of high-intensity exercise, accompanied by the potentially catabolic effects of poor sleep, indicates that further research is required to elucidate the effects of increased sleep duration on markers of post-exercise recovery.

2.3.1 Post-Exercise Recovery

High-intensity exercise bouts induce changes in immune function and increase inflammatory signalling and muscle damage (Croft et al., 2009; Fragala et al., 2015; Nieman, 1997), which may persist for up to 96 h post-exercise (Neubauer et al., 2014). Sessions of HIIE can also lead to impairments in physical outcomes. Johnston et al. (2013) found that HIIE, in the form of match-play, impairs neuromuscular function, as shown by reduced countermovement jump (CMJ) peak power at 36 h post-match in rugby league players. CMJ height is also reduced for up to 18 h post-match in soccer players (Rowell et al., 2016) and at 24 h following the Loughborough intermittent shuttle test (LIST) in healthy male participants (Bailey et al., 2007). Maximal isometric force production of the hamstrings following the LIST is also reduced by ~10% for up to 48 h, which is comparable to the ~10 % detriment in quadriceps force production observed immediately following international handball match-play (Thorlund et al., 2008), and post-match reductions in quadricep MVC in rugby league athletes (Skein et al., 2013). Indices of autonomic nervous system function also form an important part of the post-exercise recovery process, and are typically measured following a bout of short-duration submaximal exercise to monitor adaptive training responses and recovery status of athletic populations (Plews et al., 2013; Thorpe et al., 2015; Buchheit et al., 2015; Buchheit et al., 2013b). Heart-rate and heart-rate variability, typically measured as the standard deviation of R-R intervals (SDNN), are reduced in overtrained athletes (Hynynen et al., 2006). These reductions in autonomic nervous system function are also strongly correlated with daily increases in the training demands of soccer players (Thorpe et al., 2015). Intense exercise also impairs subjective ratings of perceived wellness and the perceived effort of completing submaximal exercise (Saw et al., 2015; Mann et al., 2015). HIIE leads to increased ratings of perceived muscle soreness and fatigue, which can remain elevated for up to 48 h post-exercise (McLean et al., 2010; Bailey et al., 2007). Collectively, the need for appropriate recovery of physiological status, physical function, and perceptual measures following bouts of HIIE is clear. However, the role of sleep as a potential method to facilitate post-exercise recovery requires further investigation.

2.3.2 Sleep Deprivation and Restriction

To date, the majority of scientific information regarding the importance of sleep has been derived using sleep deprivation (DEP - where sleep is completely prevented for an extended period of time; e.g. >24 h) and sleep restriction (SR - where sleep duration is reduced relative to habitual levels, but not completely abolished). These methodologies have found that DEP and SR result in reduced measures of health, wellbeing, and performance in both cognitive and physical performance tasks (Knutson et al., 2007; Leproult et al., 2014; Mougin et al., 1991; Patel, 2009; Walker, 2008). Early investigations of the physical effects of sleep deprivation on exercise performance indicated that 36 h of continuous waking reduces time to exhaustion and increases perceived exertion (RPE), yet these changes were not accompanied by significant changes in physiological measures such as heart rate (HR) and metabolic rate (Martin, 1981). The physiological response to short duration sub-maximal exercise has shown similar results. Research by Martin and Gaddis (1981) found that exercise at sub-maximal intensities following 30 h of total DEP does not result in changes in physiological variables, yet exercise RPE was increased following DEP compared to exercise following unlimited sleep opportunity. Sleep deprivation of 30 h also impairs maximal running performance, as Oliver et al. (2009) found reduced distance is covered during a 30-min time-trial effort, compared to a night of normal sleep (8:16 ± 0:18 hours). Souissi et al. (2003) also found that power production during an anaerobic cycling test was unaffected by 24 h of sleep deprivation, but power production was impaired after 36 h of total sleep deprivation. Sleep deprivation for 36 h impairs autonomic nervous system status, with reduced heart-rate variability suggestive of increased sympathetic and reduced parasympathetic nervous system activity (Zhong et al., 2005). Furthermore, Arnal et al. (2016) found that sleep deprivation increases ratings of perceived exertion during a time-to-exhaustion. Therefore, sleep deprivation has clear detrimental effects on markers of recovery; however, complete sleep deprivation is uncommon in athletic populations and athletes are more likely to experience periods of reduced or restricted sleep.

Sleep restriction appears to have a different effect on the physiological responses to maximal exercise, compared to sleep deprivation. Mougin et al. (1991) found that following a night of sleep restricted to 3 h, graded exercise significantly increased HR, elevated ventilation at both submaximal and maximal intensities, and elicited lower maximal oxygen uptake without a concomitant drop in sustained power output during maximal intensity exercise. Souissi et al. (2008) found that when sleep was restricted to 4 h in bed, compared to 6.7 – 7.5 h in bed, removing the second half of the sleep period by waking participants up early had a greater detrimental effect on power production than keeping participants up later. This pattern was also found in a later study by the same author, who found that judo athletes display greater impairments in hand-grip strength and cycling power production when sleep was restricted through early awakening, compared to delayed bed times (Souissi et al., 2013). However, earlier work by Reilly and Piercy (1994) found that just one night of SR does not impact on submaximal weight-lifting performance, but two successive nights of SR significantly increases perception of effort. Similar results were shown by Cook et al. (2012) who found that self-selected resistance exercise load for bench press, squats, and bent over rows were significantly reduced following a single night of sleep restricted from >8 h to <6 h. In summary, many studies have reported detrimental effects of DEP and SR on cognitive and physiological parameters relevant to exercise performance. Given that elite team-sport performance is dependent on both physiological ability and cognitive function, the consideration of the effects of pre-competition sleep or habitual sleep behaviours on performance may be crucial to improving performance.

2.3.3 Neuromuscular Responses to Sleep

The assessment of neuromuscular function (NMF) can serve as a useful monitoring tool in the identification of risk factors for poor performance and fatigue (McLean et al., 2010); as such, the effects of team-sport training and competition on measures of NMF have been widely investigated (McLean et al., 2010; Cormack et al., 2008a; Cormack et al., 2008b; Cormack et al., 2008c). Neuromuscular function (measured from a 30-s maximal cycling effort) has been shown to be negatively affected by DEP, resulting in greater declines in peak power, peak force and mean power, without any additional exercise stress (Souissi et al., 2003). The effects of DEP on counter-movement jump (CMJ) performance following match-play found that CMJ height declines without a significant decline in maximal voluntary contraction (MVC) force in rugby league players (Skein et al., 2013). Furthermore, two consecutive nights of DEP reduces mean 15 m sprint performance, reduces the distance covered during the first and final 10 min of self-paced exercise testing, and results in greater reductions in voluntary activation (VA) force of the quadriceps muscle following exercise, compared to normal sleeping conditions (Skein et al., 2011). However, evidence shows that elite athletes obtain sub-optimal or restricted sleep and that total DEP may not be representative of real-world situations. Given the importance placed on neuromuscular recovery following competition (Johnston et al., 2013), maximising sleep may reduce the risk of suboptimal recovery following competition and aid in faster restoration of neuromuscular functioning to facilitate the return to full-training activities. However, current literature has only assessed the effects of total DEP on NMF; therefore, further research is required to understand the effects of increased sleep durations, relative to habitual duration, on NMF during training and following competition.

2.3.4 Hormonal Effects of Sleep

Pertinent to recovery, is that limiting sleep through sleep restriction results in a loss of muscle mass and dysregulation of inflammatory, hormonal, and immunological function (Obal and Krueger, 2004; Santos et al., 2007; Vgontzas et al., 2004). This dysregulation may further impact the expression of genes relevant to muscle recovery following exercise-induced muscle damage, similar to that experienced following intermittent team-sport performance. Therefore, obtaining sub-optimal amounts of sleep may negatively affect the hormonal processes of recovery following exercise, generating longer-term impacts on performance, as recent research has revealed that recovery from high-intensity exercise is not complete for up to 96 h post exercise (Neubauer et al., 2014). In males, over 70% of the daily growth hormone (GH) release occurs during the first half of night-time sleep (Mullington et al., 2009), which is correlated with the amount of recuperative SWS during this period (Van Cauter and Copinschi, 2000). GH stimulates protein synthesis and the maintenance of an anabolic environment (Holt and Sönksen, 2008), an important component in the development of lean muscle mass via resistance training programs in elite team-sport athletes (Bilsborough et al., 2014). Fragmented or disrupted sleep leads to increased concentrations of the stress hormone cortisol, which can inhibit the effects of GH-releasing hormone (GHRH) and the subsequent secretion of GH (Van Cauter and Copinschi, 2000), with reduced GHRH also correlated with reduced nREM sleep (Obal and Krueger, 2004).

The flow-on effects of reduced GH secretion during sleep may also affect other anabolic hormones such as insulin-like growth factor-1 (IGF-1). Everson and Crowley (2004) found that a reduction in circulating GH leads to reduced IGF-1 secretion in sleep deprived rats, supporting the notion that reduced GH release following DEP leads to the development of a catabolic environment. Indeed, Nedeltcheva et al. (2010) found that a 14-day period of SR (5.5 h/night vs 8.5 h/night), under calorie-controlled diet conditions, resulted in an increased net loss of lean muscle mass indicating a proteolytic environment induced by SR. Furthermore, concentrations of the hunger-regulating hormone ghrelin increased following SR, suggesting that SR impacts on metabolic processes involved in the maintenance of the anabolic/catabolic balance. Spiegel et al. (1999) investigated the effects of SR on the physiological response to exercise and found that 6 days of SR (6 h in bed/night) significantly increased evening concentrations of the catabolic hormone cortisol and increased sympathetic nervous system activity, compared to 8 h in bed. Extending sleep to 12 h in bed per night did not improve any of these measures compared to 8 h in bed, yet this sleep extension period directly followed the SR period, which may have impacted results (Spiegel et al., 1999) due to the presence of preceding sleep debt from SR. In summary, DEP and/or SR alters the hormonal profile potentially leading to the creation of a catabolic and proteolytic environment, reducing the body's ability to maintain an anabolic state (Dattilo et al., 2011), significantly affecting subsequent physiological recovery from exercise. Further, the inability to recover between bouts of exercise may increase the risk of maladaptation to training, limiting the efficacy of a training intervention aimed at improving capacity or function (Lehmann et al., 1992). Given the negative influence of both restricted sleep and high-intensity exercise on physiological and physical function, it might be suggested that extending sleep (beyond that normally obtained) may help promote a favourable hormonal environment for recovery. However, little research has been done quantifying the magnitude of the effect of sleep extension on the hormonal profile during recovery following high-intensity exercise in athletes.

2.3.5 Sleep Extension

Sleep extension, whereby overnight sleep opportunities are increased, is a developing topic in the field due to its potential benefits on physiological function and physical performance (Arnal et al., 2016; Mah et al., 2011; Dement, 2005; Famodu et al., 2017; Horne et al., 2008; Leproult et al., 2014; Schwartz and Simon, 2015). Early sleep extension investigations focused on the role of increasing night-time sleep duration and its positive effects on reaction time performance and ability to improve ratings of fatigue and vigour using the profile of mood states (POMS) questionnaire (Carskadon and Dement, 1982; Kamdar et al., 2004). These findings have also been observed in collegiate athletes undertaking sleep extension, with Mah et al. (2011) showing improved reaction times and subjective ratings of POMS-measured fatigue and vigour. Furthermore, research supports a beneficial effect of sleep extension for physiological function and physical performance. Mah et al. (2011) reported that sleep extension in youth basketballers (>10 h in bed per night over a period of 5-7 weeks) leads to 110.9 ± 79.7 min more sleep time, which resulted in improved sprint performance, improved free-throw and 3-point shooting accuracy, and improved reaction time (Mah et al., 2011). More recently, a 1-week period of sleep extension, resulting in ~30 min more sleep per night in healthy female participants, did not appear to influence anaerobic exercise performance (Famodu et al., 2017). However, the sleep extension period was shorter, and the increased sleep duration was substantially less in the work by Famodu et al. (2017) compared to Mah et al. (2011), which may explain the disparate findings. When sleep extension (+96 min/night) is undertaken over a 6 night period preceding a night of total sleep deprivation, subsequent RPE during a time-to-exhaustion task is reduced, compared to habitual sleep durations (Arnal et al., 2016). Overall, evidence supports a beneficial effect of sleep extension on markers of physical performance and function; however, the effects of sleep extension on post-exercise recovery are unknown. Given the prevalence of reduced sleep duration following competitive matches in team-sport athletes (Fullagar et al., 2016b; Richmond et al., 2004), methods to achieve increased sleep duration and the flow-on effects that sleep extension may have for post-exercise recovery presents as an area in need of further investigation.

2.3.6 Napping

Despite the positive findings supporting a beneficial effect of sleep extension on markers of recovery, athletes' adherence to protocols of sleep extension may be problematic due to training commitments and schedules, family commitments, feelings of worsening sleep quality with increased time in bed, and other lifestyle restrictions. The role of sleep supplementation/napping in the recovery from exercise may serve as a suitable substitute capable of increasing daily total sleep duration in situations where night-time extension is impractical. Early work by Dinges et al. (1987) showed that a 2 h sleep opportunity at any point during prolonged wakefulness improved reaction time performance and ratings of subjective sleepiness. Following sleep restricted to 4 h per night, a 30 min nap opportunity can improve vigilance, subjective and EEG-measured sleepiness, short-term memory, and decision-making accuracy (Dinges et al., 1987; Waterhouse et al., 2007). Sprint performance (2 m and 20 m sprints) is improved by a 30 min afternoon nap following a single night of sleep restricted to 4 h in bed (Waterhouse et al., 2007); however, no improvement in grip strength were evident. More recently, it has been shown that multiple 30 min naps (1 nap at 9:30 am and 1 nap at 3:30 pm) following a night of sleep restricted to just 2 h attenuates the decline in interleukin-6 (IL-6) and the increase in norepinephrine levels compared to a no-nap condition (Faraut et al., 2015). Short 20 min afternoon naps have also been shown to improve countermovement jump peak jump velocity preceding a netball match (O'Donnell et al., 2018). Hormonal status, perceptual responses, physiological function, and physical performance factors are important components of recovery that are improved through the use of short naps. However, research investigating the effects of napping have not been investigated in the context of post-exercise recovery, especially in athletic populations.

2.4 Summary

Sleep is critical for human function, which also applies to athlete performance and recovery. Unlike non-athletic populations, team-sport athletes require a complex and dynamic range of physical and mental assets in order to perform at their best, which inherently exposes them to a variety of contextual factors specific to both the individual and the environment that may lead to impaired sleep. Furthermore, the majority of the literature investigating the role of sleep in post-exercise recovery has focussed on the effects of sleep deprivation or restriction, and despite positive early results indicating that increasing sleep quantity can improve physiological, cognitive, and psychological aspects considered important for athletic performance, the role of sleep extension in the context of recovery has received limited attention. Given that improving sleep quantity and/or quality is the goal of most sleep interventions for athlete populations, gaining a greater understanding of the sleep behaviours of team-sport athletes, and how sleep is impacted by factors such as chronotype, age, travel, and training and competition demands, will better facilitate decision-making and evidence-based recommendations to enhance sleep behaviours. These recommendations will help to facilitate further research to investigate the efficacy of sleep extension and how it can be implemented to enhance post-exercise recovery.

SIGNIFICANCE AND AIMS OF THE THESIS

The aim of this Thesis was to develop a better understanding of the sleep behaviours and factors that impact the sleep of professional team-sport athletes, specifically Australian Rules footballers. Furthermore, this Thesis aimed to investigate the effects of increased sleep duration on factors important for athlete recovery and performance.

The aims of this Thesis will be underpinned by the following Objectives:

- Investigate the influence of physical sleep environment during a pre-season training camp on the sleep behaviours of professional Australian Rules footballers. *Hypothesis:* Individual sleep behaviours will be negatively impacted during a training camp in the pre-season period in Australian Rules footballers (Study 1).
- Investigate the role that individual contextual factors (age and chronotype) and environmental factors (competitive matches, competition level, and competition location) have on the sleep behaviours across the pre-season and in-season periods in professional Australian Rules footballers. *Hypothesis:* Individual sleep habits will vary according to the season period, competition location, and competition level; it was further hypothesised that the influence of these factors would be affected by age and chronotype throughout an Australian Rules football season (Study 2).
- Determine the influence of changes in load variables during both the pre-season and in-season across 1-, 7-, 14-, 21- and 28-day periods and their relationships with objectively measured sleep behaviours in Australian Rules footballers. *Hypothesis:* Heightened training demands over both short- and longer-term periods would negatively influence the sleep behaviours of Australian Rules footballers (Study 3).
- Determine the effect of a single night of sleep extension on physiological, physical, and perceptual recovery. *Hypothesis:* A single night of sleep extension, by increasing time in bed overnight to 10 hours, will have a beneficial effect on recovery outcomes compared to a control condition spending 8 hours in bed overnight, following high-intensity interval running (Study 4).
- Determine the effects of post-exercise sleep extension on the status of physiological, physical, and perceptual recovery and physical performance. *Hypothesis:* Increased daily sleep duration over 3 consecutive days will enhance measures of physiological, physical, and perceptual recovery and physical performance compared to a control condition exhibiting similar sleep behaviours to those observed in athletic populations following high-intensity interval running (Study 5).

CHAPTER 3 – METHODS

3.1 General Methods

3.1.1 Field-Study Participants

Participants for Studies 1, 2 and 3 (Chapters 4, 5 and 6) were recruited from the same Australian Rules Football club competing in the Australian Football League. Participant characteristics are shown in Table 3.1. Prior to participating in the study participants were free from musculoskeletal injury and illness, and no injuries occurred during the data collection periods. Full informed consent was provided by participants and the research was approved by the University Human Research Ethics Committee (HRE14-312) and followed guidelines from the Declaration of Helsinki.

Table 3.1. Physical characteristics of participants from Studies 1, 2 and 3.

	Study 1 (Chapter 4)	**Study 2 (Chapter 5)**	**Study 3 (Chapter 6)**
Number of participants	19	35	35
Age (years)	22 ± 4	23 ± 4	23 ± 4
Height (cm)	185 ± 8	187 ± 7	187 ± 7
Body mass (kg)	83 ± 8	85 ± 8	85 ± 9

3.1.2 Laboratory Study Participants

Participants for Studies 4 and 5 (Chapters 7 and 8) were healthy and physically active male volunteers who had a history of playing team-sports. Participant characteristics are shown in Table 3.2. Participants were free from musculoskeletal injury and illness prior to participating in the study, were classified as “low-risk” using the Adult Pre-Exercise Screening Tool (Appendix 1), and full informed consent was provided by all participants. The study protocol was approved by the Victoria University Human Research Ethics Committee (HRE15-293). Participants refrained from alcohol for 24 hours prior to, caffeine consumption for 12 hours prior to, and both alcohol and caffeine consumption during, all experimental procedures.

Table 3.2. Physical characteristics of participants from Studies 4 and 5.

	Study 4 (Chapter 7)	**Study 5 (Chapter 8)**
Number of participants	11	8
Age (years)	27 ± 4	28 ± 2
Height (cm)	182 ± 8	183 ± 6
Body mass (kg)	78 ± 8	79 ± 8
$\dot{V}O_2max$ (ml·kg·min^{-1})	52 ± 5	52 ± 6

3.1.3 Field-Study Schedule

The daily training schedules undertaken by participants in Studies 2 and 3 (Chapters 5 and 6) are presented in Figure 3.1. Training sessions incorporated skill-based and physical conditioning training, resistance training, non-sport-specific cross-training conditioning sessions, competition matches, and prescribed post-training, team-based recovery sessions on planned recovery days – consisting of cold-water immersion, stretching, self-myofascial release and hydrotherapy. All sessions were designed and implemented by coaching staff of the participating Australian Rules football club.

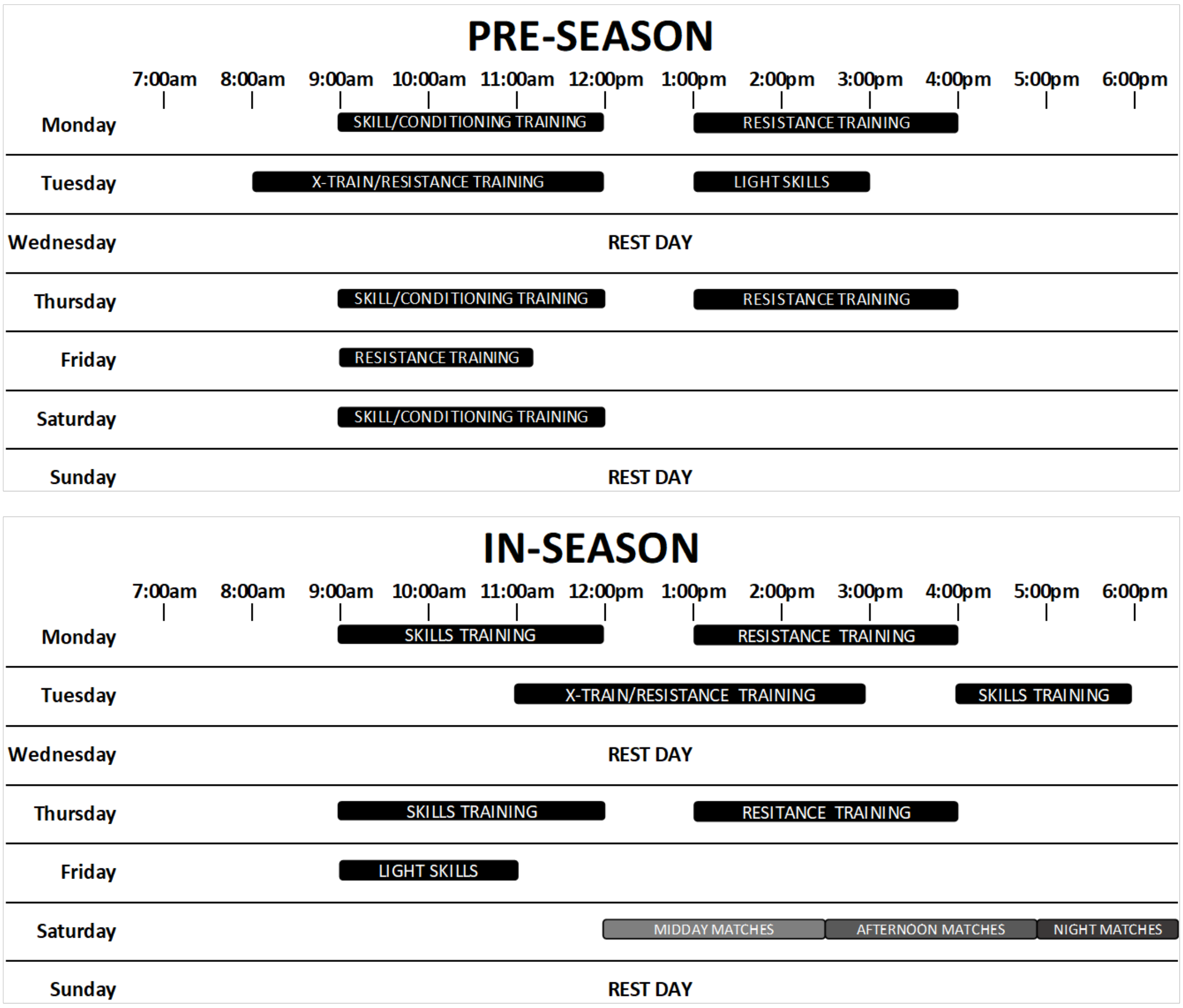


Figure 3.1. Schematic representation depicting a typical training week between Pre-Season and In-Season phases for Chapters 5 and 6. X-Train; non-sport specific cross-training conditioning.

3.2 Sleep Assessment

3.2.1 Wrist-Watch Activity Devices

Sleep was assessed using a wrist-watch activity device, the Actiwatch 2 (Philips Respironics, PA, USA). These devices are preferred to polysomnography during extended field-based studies due to their portable and non-intrusive nature and low participant burden (Sargent et al., 2015), and have been deemed effective and appropriate for use in sleep extension studies (Claudino et al., 2019). These devices possess high correlations with gold-standard polysomnography-measured sleep for sleep duration (i.e. r = 0.84-0.89) and moderate to high correlations for wake time within sleep (i.e. r = 0.65-0.76) (Jean-Louis et al., 1998; Weiss et al., 2010), as well as low coefficient of variation (CV; shown as CV (95%CI)) for sleep efficiency; 7 (6 to 8), and total sleep time; 10 (7 to 14) (Claudino et al., 2019). Participants were instructed to wear the device on the wrist of the non-dominant hand, to keep the device dry, and press a button on the side of the device when lying in bed initiating an attempt to sleep and when ending the attempt to sleep. Activity counts were collected by the device at a rate of 32 Hz and were then summed across the designated 30 s epoch length, to be scored using a previously validated automated scoring algorithm (Oakley, 1997). Device activity sensitivity was set to Medium (40 activity counts per epoch; (Kosmadopoulos et al., 2014; Sargent et al., 2015)). All epochs were scored as ‘wake’ unless the subjective sleep diary (Section 3.2.2) identified that the participant was in bed attempting to sleep (identified as being between bed time and wake time of the subjective sleep diary), and the activity count was simultaneously below the 40 count per threshold. Epochs were scored as ‘sleep’ if the aforementioned criteria were satisfied.

Sleep behaviours derived from the activity device and subjective sleep diary were defined in the following way:

- *Bed Time* – the self-reported 24-hour time at which a participant went to bed to attempt to sleep, recorded by pressing the marker button on activity devices and confirmed by subjective sleep diaries.
- *Wake Time* – the self-reported 24-hour time at which a participant got out of bed and stopped attempting to sleep, recorded by pressing the marker button on activity devices and confirmed by subjective sleep diaries.
- *Time in Bed (TIB)* – the amount of time spent in bed attempting to sleep between Bed Time and Wake Time.

- *Total Sleep Time (TST)* – the amount of time spent in bed asleep, calculated by the automated scoring algorithm in the Philips proprietary software under the satisfaction of the ‘sleep’ scoring criteria.
- *Sleep Onset Latency (SOL)* – the period of time between Bed Time and the first of 3 consecutive ‘sleep’ scored epochs.
- *Wake After Sleep Onset (WASO)* – the amount of time spent awake between the initial sleep onset and the last epoch scored as ‘sleep’.
- *Sleep Efficiency (SEF)* – Total Sleep Time expressed as a percentage of Time in Bed (SEF = [TST ÷ TIB] x 100).

All sleep assessments in Chapters 4, 5 and 6 took place either in the participant’s home or whilst staying in hotel rooms outside of the normal sleeping environment. In Chapters 7 and 8, the home-based sleep assessments were completed with participants sleeping in their normal home-based sleeping environment. During laboratory-based sleep assessments, participants slept in individual bedrooms in the sleep facility on campus at Victoria University (Footscray, Victoria) under continued researcher supervision and whilst following sleep hygiene guidelines (avoiding electronic device usage and excessive light exposure 60 min prior to lights out, sleeping in cool and quiet environments, and avoiding caffeine consumption) that have previously been shown to enhance sleep duration in athlete populations (Caia et al., 2018a; Duffield et al., 2014; O'Donnell and Driller, 2017); Fullagar et al. (2016a). Indeed, the sleep facility allowed for control of temperature (22.23 ± 0.45 °C) and standardised light exposure; however, participants were free to leave the sleep facility during the day and undertake normal daily activities, other than exercise. Lights were dimmed and electronic device usage was restricted 60 min prior to lights out, with bedrooms kept free from external light sources and electronic devices.

3.2.2 Subjective Sleep Diaries

In all Studies, wrist-watch activity devices were paired with subjective daily sleep diaries (Appendix 2) to collect bed time, wake time and a subjective sleep quality rating; this method has previously been used to quantify the sleep/wake behaviour (Roach et al., 2013; Sargent et al., 2014a). In brief, each morning participants detailed the time they went to bed with the intent of sleeping, what time they woke up and arose from bed, and a subjective rating of sleep quality based on the descriptors; “very good”, “good”, “average”, “poor”, and “very poor”.

3.2.3 Morningness-Eveningness Questionnaire

Prior to the first night of sleep assessment, each participant completed the Morningness-Eveningness Questionnaire (MEQ; see Appendix 3) that was developed by (Horne and Ostberg, 1976). The MEQ has been widely used in sleep and chronobiology research (Dosseville et al., 2013) and accurately represents individual differences in core temperature fluctuations and sleep-wake schedules in adults (Baehr et al., 2000). The MEQ consists of 19 questions relating to preferred wake and sleep schedules, preferred performance times, and self-reported chronotype. Question responses are a given a nominal score and then tallied to give a total, to classify participants into Definite Evening = 16-30, Moderate Evening = 31-41, Intermediate = 42-58, Moderate Morning = 59-69 and Definite Morning = 70-86, with broader classifications of Evening-type = 16-41, Intermediate-type = 42-58 and Morning-type = 59-86.

3.2.4 Cross-Device Validity Assessment

During the Home sleep assessment period in Chapter 4, participants had two different wrist-worn activity monitors available for use. To assess whether the data from both devices would be suitable for pooled analysis, data from the Actiwatch 2 (Actiwatch 2, Philips Respironics, PA, USA) and Actigraph wGTX3 (Actigraph wGTX3 monitor, Actigraph, FL, USA) were compared. In a pilot study, six healthy adult male participants (age; 30±7 y, height; 179.2±10.8 cm, body mass; 79.0±10.7 kg) wore both the Actiwatch 2 and Actigraph wGTX3 wrist-worn activity devices simultaneously on the wrist of the non-dominant hand for 3 consecutive nights in the Home environment. Participants followed the same instructions as previously described to participants in Section 3.2.1. Activity counts were collected by the devices at a rate of 32 Hz and were then summed across the designated 30 s epoch length, to be scored using a previously validated automated scoring algorithm (Oakley, 1997). Device activity sensitivity was set to Medium (40 activity counts per epoch; (Kosmadopoulos et al., 2014; Sargent et al., 2015)). All epochs were scored as ‘wake’ unless the subjective sleep diary (Section 3.2.2) identified that the participant was in bed attempting to sleep (identified as being between bed time and wake time of the subjective sleep diary), and the activity count was simultaneously below the 40 count per threshold. Epochs were scored as ‘sleep’ if the aforementioned criteria were satisfied. Resultant sleep behaviour variables derived from the activity device and subjective sleep diary included time in bed, total sleep time, sleep onset latency, wake after sleep onset, and sleep efficiency, as described previously in Section 3.2.1.

The concurrent validity of the devices was assessed using Pearson correlation coefficients and typical error of estimate (TEE) as described elsewhere (Hopkins, 2000). Sleep efficiency (SEF, r = 0.92, TEE = 2.1%), time in bed (TIB, r = 0.97, TEE = 2.9%), total sleep time (TST, r = 0.91, TEE = 6.2%) and wake after sleep onset (WASO, r = 0.96, TEE = 21.1%) demonstrated strong validity between devices. However, sleep onset latency (SOL) was deemed not reliable (r = 0.41, TEE = 57%). As such, four objective measures were deemed suitable to determine sleep quantity (TIB, TST) and sleep quality (SE, WASO) for use in Chapter 4, whereas SOL was excluded from consideration.

3.3 Physical and Physiological Measurements

3.3.1 Maximal Oxygen Consumption

Maximal oxygen consumption ($\dot{V}O_2max$) and maximum velocity obtained at volitional fatigue ($v\dot{V}O_2max$; the speed at which the participants obtain $\dot{V}O_2max$) were determined for all participants in Chapters 7 and 8. This process involved completing a graded maximal exercise test on a motorised treadmill (Katana Sport, Lode, Netherlands). The test began at 10 $km \cdot h^{-1}$ for 3 min, before increasing the speed by 2 $km \cdot h^{-1}$ every 3 min until the speed reached 16 $km \cdot h^{-1}$. After reaching 16 $km.h^{-1}$ the rate of increase changed to 0.5 $km \cdot h^{-1}$ every 1 min, until participants could not keep pace with the treadmill or reached volitional fatigue. Expired gases were collected every 15 s using an automated gas analyser (Moxus Modular $\dot{V}O_2$ System, AEI Technologies, USA) and the individual $\dot{V}O_2max$ was defined as a plateau in $\dot{V}O_2$ with an increase in running speed. At the end of each 3 min stage heart rate and rating of perceived exertion (RPE) were measured. Subjects reported instantaneous RPE during exercise according to a 15-point Borg scale (Borg, 1970). Table 3.3 displays the scale used for RPE. During the $\dot{V}O_2max$ participants were given access to information about speed and were informed of the time elapsed during each 3 min stage. A familiarisation test was performed at least 48 hours prior to true $\dot{V}O_2max$ and $v\dot{V}O_2max$ recording. Prior to each test a two-point calibration was performed using known gas concentrations (20.83% O_2 and 0.04% CO_2, 15.43% O_2 and 3.93% CO_2) and a 3 L calibration syringe.

Table 3.3. Borg scale used for subjects' ratings of perceived exertion during exercise (Borg, 1970).

Rating	Description
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

3.3.2 Performance Testing

All performance testing took place at the same time of day for the studies described in both Chapters 7 and 8. Participants were familiarised to the performance testing protocols before undertaking baseline testing prior to the first experimental condition. Following a standardised warm-up routine consisting of general movements, dynamic stretching and warm-up sprints at 50%, 75%, 90% and 100% of maximal effort, participants undertook three maximal 20 m sprint efforts interspersed with 60 seconds of rest on an indoor athletics track surface; performance on this test has been reported to be positively influenced by sleep extension (Mah et al., 2011). Timing was conducted using infrared timing gates (Smartspeed, Fusion Sport, Australia) placed at 5 m, 10 m and 20 m intervals. Split times from each participant's fastest 20 m effort were used for analysis, which possesses high reliability (CV = 3.1%; Hopker et al. (2009)). Aerobic endurance testing was performed following a 5 min rest after the 20 m sprint testing, using the YoYo Intermittent Recovery Level 1 (YoYo IR1) test. The YoYo IR1 is commonly used in team-sport environments to assess intermittent endurance performance (Krustrup et al., 2003) and has been shown to be a reliable measure ($r = 0.69$) of training status and aerobic performance (Fanchini et al., 2015). The YoYo IR1 consists of repeated 40 m efforts (20 m shuttles), which increase from 10 $km \cdot h^{-1}$ as stages progress, with a 10 seconds of active recovery period between efforts (Krustrup et al., 2003). The test continues until the participant fails to keep pace with the test, with each participant receiving one warning for failure to keep pace.

3.3.3 Recovery Assessments

Recovery assessments took place at the sime time of day between conditions in both studies described in Chapters 7 and 8. The measurement of submaximal heart rate (HR) and heart rate variability (HRV) were done using similar methods to previously (Buchheit et al., 2013b) using Polar RS800CX heart-rate monitors and chest-worn straps (Polar Instruments Inc., Finland). Briefly, participants stood stationary on a motorised treadmill for 60 s to measure resting HR (RHR) and measures of HRV, including the standard deviation of R-R intervals (SDNN), root mean square of the successive differences in R-R intervals (r-MSSD), and log r-MSSD (CV 10.7% (9.6 to 11.9%)). Participants then ran continuously for 5 min at 13 $km \cdot h^{-1}$ to assess peak HR during submaximal exercise (HRex; CV 3.4% (3.1 to 3.7%)), before standing stationary for 60 s to assess HR recovery (HRr; CV 13.3% (12.2 to 14.3%)). HR recovery was calculated as the HR 60 s post-exercise subtracted from the HR at the completion of the submaximal exercise, expressed as either absolute (HRr) or as a percentage of HR at the completion of the submaximal exercise (%HRr).

Neuromusuclar function was assessed using the countermovement jump (CMJ) and maxmimal voluntary contraction (MVC) peak torque production. Performance of CMJ was measured as the average of 3 jumps performed on a force platform and linear position transducer (400 Series Performance Plate; Fitness Technology, Australia) using purpose-built software for reliable (ICC = 0.98, CV = 2.8%) CMJ analysis (Ballistic Measurement System, Fittech) (Markovic et al., 2004). Jumps were performed following the HRV testing and a standardised warm-up procedure, consisting of 10 bodyweight squats and 3 submaximal jumps at 50%, 75% and 90% of perceived maximal effort, separated by 1 min of passive rest. Participants were instructed to jump as high as possible for each jump and 60 s of recovery was allowed between efforts. Assessment of MVC peak torque of the left leg was performed on an isometric force dynamometer (Humac Norm, Cybex, USA) following a 2 min rest after CMJ testing following similar methods to those used by Cheng and Rice (2005), which have been shown to possess low CV (5.0 – 4.2%), high ICC (0.92 – 0.97) and low standard error of measurement (SEM; 3.45 Nm) (Zech et al., 2008). Participants were placed in a seated position with the left hip and knee flexed at 90° with the trunk and left thigh tightly secured by velcro-straps to the experimental chair, and the rotational axis of the left knee (tibio-femoral joint) was aligned with the axis of rotation of the dynamometer's mechanical lever arm. The left leg was also strapped to the transducer arm-pad, aligning the bottom of the pad with the medial malleolus of the tibia. Participants performed one warm-up isometric contraction at 75% of self-perceived maximal effort and three experimental isometric contractions at 100% effort lasting 5 s, interspersed with 60 s of rest. Peak torque production was taken as the maximal torque value produced across the 3 efforts (Cheng and Rice, 2005).

Subjective recovery is further explained in Section 3.5.1. At Pre and 84 h post-exercise, participants were asked to complete the profile of mood states (POMS; Appendix 4) questionnaire to assess overall mood disturbance (McNair et al., 1971). The 65 question POMS questionnaire rates feelings from “not at all” to “extremely” over the past 7 days, with each response given a score from 1 to 5 and tallied to give a total score. Questions are grouped into feelings of Anger, Confusion, Depression, Fatigue, Tension and Vigour to characterise mood states during sleep extension (Kamdar et al., 2004; Mah et al., 2011). This measure also possesses high internal reliability ($\alpha = 0.72 – 0.84$; Terry and Lane (2000)).

3.3.4 Blood Analysis

Blood samples for the studies described in Chapters 7 and 8 were taken from a vein in the antecubital crease of the forearm. Samples were placed into a serum separator vacutainer (5 mL; Becton, Dickson and Company, UK) and were allowed to sit at room temperature for 30 min before being centrifuged. Samples were spun at 2,500 rpm at 4°C for 15 min. Following centrifugation, 1 mL serum aliquots were frozen at -80°C for later analysis. Concentrations of biochemical markers were determined in duplicate by enzyme-linked immunosorbent assays (ELISA) using commercially available kits (Abcam, UK) for interleukin-6 (IL-6; ab46042 – IL-6 High Sensitivity Human ELISA kit, intra-assay precision = 4.4% and inter-assay precision = 9.1%.), Human Growth Hormone (GH; ab108643 – Human Growth Hormone ELISA Kit, intra-assay precision = 8.1% and inter-assay precision = 8.3%) and insulin-like growth factor-1 (IGF-1; ab211651 – Human IGF-1 SimpleStep ELISA Kit, intra-assay precision = 2.3% and inter-assay precision = 6.2%).

3.4 Training Load Quantification

3.4.1 Internal Training Load

Post-training ratings of session RPE (s-RPE) were reported using the 10-point modified category ratio Borg scale, the CR-10 (Foster et al., 2001). Table 3.4 displays the category ratio used for the CR-10 s-RPE. In Chapters 4, 5 and 6 the CR-10 was multiplied by the session duration to calculate internal training load, which has been used extensively in team-sport athletes to quantify training load (Scott et al., 2013).

Table 3.4. Modified CR-10 Borg scale used for subject's ratings of s-RPE following exercise.

Rating	Description
0	Nothing at all
1	Very Light
2	Light
3	Moderate
4	Somewhat Hard
5	Heavy
6	
7	Very Heavy
8	
9	Very Very Heavy
10	Maximal

3.4.2 External Training Load

External training load data (total distance; TD, TD per minute; $m \cdot min^{-1}$, high-speed running distance above 14.4 $km \cdot h^{-1}$; HSR, and running distance above 24.9 $km \cdot h^{-1}$; VHSR) was collected using commercially-available wearable devices (OptimEye S5, Catapult Innovations, Australia) during all outdoor training sessions and matches completed by participants in Chapters 4, 5 and 6. Each athlete wore the same device for all training sessions and matches, which was worn inside a custom-made pouch positioned on the upper back between the scapulae. The devices have a global positioning system (GPS) that sample at 10 Hz and an accelerometer that sample at 100 Hz. The accuracy of GPS units sampling at 10 Hz has been described previously as possessing 2.8 – 10.5% error compared to radar-guided criterion measures (Rampinini et al., 2014).

3.5. Measurement of Psycho-Cognitive Variables

3.5.1 Subjective Wellbeing

Subjective wellness measures were taken at the same time of day each morning prior to daily training activities in Chapters 4. Based on previous research by Hooper and Mackinnon (1995), performance staff at the Western Bulldogs implemented a custom-designed daily subjective wellness questionnaire, where athletes subjectively rated measures of fatigue, stress, muscle soreness, sleep quality and mood on a 1 to 10 scale (1 being worst possible, 10 being best possible). Laboratory-based measures of subjective wellness in Chapters 7 and 8 (Appendix 5) were completed to assess fatigue, sleep quality, muscle soreness, stress and mood, using a 1 to

5 scale (e.g., Fatigue = 5; Very Fresh vs Fatigue = 1; Always Tired) that has been previously used to assess perceived recovery (McLean et al., 2010). Total wellbeing was calculated as the sum of scores for each question, with higher values representing more favourable outcomes.

3.6 High Intensity Interval Exercise

In Chapter 7 the high-intensity exercise (HIIE) bout started at 4:00 pm, whereas in Chapter 8 the HIIE bout started at 8:00 pm. The HIIE consisted of four consecutive 15 min blocks of interval running (Figure 3.2) on a motorised treadmill (Katana Sport, Lode, Netherlands) in ambient laboratory conditions (22.1 ± 1.5 °C and 44.9 ± 7.1 % relative humidity). Each 15 min block consisted of running for 5 min at an intensity corresponding to 65% of the velocity at maximal oxygen uptake ($v\dot{V}O_2max$), 1 min at 50% $v\dot{V}O_2max$, 3 min at 90% $v\dot{V}O_2max$, 2 min at 50% $v\dot{V}O_2max$, three 30 s efforts at 120% $v\dot{V}O_2max$ interspersed with 30 s at 50% $v\dot{V}O_2max$ and 90 s at 50% $v\dot{V}O_2max$. The final 15 min block did not utilise the final 90 s recovery at 50% $v\dot{V}O_2max$ resulting in a total exercise time of 58 min 30 s. Pilot work showed that this protocol induces similar post-exercise reductions in physical function and perceived wellbeing to team-sport competition (McLean et al., 2010), with ~22% decreases in a maximal isometric torque production of the knee and increased subjective muscle soreness ratings for up to 48 h following HIIE, deeming it appropriate for use in Chapters 7 and 8 (Figure 3.3).

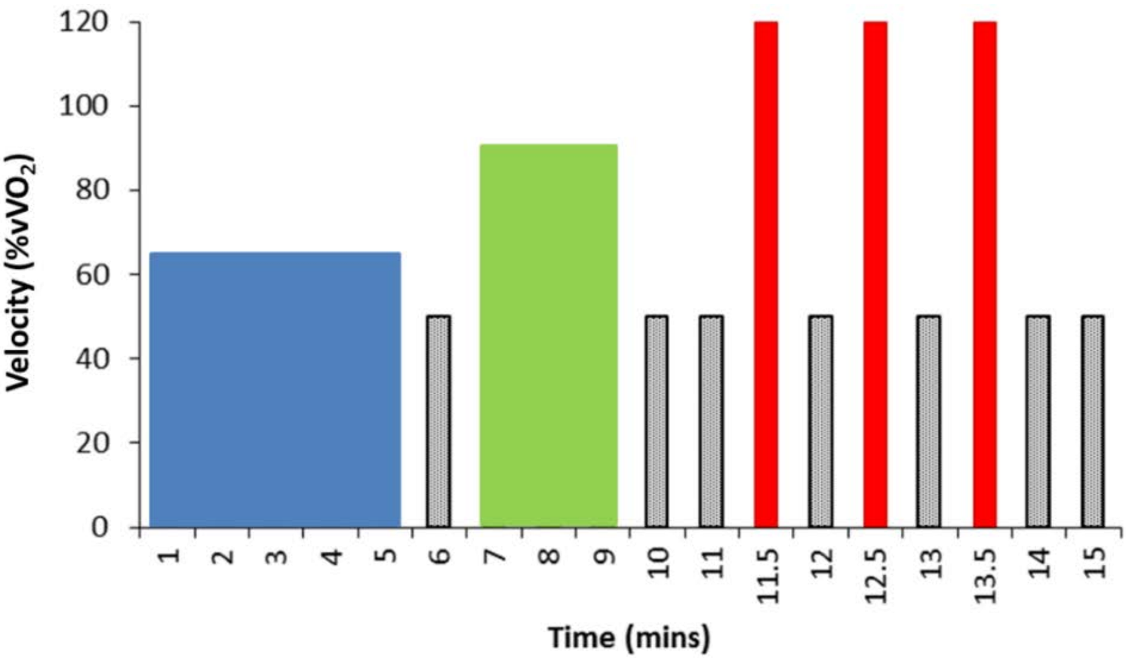


Figure 3.2. Schematic representation of the 15 min blocks of running during the HIIE bout.

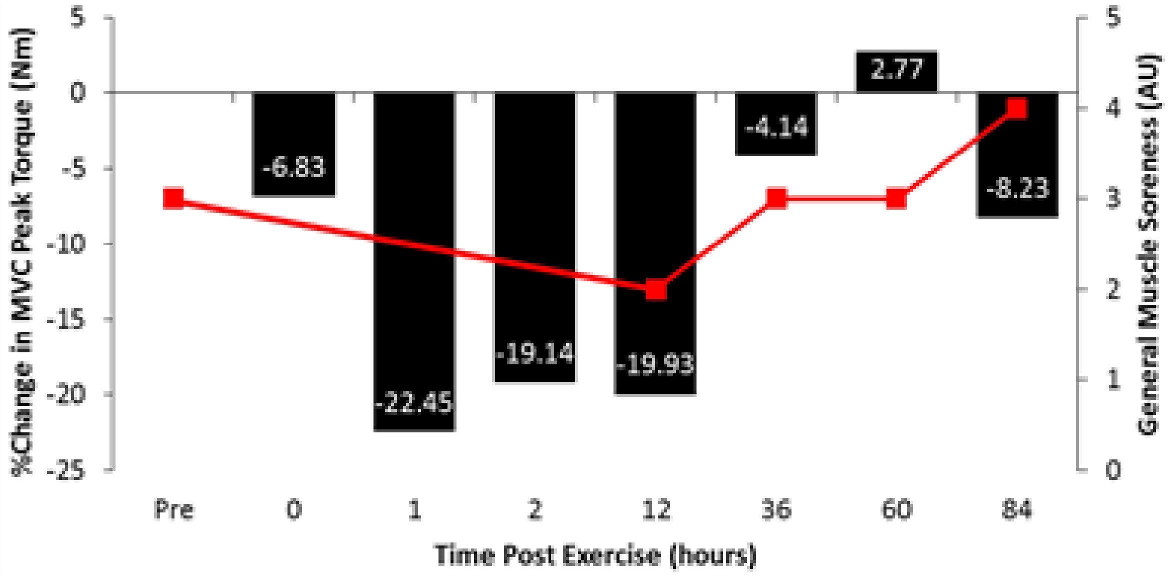


Figure 3.3. Change is isometric maximal voluntary contraction torque production (black bars) and subjective ratings of muscle soreness (closed red squares and red line) following pilot testing of the HIIE bout utilised in Chapters 7 and 8.

3.7 Dietary Standardisation

Participants were supplied with a standardised diet throughout the duration of Studies 4 and 5. Pre-HIIE a meal was consumed 2 h prior consisting of 1.5 g·kg^{-1} carbohydrate (CHO), 0.3 g·kg^{-1} protein (PRO) and 0.2 g·kg^{-1} fat. A snack was provided 2 h post-HIIE consisting of a protein supplement providing 0.25 g·kg^{-1} PRO and muesli bar containing 52 g of CHO, 7 g PRO and 26 g fat. Daily macronutrient intakes on the days following HIIE consisted of 4.0 g·kg^{-1} CHO, 1.5 g·kg^{-1} PRO and 1.0 g·kg^{-1} fat which aligns with observed macronutrient intakes of team-sport athletes (Bradley et al., 2015a; Bradley et al., 2015b; Devlin et al., 2017). Breakfast on the final morning prior to performance testing contained the same macronutrient content as the pre-HIIE meal.

CHAPTER 4. STUDY 1 – A CHANGE IN TRAINING ENVIRONMENT ALTERS SLEEP QUALITY BUT NOT QUANTITY IN ELITE AUSTRALIAN RULES FOOTBALL PLAYERS

Australian Rules footballers undertake intensified periods of training, known as training camps, that expose athletes to new and unfamiliar environments and training stimuli to enhance preparation for the in-season competitive period. Intensified training periods, travel, and a change in sleeping environment can negatively influence sleep behaviours in athlete populations. As such, this study was designed to investigate how pre-season training camps influence the sleep behaviours of Australian Rules footballers. This study has been published in the International Journal of Sport Physiology and Performance (Appendix 6): Pitchford NW, Robertson SJ, Sargent C, Cordy J, Bishop D & Bartlett JD (2017). “A Change in Training Environment Alters Sleep Quality but not Quantity in Elite Australian Rules Football Players.” *International Journal of Sports Physiology and Performance* 12: 75-80. This work was also an Oral Presentation at Sports Medicine Australia Conference, Queensland, Australia 2015.

4.1 Introduction

Australian Rules football (ARF) clubs commonly undertake pre-season training camps to improve team cohesion and morale, and to maximise training adaptations using specific training methods (Buchheit et al., 2013b). However, camps also often require athletes to travel and stay in unfamiliar environments, which may negatively impact sleep (Bishop, 2004; Erlacher et al., 2011). Sleep is widely considered to be a major contributor to athletic recovery (Lastella et al., 2014c) and performance (Samuels, 2008), with evidence that sleep disruption negatively affects psychological and physiological performance measures (Belenky et al., 2003; Mougin et al., 1991). Investigating the influence of changing the training environment on the sleep of elite AF players may aid in the design of training interventions that minimise the potentially negative influences of poor sleep and recovery to maximise training adaptations.

Training camps often combine changes in the training environment with additional environmental stressors, such as altitude or heat (Buchheit et al., 2013a; Sargent et al., 2013). In isolation, altitude and heat exposure have been shown to negatively influence objective measures of sleep quantity and quality (Okamoto-Mizuno et al., 2005; Roach et al., 2013). However, the impact of changing training environment alone, such as during a training camp, on sleep quantity and quality is unknown. Changes in sleep location may disrupt sleep (Bishop, 2004), with ~28% of athletes from a German sample reporting unusual surroundings as disruptive to sleep on the night prior to competition (Erlacher et al., 2011). AF players also regularly travel interstate for pre-season camps and during the in-season period, resulting in reduced sleep durations when away from home on the night pre-game (Richmond et al., 2004).

Another important consideration is the effect of increased training load on sleep. For example, Killer et al. (2015) reported disturbed sleep and mood state during a period of intensified training, while Kölling et al. (2016) reported less restful sleep in the first half of a 4-week training camp in elite youth rowers. Indeed, poor or disrupted sleep may negatively influence training adaptations and the efficacy of training interventions, an unfavourable situation for elite team-sport athletes. Given this, further research is required to uncover the influence of changing training and sleep location on quality and quantity of sleep during periods of high-training load.

The aim of the current study was to assess the effects of a change in physical sleeping environment on objective and subjective measures of sleep quality and quantity in elite Australian Rules footballers during a training camp in the pre-season training phase.

4.2 Methods

4.2.1 Participants

Participant information is detailed in Chapter 3 Section 3.1.1.

4.2.2 Sleep Assessment

Methods regarding the sleep assessment in this study are as previously described in Chapter 3, Sections 3.2.1 and 3.2.2. In brief, sleep was assessed using wrist-watch activity devices across an 8-day Home and 8-day Camp period. Actiwatch 2 (Actiwatch 2, Philips Respironics, PA, USA) and Actigraph wGTX3 (Actigraph wGTX3 monitor, Actigraph, FL, USA) devices were used interchangeably during the Home period and, as such, cross-device validity was assessed prior to measurement. Methods regarding the cross-device validity assessment used to inform this study are as previously described in Chapter 3, Section 3.2.4. In brief, six participants from a separate sample of healthy adult males wore both the Actiwatch 2 and Actigraph wGTX3 wrist-worn activity devices simultaneously and completed subjective sleep diaries on each morning for 3 consecutive nights in the home environment. Concurrent validity of the devices was assessed using Pearson correlation coefficients and typical error of estimate (TEE) (Hopkins, 2000). Sleep efficiency (SEF, $r = 0.92$, TEE = 2.1%), time in bed (TIB, $r = 0.97$, TEE = 2.9%), total sleep time (TST, $r = 0.91$, TEE = 6.2%) and wake after sleep onset (WASO, $r = 0.96$, TEE = 21.1%) demonstrated strong validity between devices. As such, these four objective measures were deemed suitable to determine sleep quantity (TIB, TST) and sleep quality (SE, WASO) for the current study. Sleep onset latency (SOL) was deemed not reliable ($r = 0.41$, TEE = 57%) and so was not used in the study.

4.2.3 Data Collection

During both the Home and Camp periods, participants completed 5 ± 1 training-days and 3 ± 1 recovery-days. Both the Home (December 2014, n = 8, Actiwatch 2; or January 2015, n = 11, Actigraph wGTX3) and Camp (January-February 2015, n = 19, Actigraph wGTX3) periods took place during the pre-season training phase and followed similar time-of-day training schedules. Home training occurred at the club's training facility in Melbourne, Australia (Latitude 37°S, Longitude 144°E), with participants sleeping in their normal home-based sleeping environment (in their own beds); they were not grouped or paired with other participants. The Camp occurred at the Sunshine Coast, Australia (Latitude 27°S, Longitude 153°E), with participants sleeping in a 4-Star hotel with access to air conditioning and comfortable bedding. On Camp, participants chose who to room with and were subsequently placed in a shared living environment with another participant. Training times were consistent between the Home (Figure 3.1; Pre-Season panel) and Camp environments (commencing between 9:00 - 10:00 am, concluding before 6:00pm), and participants did not experience competition, transmeridian travel or a change in altitude, leaving location as the difference between Home and Camp environments. Daytime training environmental conditions for Home (23.6 ± 4.4°C, 66.5 ± 3.2% RH) and Camp (29.0 ± 1.8°C, 67.8 ± 6.5% RH) were retrospectively obtained via Australia's Bureau of Meteorology (www.bom.gov.au). Overnight room temperature at both locations ranged between 18 to 22 °C and was kept constant through the use of air conditioning at the discretion of participants. Internal training load was collected as per Chapter 3 Section 3.4.1 and subjective wellness was collected as per Chapter 3 Section 3.5.1.

4.2.4 Statistical Analysis

Repeated-measures ANOVA were used to analyse differences in objective sleep measures (TIB, TST, SEF (TST ÷ TIB x 100) and WASO), s-RPE training load, temperature, relative humidity and subjective wellness between Home and Camp. One-way ANOVA was used to compare sleep onset and wake times for differences in sleep behaviour between Home and Camp. The summation of fatigue, muscle soreness, stress, mood and sleep quality scores from the subjective wellness questionnaire represented total wellness, which has previously been used to track the response to competition in team-sport athletes (McLean et al., 2010). Statistical significance was set to $p = 0.006$ via Bonferonni correction. Pearson correlation coefficients, controlling for repeated observations on players, were used to assess the relationship between sleep behaviours and s-RPE training load, relative Camp sleep behaviours (expressed as absolute change from individual environment mean), and absolute change in s-RPE training load from the individual environment mean. Cohen's effect sizes (d) were calculated using player mean values between Home and Camp (<0.2 = very small effect, 0.2-0.5 = small effect, 0.5-0.8 = moderate effect, >0.8 = large effect).

4.3 Results

4.3.1 Home versus Camp

Descriptive statistics for sleep behaviours and training-related parameters between Home and Camp are compared in Table 4.1. One-way ANOVA showed that sleep onset ($p < 0.001$) and wake times ($p = 0.003$) were significantly earlier on Camp compared to Home (Table 3.1). Repeated measures ANOVA revealed that time in bed ($p < 0.001$) and wake after sleep onset ($p < 0.001$) were significantly increased on Camp compared to Home. However, there was no significant change in total sleep time ($p = 0.846$), resulting in a significant decrease in sleep efficiency ($p < 0.001$) on Camp. Despite the observed changes in objective sleep measures, there was no difference between Home and Camp for subjective ratings of sleep quality (Table 4.1). Effect size calculations between grouped player mean values revealed a moderate effect of Camp on sleep onset ($d = -0.47$), a small effect on wake times ($d = -0.36$), large effects on time in bed ($d = 1.21$), sleep efficiency ($d = -0.93$) and wake after sleep onset ($d = 0.87$), and only a very small effect on total sleep time ($d = -0.07$).

Repeated measures ANOVA also showed that mean daily s-RPE training load ($p = 0.398$) and total player wellness ($p = 0.023$) were not significantly different on Camp compared to Home. Although training temperature ($p < 0.001$) during Camp was significantly hotter than Home, relative humidity ($p = 0.277$) did not differ (Table 3.1). Effect size calculations also revealed a very small effect of a change in training environment on s-RPE training load ($d = 0.10$), a small effect on total player wellbeing ($d = -0.36$), a large effect on daytime training temperatures ($d = 1.63$), and only a very small effect on daytime training humidity ($d = 0.13$).

Table 4.1. Sleep behaviours and training characteristics between Home and Camp in elite Australian Rules Footballers. Data presented as mean ± SD. Comparisons between Home and Camp are expressed as standardised effect sizes (±95% confidence interval) and p-value.

	Home	Camp	Effect Size (95% CI)	p-value
Sleep-specific measures				
Bed time (hh:mm)	22:25 ± 02:02	21:40 ± 00:46	-0.47 (-0.71, -0.24)	***<0.001****
Wake time (hh:mm)	06:51 ± 01:03	06:31 ± 00:44	-0.36 (-0.59, -0.13)	***0.003****
Time in bed (h:mm)	8:17 ± 0:32	8:51 ± 0:24	1.21 (0.50, 1.88)	***< 0.001****
Total sleep time (h:mm)	6:59 ± 0:26	6:57 ± 0:38	-0.07 (-0.71, 0.56)	0.846
Sleep efficiency (%)	84.7 ± 6.5	78.7 ± 6.5	-0.93 (-1.57, -0.24)	***< 0.001****
Wake after sleep onset (h:mm)	1:09 ± 0:30	1:37 ± 0:34	0.87 (0.19, 1.51)	***< 0.001****
Subjective sleep quality (AU)	3.50 ± 0.43	3.46 ± 0.52	-0.08 (-0.72, 0.55)	0.946
Training-specific measures				
s-RPE load (AU)	396 ± 394	440 ± 502	0.10 (-0.13, 0.32)	0.398
Temperature (°C)	23.6 ± 4.4	29.0 ± 1.8	1.63 (1.36, 1.88)	***< 0.001****
Relative humidity (%)	66.5 ± 13.2	67.8 ± 6.5	0.13 (0.10, 0.35)	0.277
Total wellness (AU)	39.7 ± 2.9	38.8 ± 2.2	-0.36 (-0.65, -0.07)	0.023

AU = arbitrary units, CI = confidence intervals, hh:mm = time in hours and minutes, min = minutes, °C = degrees Celsius, % = percent, * = significant difference ($P < 0.006$).

4.3.2 Load and Sleep Relationship

When analysing individualised responses to a change in physical sleep environment, relative changes in time in bed ($r = -0.75$, $p < 0.001$) and wake after sleep onset ($r = -0.72$, $p < 0.001$) on Camp had a strong negative correlation with absolute Home values (Figure 4.1). When accounting for daily variations of within-player training load, changes in s-RPE training load had weak correlations with changes in total sleep time in the Home environment for both increased ($r = 0.051$, $p = 0.74$) and decreased s-RPE training load ($r = -0.033$, $p = 0.74$). Comparatively, in the Camp environment, changes in s-RPE training load displayed a moderate negative correlation with changes in total sleep time for increased load ($r = -0.367$, $p = 0.010$) and a moderate positive correlation for decreased load ($r = 0.319$, $p = 0.003$) (Figure 4.2).

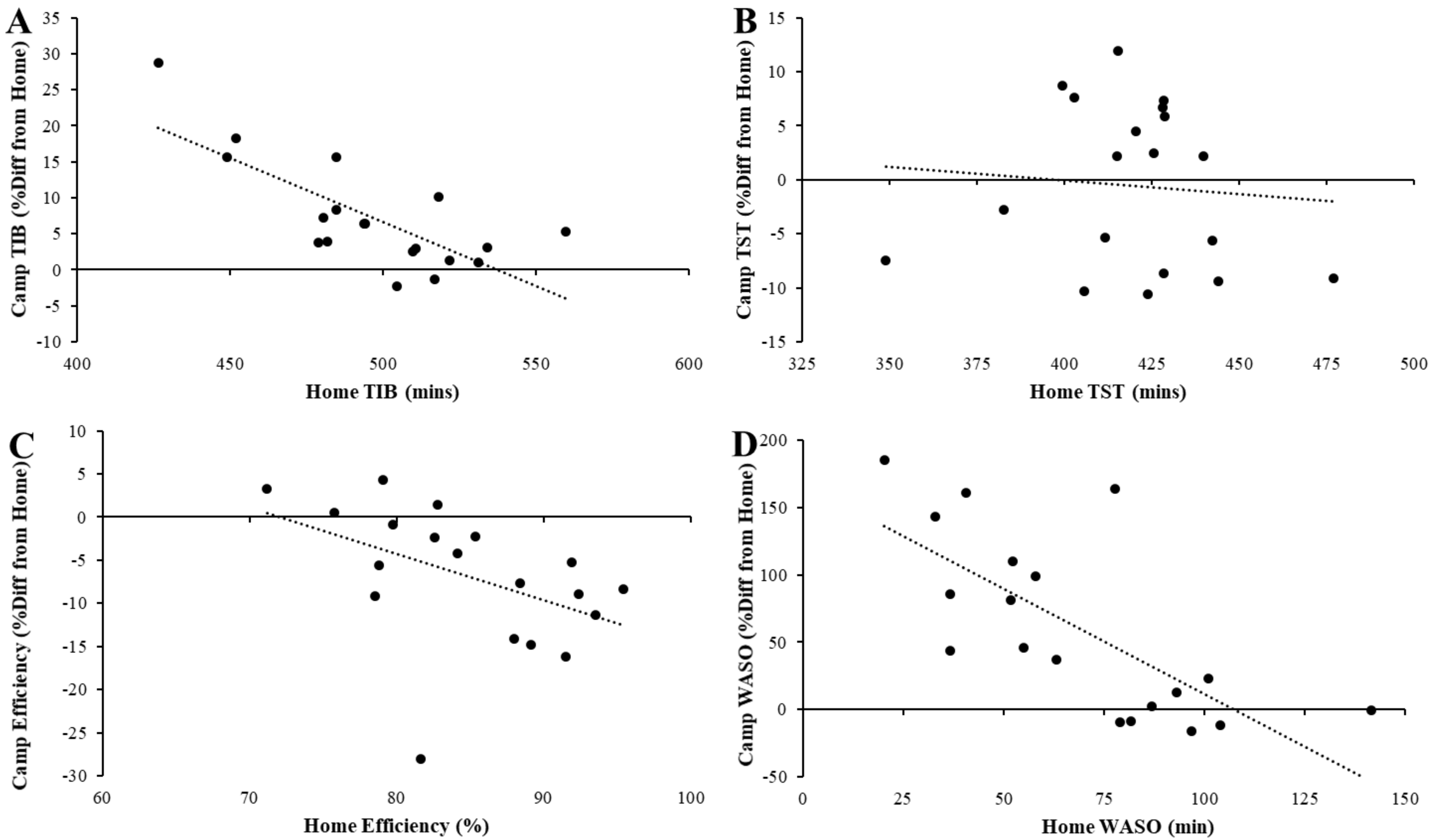
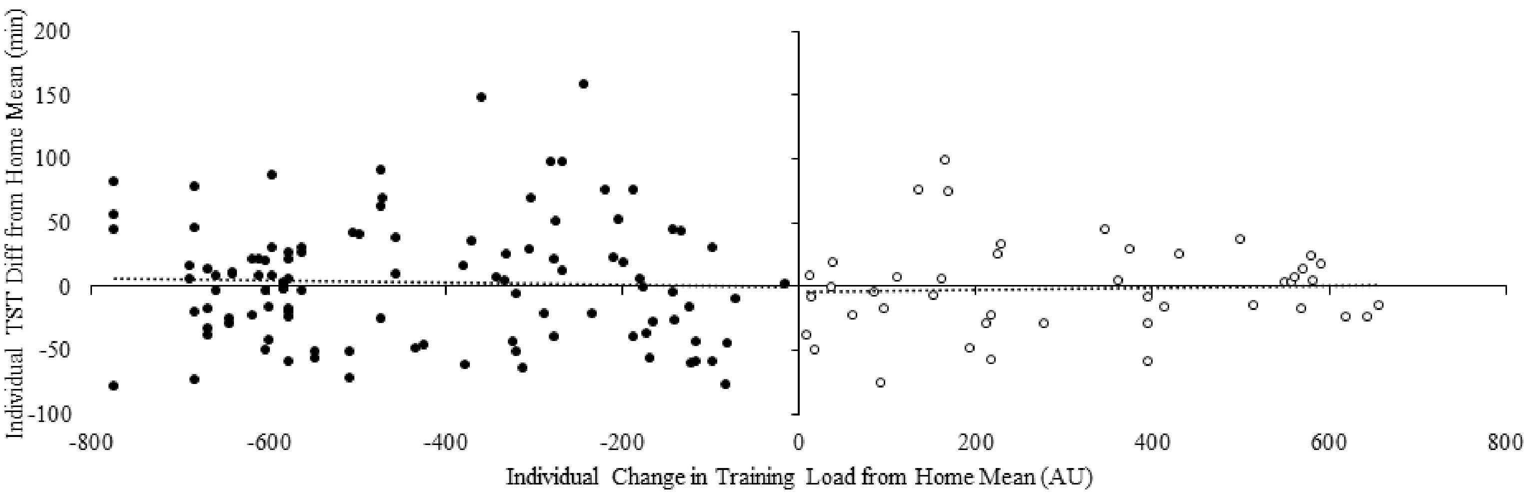


Figure 4.1. Sleep behaviours on Camp expressed as relative individual changes from mean Home (A) time in bed, (B) total sleep time, (C) sleep efficiency and (D) wake after sleep onset.

A



B

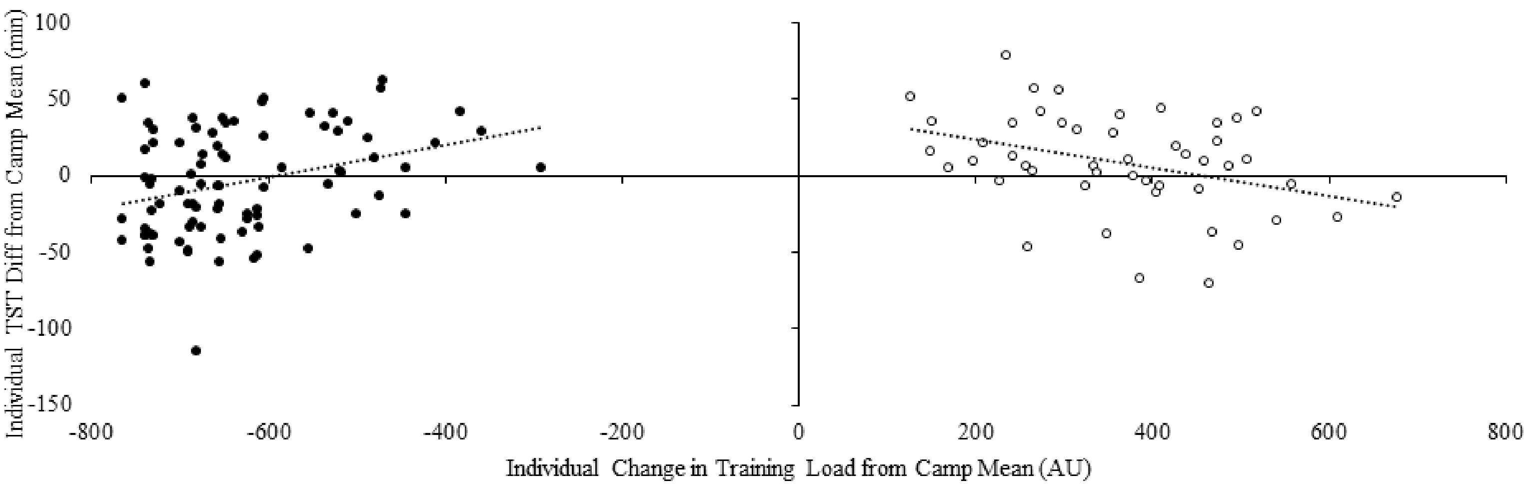


Figure 4.2. Variations in total sleep time from the environment mean in response to increased (Open circles) and decreased (Solid circles) daily training load from (A) the environment mean at Home and (B) on Camp.

4.4 Discussion

The aim of the current study was to determine the effect of changing physical sleep environment on objective sleep quality and quantity in elite AF players during the pre-season training period. This study found that during Camp players spent longer in bed, as a result of earlier sleep onset times that were not matched by equal alterations in wake times, and exhibited more wake after sleep onset, resulting in lower sleep efficiency compared to Home. Further, players who spent less time in bed at Home increased time in bed to a greater extent on Camp compared to those who spent longer in bed at Home. Whilst these results are independent of mean daily training load, when changes in the individual daily training load are accounted for, alterations in daily training load on Camp resulted in greater changes in total sleep time compared to Home. Together, these results have relevance for practitioners in highlighting the need for individualised sleep strategies so as to overcome the negative effects of changes in sleep environment.

This is the first study to observe a negative effect of changing sleep environment on sleep quality during periods of similar training loads in team-sport athletes. We found that athletes with higher sleep quality at Home were worse sleepers at Camp, whereas those that slept poorer at Home slept similarly on Camp. Sleep quality in athletes can be affected by numerous factors, such as travel (Reilly et al., 2005), competition (Fullagar et al., 2015b) and training load (Taylor et al., 1997). Further, Lastella et al. (2015) have shown that increased daily competition load in cyclists significantly reduces time in bed and total sleep time, without changes in subjective or objective sleep quality. The current study showed that a change from Home to Camp, where participants stayed in a hotel and roomed with a teammate, negatively impacted sleep quality, despite no difference in mean training load. Whilst poor sleep can result from changes in training load (Killer et al., 2015; Taylor et al., 1997), these changes have predominantly been assessed on a global scale, without consideration for an individual's daily variation in load and sleep. Indeed, when accounting for variations in daily training load, this study found that when there is a change in sleep location, total sleep time responds in a different manner. For example, on Camp, as the change in daily training load varied further from the mean training load for each individual, there was a reduction in sleep duration (Figure 3.2). Although these results appear consistent with previous research (Taylor et al., 1997; Hausswirth et al., 2014), it unclear as to the reason for this and so further research is required to determine the longer term effect on training adaptation.

Studies investigating changes in physical sleeping environment have focussed on situations where participants travel across multiple time-zones, creating a circadian dysrhythmia and reduced sleep quality (Lastella et al., 2014b). Although the current study involved travel, it was in a Northerly direction during the day, without crossing time-zones and without impacting on participants' sleep opportunities. Furthermore, camp situations are often accompanied by altered daily schedules, as a result of commitments outside of training, which may impact on sleep behaviour. Although sleep onset and wake times were earlier on Camp in the present study, this did not appear to be a result of altered daily schedules as there was no change between Home and Camp. However, it should be noted that due to the change in latitude, there is a small change in daylight savings, with earlier sunrise and sunset on Camp. Hence, it should not be discounted that the earlier sunset influenced the choice of bedtime each night.

Previous work involving changes in physical sleeping environment have examined tournament-type competition (Fullagar et al., 2015b) or regular/weekly competition (Richmond et al., 2004) and compared sleep during periods of competition in a different physical environment to sleep during periods of training at home (Lastella et al., 2015; Lastella et al., 2014a). Lastella et al. (2014a) found that ~68% of athletes report poorer sleep quality on nights prior to competition and that this is often related to feelings of anxiety, fatigue, mood, tension and vigour. Although no competition occurred in the Camp environment, athletes in the current study spent significantly longer in bed, without the benefits of increased sleep time. Indeed, wake after sleep onset was ~30 min higher on Camp, and, therefore, may explain the difference in time in bed between Home and Camp (~34 min). However, due to the very high TEE (57%) between activity devices for sleep onset latency measurements, this study is limited in its application of this measure. In this regard, this should be seen as a limitation of the current results. Nevertheless, future work should aim to identify the behavioural changes that are associated with changes in sleep behaviour.

The consideration of non-training related factors relevant to the physical environment are also important. Ambient environmental temperature can negatively impact sleep, with exposure to heat before and during the sleep period reducing sleep duration and increasing night-time awakenings (Libert et al., 1988). The present study showed significantly higher day-time temperatures on Camp compared to Home, corresponding with increased wake after sleep onset and reduced sleep efficiency, but no change in sleep duration. However, the temperature difference between Home and Camp in the present study was much less than in previous literature and did not reach temperatures commonly used in studies of heat exposure and sleep

(Okamoto-Mizuno et al., 2005; Libert et al., 1988). Further, night-time temperatures in this study were athlete-controlled (18-22 °C) through the use of air conditioning, thus in keeping with recent sleep hygiene recommendations for athletic populations (Nédélec et al., 2015). Although it cannot be entirely ruled out that the elevated daytime temperature on Camp influenced sleep in the present study, this does not explain the increased time in bed and the lack of overnight heat being reported as a reason for disrupted sleep from the subjective sleep diaries. In addition, it is difficult to say whether air conditioning had any impact on wake after sleep onset. Thus, future research should examine the impact of both air conditioning and ambient overnight temperature on sleep. It is important to note that it is a possibility that the change in sleep behaviour may be driven by a conscious process of respecting their team-mates space and noise, as all participants in the present study shared rooms with another participant during the Camp period only. The degree and variation in the consideration of fellow participants may also vary depending on the individual relationships and habits of room-sharing participants and therefore should be considered in the interpretation of findings. Despite the need for individualised approaches so as to promote optimal sleep opportunities, the individualised nature of responses to changes in the physical sleep environment requires greater investigation. Together, this may have implications in the provision of sleep interventions and sleep hygiene recommendations.

In the current study we observed that those with higher Home sleep efficiency experienced a greater decline in sleep efficiency during Camp. Hence, it is important that individually tailored sleep interventions are implemented to maximise total sleep time. For instance, if participants in the current study maintained Home sleep efficiency of 84.7% whilst on Camp, total sleep time as a result of increased time in bed would have been extended by 29 min. Indeed, sleep extension in basketball players improved sprint time, free throw accuracy, reaction time and ratings of physical and mental wellbeing (Mah et al., 2011). Theoretically, maximising total sleep time and therefore recovery during a period of high training stress may accentuate training adaptations and aid in reducing the risk of injury (Milewski et al., 2014). However, given the lack of evidence on sleep extension in athletes, future research should aim to uncover the smallest worthwhile increase in sleep so as to improve training and/or competition performance.

A change in physical sleep environment, without external influences such as circadian phase-shifting, altered training schedules or increased total training load, reduces the quality of sleep and effects the attainment of increased duration of sleep, despite spending longer periods of time in bed. This may have further flow-on effects to recovery and the adaptive training response during periods where physiological adaptations are crucial to performance. Furthermore, the individual variation in response to a change in environment stresses the importance of assessing sleep on a case-by-case basis, especially if assessment leads to the provision of interventions designed at improving the sleep of athletes during time spent in unfamiliar physical sleeping environments.

CHAPTER 5. STUDY 2 – FACTORS THAT INFLUENCE SLEEP BEHAVIOURS OF AUSTRALIAN RULES FOOTBALL PLAYERS ACROSS A COMPETITIVE SEASON.

The previous Chapter revealed that Australian Rules footballers experience worse sleep quality when sleeping in an unfamiliar environment and that large between-individual factors may influence sleep behaviours. However, this was only completed during a pre-season training camp and there is a lack of literature that has investigated the sleep behaviours of athletes across both the pre-season and in-season phases. Therefore, this second study was designed to investigate the effects of influencing factors relevant to the individual and team-environment on the sleep behaviours of Australian Rules footballers. This work was presented as an Oral Presentation at the 21st Annual Congress of the European College of Sport Science, Vienna, Austria 2016 (given by Supervisor Dr Bartlett).

5.1 Introduction

Reduced quality and quantity of sleep impairs cognitive function, physiological markers of recovery, and exercise ability, all of which can lead to impaired athletic performance (Fullagar et al., 2015c; Halson, 2008). Previous research indicates that team-sport athletes experience changes in sleep quality and quantity between the pre-season and in-season periods (Chapter 4; (Caia et al., 2017b; Lalor et al., 2017)). Furthermore, during the in-season period team-sport athletes sleep longer on the night before a match, sleep less and with lower sleep efficiency on match nights, before restoring sleep to 'habitual' or 'normative' durations during recovery nights following matches (Eagles et al., 2016; Sargent and Roach, 2016; Lalor et al., 2017; Richmond et al., 2004; Carriço et al., 2018). However, athlete-specific contextual factors, such as age and chronotype, may vary the effect of environment-specific contextual factors, such as season period and training schedules, competition, and travel requirements, on sleep behaviours of athletes. At present, the effects that contextual factors relevant to team-sport athletes have on subsequent sleep behaviours are yet to be investigated.

The sleep behaviours of athletes are highly individualised and can vary even within sports (Lastella et al., 2014e). For example, Caia et al. (2017b) reported that rugby league athletes go to bed and wake earlier during the pre-season period without changes in sleep duration, yet Thornton et al. (2017a) observed that a different cohort of rugby league athletes experience increased sleep duration during the pre-season period as a result of heightened training load. Hence, the consideration of contextual factors relevant to both the environment and individual athlete is paramount to the interpretation of changes in sleep behaviour that occurs. Contextual factors specific to the environment, such as season period, training schedules, and travel requirements, may have compounding effects on the sleep behaviours of athletes. For example, results from Chapter 4 showed that sleeping in unfamiliar environments during pre-season camps reduces the sleep quality and quantity of Australian Rules footballers (Pitchford et al., 2017); similar results have been reported for rugby league players (Thornton et al., 2017b). Furthermore, sleep duration is reduced on the night of away matches compared to home matches in Australian Rules footballers (Richmond et al., 2004) and soccer players (Carriço et al., 2018). However, in previous investigations, athletes were required to attend early-morning training or recovery commitments on the morning following matches (Lalor et al., 2017), or athletes travelled after matches (Richmond et al., 2004; Carriço et al., 2018), which may limit the opportunity for sleep and influence results. Yet, this provides further support to previous evidence indicating the negative effects of restrictive scheduling on sleep opportunity and subsequent sleep duration in athletes (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b). Despite previous evidence showing the effects of environment-specific contextual factors on the sleep behaviours of team-sport athletes, the contextual factors specific to the individual athlete that may modify sleep behaviours, such as age and chronotype, have not been as thoroughly investigated.

Athletes from both individual and team sport populations display a greater propensity for morning-type and intermediate-type chronotypes than evening-type chronotypes compared to non-athletic populations (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016). Within athlete populations, team-based sports display a greater proportion of later chronotypes compared to individual sports (Lastella et al., 2016). An individual's preference for the arrangement of their daily schedule (e.g. chronotype) can influence exercise performance. Indeed, maximal oxygen consumption is higher in the evening for evening-type chronotypes, whereas no change in maximal oxygen consumption is observed between the morning and evening for morning-types chronotypes (Hill et al., 1988). Morning-type athletes perceive high-intensity exercise to be harder during the evening (6:00 pm and 10:00 pm), than during the morning and afternoon sessions (6:00 am, 10:00 am and 2:00 pm) (Kunorozva et al., 2014). This may be related to the reduced sleep duration and sleep efficiency observed in morning-type soccer players following evening exercise, but not morning exercise (Vitale et al., 2017). Age may also influence an individual's sleep behaviours. During adolescence, there is a shift towards delayed sleep-wake patterns and a more evening chronotype (Hagenauer and Lee, 2012), which may increase sleep variability (Carskadon, 2011; Danielsson et al., 2016; Wolfson and Carskadon, 2003). Indeed, Caia et al. (2017a) found that elite-level senior (25.5 ± 3.7 y) rugby league athletes display significantly earlier bed times, sleep onset times, and wake times compared to their junior elite counterparts (18.8 ± 0.9 y). Although this was not accompanied by substantial differences in absolute sleep duration or quality, greater intra-individual variability for sleep onset time, sleep duration and sleep quality was observed in the elite junior athletes (Caia et al., 2017a). These differences may be explained by aforementioned chronotype-shifts observed in adolescent athletes (Hagenauer and Lee, 2012). Of note, however, morningness-eveningness was not measured by Caia et al. (2017a). Despite the evidence from Caia et al. (2017a), and existing literature on chronotype in athletic populations, the effects of these contextual factors on sleep across an entire competitive season in team-sport athletes is lacking. An improved understanding of how age and chronotype can influence the sleep behaviours of athletes during pre-season and in-season periods, and their effect on sleep surrounding competition, may provide practitioners with an improved capacity to optimise sleep and enhance training outcomes, competition preparation, and recovery.

Professional Australian Rules footballers are regularly exposed to changes in environment-specific factors. These changes may expose athletes to an increased chance of altered sleep behaviour, which has previously not been assessed when considering within-individual contextual factors. Furthermore, recent investigations have identified the need for further investigation of the effects that competition, travel, age and chronotype have on the sleep behaviours of athletes (Caia et al., 2017b; Lalor et al., 2017; Caia et al., 2017a) utilising within-subject modelling to better understand the influence of these factors on the sleep behaviours of athletes (Fullagar and Bartlett, 2015; Thornton et al., 2017a). Accordingly, the aim of the present study was to explore the role that age and chronotype have in moderating the effect of seasonal period, competitive matches, competition level, and competition location, on sleep behaviours of Australian Rules footballers. It was hypothesised that Australian Rules footballers would exhibit different sleep behaviours according to the season period, competition location, and competition level; it was further hypothesised that the influence of these factors would be affected by age and chronotype.

5.2 Methods

5.2.1 Participants

Participant information is detailed in Chapter 3 Section 3.1.1.

5.2.2 Data Collection

Table 5.1 provides descriptive information for participants who either underwent pre-season assessment only, in-season assessment only, or both pre-season and in-season assessments. Nights during the in-season period were categorised into the night before a match (MN-1), the night of a match (MN), and the first (R1) and second (R2) recovery nights after a match. MN-1 sleep took place either in each participant's home sleeping environment or in a hotel before interstate matches, following a short (~30 min at 10:00 am) skill-based training session either at the Club's home training facility for home matches, (Melbourne, Victoria; UTC +10 hours) or at the venue where away matches took place (UTC +10 hours in Launceston, Tasmania; Sydney, New South Wales; Brisbane, Queensland; and Cairns, Queensland; UTC +9.5 hours in Adelaide, South Australia; UTC +8 hours in Perth, Western Australia). MN sleep took place either in each participant's home sleeping environment or in a hotel following interstate matches, with room partners either absent or self-selected by participants, but were not recorded (Adelaide, South Australia; Perth, Western Australia and Cairns, Queensland in Australia). All R1 and R2 assessments took place in the participants' home sleeping environment, with no scheduled training commitments on R1 and recovery/light skills training on the morning before R2 (~45 min at 3:00 pm). Home and away match comparisons were conducted using data from national level competition (Australian Football League; AFL) only, as players competing in the state level competition (Victorian Football League; VFL) did not travel for competition. Due to the differences between home and away matches during the in-season period, the effects of individual in-season nights surrounding competition include data from home matches only. The competition level of matches was classified as AFL or VFL to represent that when a player was not selected for AFL, they instead played in the VFL. However, the training demands were identical for both AFL and VFL players, as players were selected for competition at the conclusion of the training week, prior to competitive matches. Comparisons for the effect of competition level were conducted using data from home matches only as the VFL did not undertake interstate travel for competition.

Table 5.1. Participant characteristics based on data collection period involvement. Data are expressed as mean ± standard deviation.

	Pre-Season Only n = 17	**In-Season Only n = 5**	**Pre- and In-Season n = 13**
Age (y)	22.6 ± 3.7	24.4 ± 4.9	21.7 ± 4.4
Height (cm)	185.3 ± 5.3	190.0 ± 8.6	187.2 ± 9.2
Mass (kg)	84.0 ± 6.0	89.0 ± 8.6	84.5 ± 10.9

5.2.3 Sleep Assessment

Methods regarding the sleep assessment in this study are as previously described in Chapter 3, Sections 3.2.1 and 3.2.2. In brief, data was collected using a wrist-watch activity device, the Actiwatch 2 (Philips Respironics, PA, USA) paired with subjective sleep diaries and analysed as individual mean values from data collected across 11 ± 2 consecutive days during the pre-season period incorporating both training and non-training days (December 2014 to January 2015), and across 8 ± 6 separate 4-consecutive-day collection periods during the in-season period (April to September 2015).

5.2.4 Age and Chronotype

Participants were grouped based on common age-groupings utilised with Australian Rules football, which typically align with years of experience based on a draft age of 18. Participants aged 18-21 years of age: One to Three years post draft; Four-Seven; participants aged 22-25 years of age, and Eight-Plus; participants aged 26 years and older. At the start of the pre-season period each player completed the Horne-Ostberg morningness-eveningness questionnaire, described further in Chapter 3 Section 3.2.3. In brief, the Morningness-Eveningness Questionnaire (MEQ; Horne and Ostberg (1976)) is designed to indicate preferred sleep schedule and time-of-day for performance, classifying participants as Definite Evening, Moderate Evening, Intermediate, Moderate Morning and Definite Morning.

5.2.5 Statistical Analysis

Linear mixed models were constructed to examine differences in sleep behaviours between the pre-season training period and in-season period, and between the pre-season training period and individual in-season nights (MN-1, MN, R1 and R2). To investigate the influence of between-individual factors, age and chronotype were initially assessed by including them as fixed effects in the models. Following this, the effects of season period and nights, competition location, competition level, and match start-times on subsequent sleep behaviour was achieved by including them as fixed effects in the models, which described the relationship between the dependent variable and covariates (West et al., 2014). Quantile-Quantile (Q-Q) plots were used to examine the normality of the dependant variable's residuals using the Shapiro-Wilk test; if normality was violated the dependent variables were log-transformed and models were re-run. Following initial investigations, to account for error associated with individual repeated measures, participant was included as the random intercept effect and chronotype as the random slope. Pairwise fixed-effect comparisons were completed using the Least Squares mean test and were expressed as standardised effect sizes (ES) using between subject standard deviation, categorised according to Hopkins et al. (2009): <0.20 trivial, 0.21 – 0.60 small, 0.61 – 1.20 moderate, 1.21 – 2.0 large and > 2.1 very large. The likelihood of the observed effect was established using a non-clinical magnitude-based approach, where effects were considered clear at the 75% level (Hopkins et al., 2009). Comparative differences in text are presented as mean difference, ES, and ±90% confidence limits of ES, unless otherwise stated. Descriptive statistics in figures are presented as individual mean values, and group means ± standard deviation, unless otherwise stated. Statistical analyses were performed using R statistical software (R 3.1.0, R foundation for Statistical Computing).

5.3 Results

5.3.1 Age

Comparison between age groups revealed that the 18-21 age group displayed shorter wake after sleep onset (-0:13 h, ES = -0.55; ±0.86) and a greater sleep efficiency (3 %, ES = 0.71; ±0.68) compared to the 22-25 age group (Figure 5.1). There were no other substantial differences in sleep behaviours between age groups.

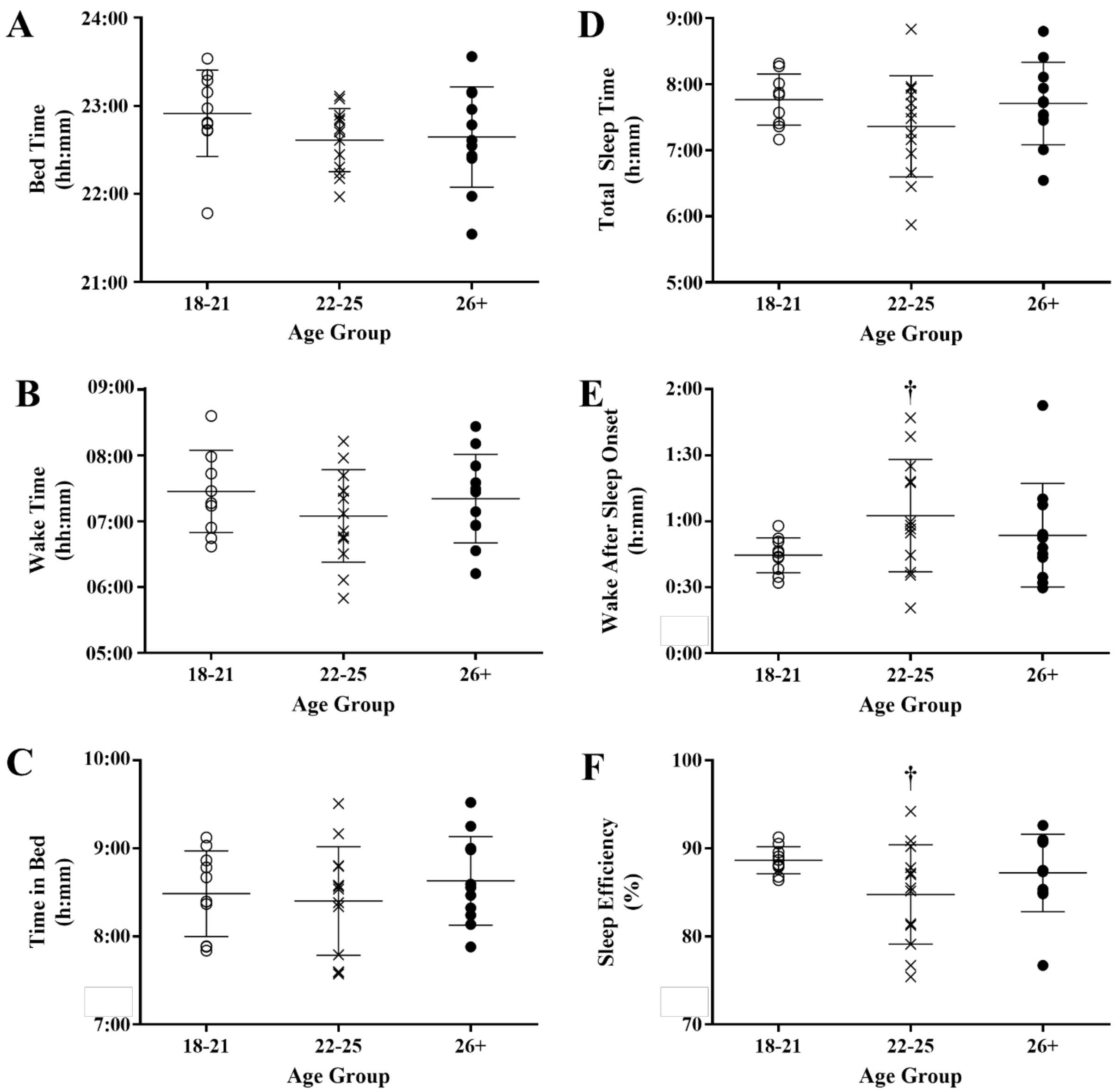


Figure 5.1. Between age group mean A) bed time, B) wake time, C) time in bed, D) total sleep time, E) wake after sleep onset, and F) sleep efficiency for the 18-21 (open circles), 22-25 (crosses), and 26+ (closed circles) age groups. Bars represent the group mean (long horizontal bar) ± standard deviation (short horizontal bars). Substantial between age group differences are expressed using †; 18-21 v 22-25.

5.3.2 Chronotype

Descriptive information and comparisons of sleep behaviours between participant's chronotypes are shown in Table 5.2. There were no substantial differences between chronotypes for time in bed nor sleep onset latency. However, bed time was later for intermediate types compared to both definite morning (0:52 h, ES = 0.89; ±0.67) and moderate morning types (0:36 h, ES = 0.62; ±0.33). Definite morning types displayed earlier wake time compared to moderate morning types (-0:48 h, ES = -0.73; ±0.67). Wake time was later for intermediate types compared to definite morning types (1:15 h, ES = 1.01; ±0.59), and later compared to moderate morning types (0:27 h, ES = 0.38; ±0.27). Compared to moderate morning types, definite morning types obtained less total sleep time (-0:46 h, ES = -0.71; ±0.73) and more wake after sleep onset (0:15 h, ES = 0.51; ±0.71). Whereas compared to moderate morning types, intermediate types displayed more wake after sleep onset (0:08 h, ES = 0.37; ±0.25) and lower sleep efficiency (2 %, ES = -0.36; ±0.28).

5.3.3 Pre-Season versus In-Season

Differences between the pre-season and in-season periods are summarised in Figure 5.2. During the in-season, compared to pre-season, later bed times (0:30 h, ES = 0.50; ±0.15), later wake times (1:07 h, ES = 1.01; ±0.19), longer time in bed (0:37 h, ES = 0.52; ±0.14), longer total sleep time (0:46 h, ES = 0.70; ±0.14), and increased sleep efficiency (2 %, ES = 0.32; ±0.10) were observed. There were no substantial differences for SOL or WASO.

Table 5.2. Descriptive data detailing the sleep behaviours between definite morning (DM), moderate morning (MM) and intermediate (INT) chronotypes. Comparisons between chronotypes were performed using linear mixed models and are expressed as standardised effect sizes and; ± 90% confidence intervals. Likelihoods are expressed as; *, likely; **, very likely; ***; most likely.

Sleep Characteristic	Chronotype DM (n = 5)	MM (n = 11)	INT (n = 17)	Comparison DM v MM	DM v INT	MM v INT
Age (y)	27 ± 5	23 ± 4	21 ± 3	***ES = -1.12; ±0.95****	***ES = -2.06; ±0.90******	ES = -0.75; ±0.70
Bed Time (AM/PM)	10:17 ± 0:52 PM	10:33 ± 0:57 AM	11:09 ± 0:59 PM	ES = 0.28; ±0.54	***ES = 0.89; ±0.67*****	ES = 0.62; ±0.33**
Wake Time (AM/PM)	6:32 ± 0:45 AM	7:20 ± 1:07 AM	7:47 ± 1:16 AM	***ES = 0.73; ±0.67****	***ES = 1.01; ±0.59*****	***ES = -0.38; ±0.27****
TIB (h:mm)	8:15 ± 1:02	8:46 ± 1:09	8:37 ± 1:16	ES = 0.45; ±0.65	ES = 0.29; ±0.79	ES = -0.12; ±0.22
TST (h:mm)	7:11 ± 1:03	7:57 ± 1:06	7:45 ± 1:11	***ES = 0.71; ±0.73****	ES = 0.49; ±0.79	ES = -0.18; ±0.22
SOL (h:mm)	0:19 ± 0:21	0:24 ± 0:23	0:24 ± 0:22	ES = 0.29; ±0.33	ES = 0.35; ±0.53	ES = 0.04; ±0.08
WASO (h:mm)	1:02 ± 0:43	0:47 ± 0:23	0:55 ± 0:22	***ES = -0.51; ±0.71****	ES = -0.17; ±1.31	***ES = 0.37; ±0.25****
SEF (%)	86 ± 8	89 ± 5	87 ± 5	ES = 0.59; ±1.01	ES = 0.27; ±1.81	***ES = -0.36; ±0.28****

AM/PM = time of day in hours and minutes, h:mm = time in hours and minutes, % = percent, TIB = time in bed, TST = total sleep time, SOL = sleep onset latency, WASO = wake after sleep onset, SEF = sleep efficiency.

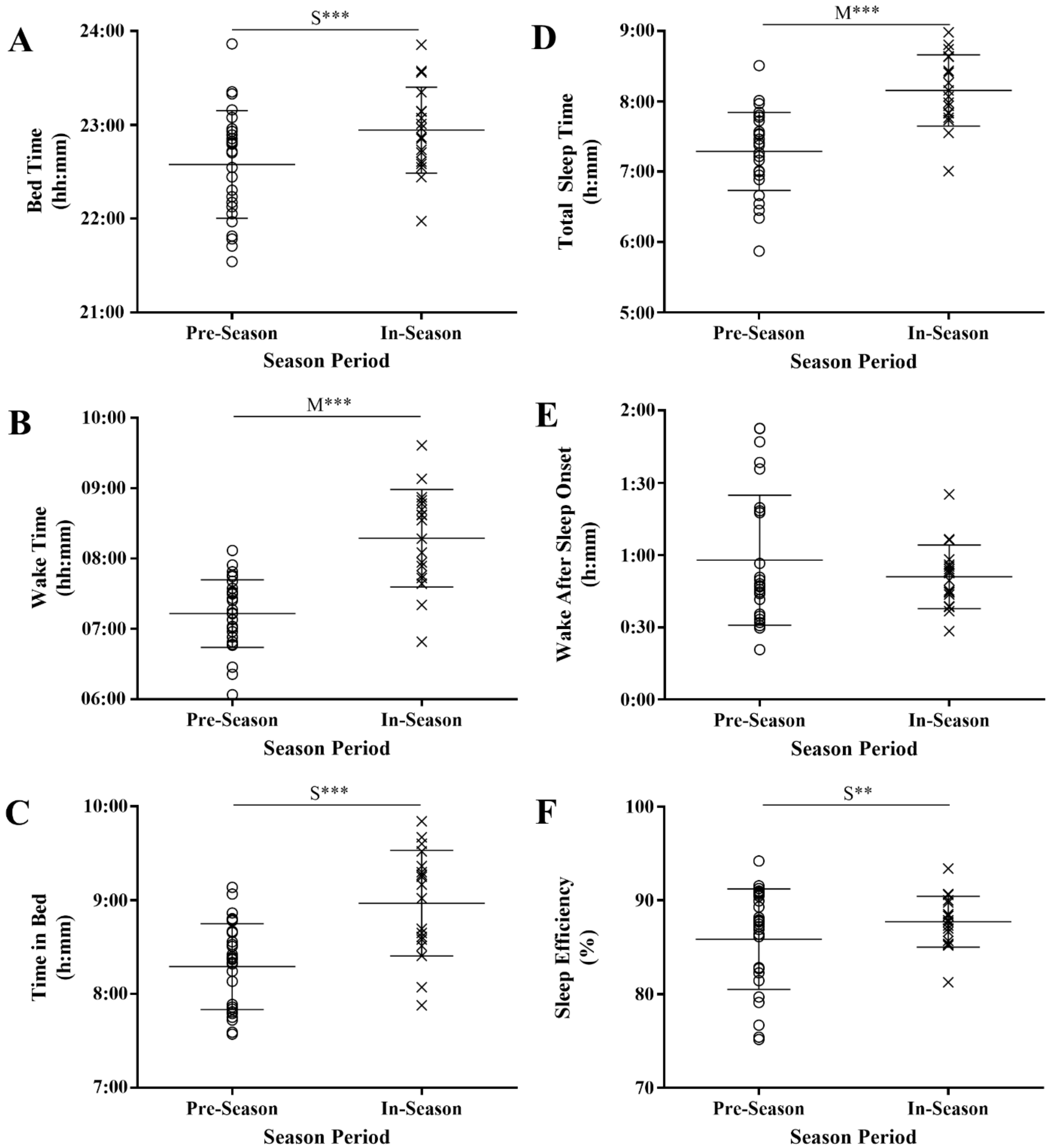


Figure 5.2. Between season period comparison of A) bed time, B) wake time, C) time in bed, D) total sleep time, E) wake after sleep onset, and F) sleep efficiency for the pre-season (open circles) and in-season periods (crosses). Data are displayed as mean (long horizontal bar) ± standard deviation (short horizontal bars). Differences between pre-season and in-season periods are expressed as effect size magnitudes; S, Small; M, Moderate. Likelihood of effects being greater than 75% are expressed as **, very likely; ***, most likely.

5.3.4 Pre-Season and In-Season Nights

Descriptive sleep behaviour data for, and the effects between, the pre-season period and individual in-season nights are summarised in Figure 5.3. Bed time is earlier during the pre-season period compared to MN (-1:24 h, ES = -1.39; ±0.27), and earlier compared to both R1 (-0:21 h, ES = -0.38; ±0.21) and R2 (-0:17 h, ES = -0.30; ±0.20). Wake time is earlier during the pre-season period compared to MN-1 (-1:24 h, ES = -1.25; ±0.24), MN (0:52 h, ES = -0.75; ±0.19), R1 (-1:08 h, ES = -0.98; ±0.19) and R2 (-1:01 h, ES = -0.88; ±0.19). Time in bed is shorter during the pre-season period compared to MN-1 (-1:20 h, ES = -1.34; ±0.26), longer compared to MN (0:33 h, ES = 0.47; ±0.18), and shorter compared to R1 (1:14 h, ES = -0.74; ±0.20) and R2 (-0:44 h, ES = -0.71; ±0.20). Similarly, total sleep time is shorter during the pre-season period compared to MN-1 (-1:31 h, ES = -1.64; ±0.32), shorter compared to R1 (-0:51 h, ES = -0.87; ±0.19) and R2 (-0:48 h, ES = -0.82; ±0.19), but not compared to MN (0:17 h, ES = 0.26; ±0.22). No substantial differences in sleep onset latency were observed between the pre-season period compared to MN-1, MN, R1 or R2. Wake after sleep onset is greater during the pre-season period compared to MN (0:10 h, ES = 0.30; ±0.09), but is not substantially different to MN-1, R1 or R2. Sleep efficiency is lower during the pre-season period compared to MN-1 (-3 %, ES = -0.51; ±0.12), but is not different between pre-season and MN, R1 or R2.

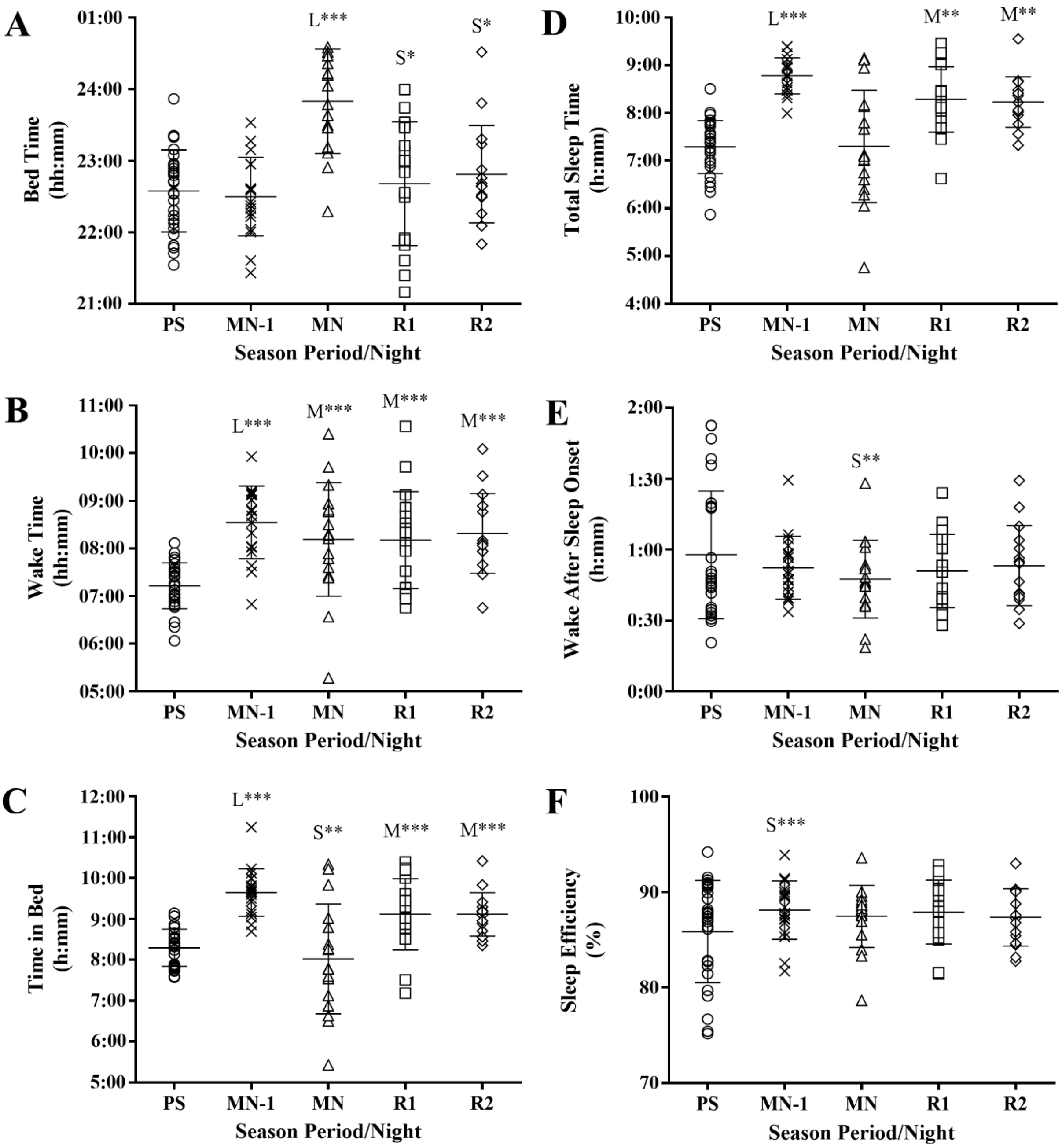


Figure 5.3. Effects of individual in-season nights on players' mean sleep compared to the pre-season period for the night before a match, match night, recovery night 1 and recovery night 2. Data displayed as mean (long horizontal bar) ± standard deviation (short horizontal bars). Differences between pre-season average and individual in-season nights are expressed as effect size magnitudes; S, Small; M, Moderate; L, Large. Likelihood of effects being greater than 75% are expressed as *, likely; **, very likely; ***, most likely.

5.3.5 Competition Nights

Comparisons of sleep behaviours, and effects between, in-season nights are summarised in Figure 5.4. When MN-1 is compared to MN, players' bed time is later on MN (1:20 h, ES = -.43; ±0.28), wake time is earlier on MN (-0:32 h, ES = -0.53; ±0.24), TIB is shorter on MN (-1:53 h, ES = -1.62; ±0.32), TST is shorter on MN (-1:48 h, ES = -1.77; ±0.35), WASO is lower on MN (-0:05 h, ES = -0.41; ±0.17), and sleep efficiency is lower on MN (-2 %, ES = -0.44; ±0.23). When MN-1 is compared to R1, bed time is later on R1 (0:17 h, ES = 0.39; ±0.26), TIB is shorter on R1 (-0:34 h, ES = -0.63; ±0.27), TST is shorter on R1 (-0:39 h, ES = -0.85; ±0.27), and sleep efficiency is lower on R1 (-2 %, ES = -0.49; ±0.26). When MN-1 is compared to R2, TIB is shorter on R2 (-0:36 h, ES = -0.70; ±0.28), TST is shorter on R2 (-0:43 h, ES = -0.95; ±0.28), and sleep efficiency is lower on R2 (-2 %, ES = -0.52; ±0.29). When MN is compared to R1, bed time is earlier on R1 (-1:03 h, ES = -1.00; ±0.20), TIB is longer on R1 (1:19 h, ES = 1.04; ±0.20), TST is longer on R1 (1:08 h, ES = 1.01; ±0.20), and WASO is greater on R1 (0:07 h, ES = 0.44; ±0.18). Similarly, when MN is compared to R2, bed time is earlier on R2 (-1:07 h, ES = -1.07; ±0.21), TIB is longer on R2 (1:16 h, ES = 1.03; ±0.20), TST is longer on R2 (1:05 h, ES = 0.97; ±0.19), and WASO is greater on R2 (0:08 h, ES = 0.49; ±0.20). When R1 and is compared to R2, sleep onset latency is longer on R2(0:05 h, ES = 0.34; ±0.21).

5.3.6 Competition Location

Descriptive sleep behaviour data for, and the effects between, individual nights from home and away matches are summarised in Figure 5.5. Compared to home matches, on MN-1 before an away match sleep onset latency is increased (0:11 h, ES = 0.60; ±0.49) and sleep efficiency is reduced (3 %, ES = 0.84; ±0.61). Compared to home matches, on MN of an away match, sleep onset latency is increased (0:04 h, ES = 0.45; ±0.28). Compared to home matches, there were no substantial differences on R1 or R2 following an away match.

5.3.7 Competition Level

Descriptive sleep behaviour data for, and the effects between, individual nights from AFL and VFL matches are shown in Figure 5.6. Compared to VFL matches, on MN-1 before an AFL match sleep efficiency is increased (2 %, ES = 0.63; ±0.79). Compared to VFL matches, on MN of an AFL match wake time is earlier (0:34 h, ES = 0.56; ±0.68), TIB is shorter (0:45 h, ES = 0.52; ±0.28), TST is shorter (0:37 h, ES = 0.44; ±0.27), SOL is longer (0:11 h, ES = 0.52; ±0.46) and WASO is less (0:13 h, ES = 0.72; ±0.40). There were no substantial differences in sleep behaviours between AFL and VFL matches on R1 or R2 following an AFL match.

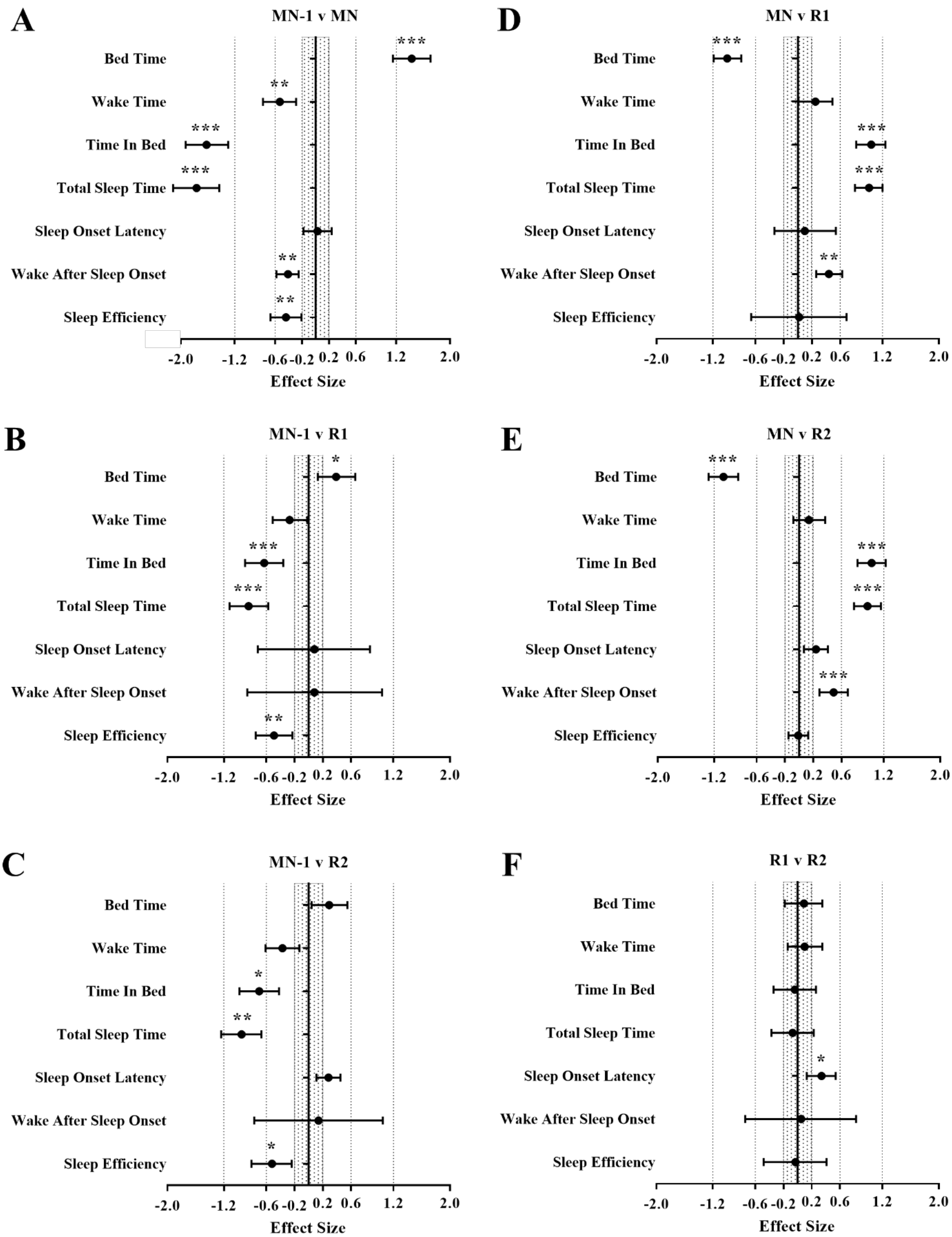


Figure 5.4. Comparison between individual in-season nights on sleep behaviours for A) MN-1 v MN, B) MN-1 v R1, C) MN-1 R2, D) MN v R1, E) MN v R2, and F) R1 v R2. Differences are expressed as effect sizes ±90% confidence limits and likelihood of effects being greater than 75% are expressed as; *, likely; **, very likely; ***, most likely.

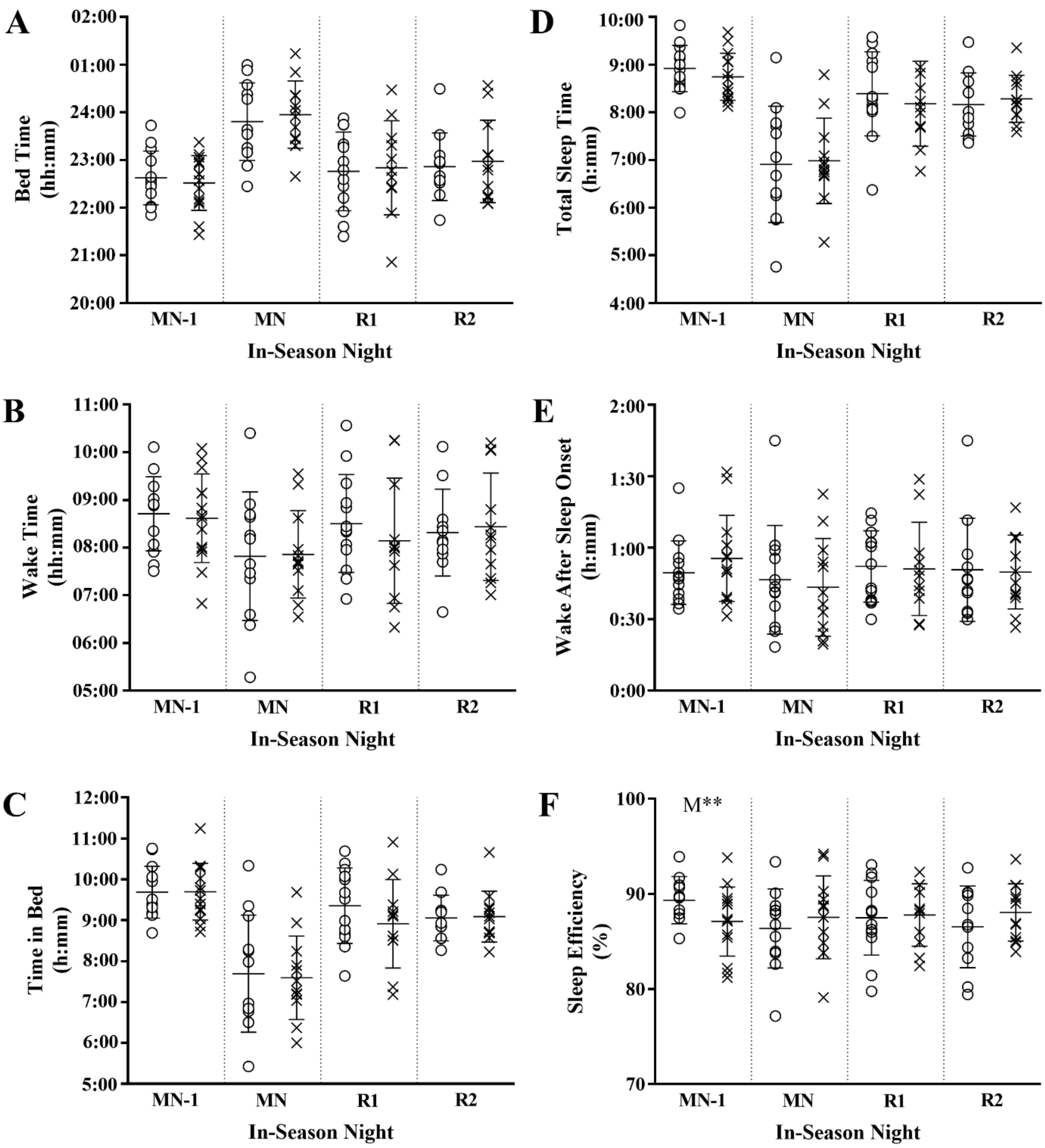


Figure 5.5. Home and away match comparison of A) bed time, B) wake time, C) time in bed, D) total sleep time, E) wake after sleep onset, and F) sleep efficiency for the home matches (open circles) and away matches (crosses). Data are displayed as mean (long horizontal bar) ± standard deviation (short horizontal bars). Differences between pre-season and in-season periods are expressed as effect size magnitudes; M, Moderate. Likelihood of effects being greater than 75% are expressed as **, very likely.

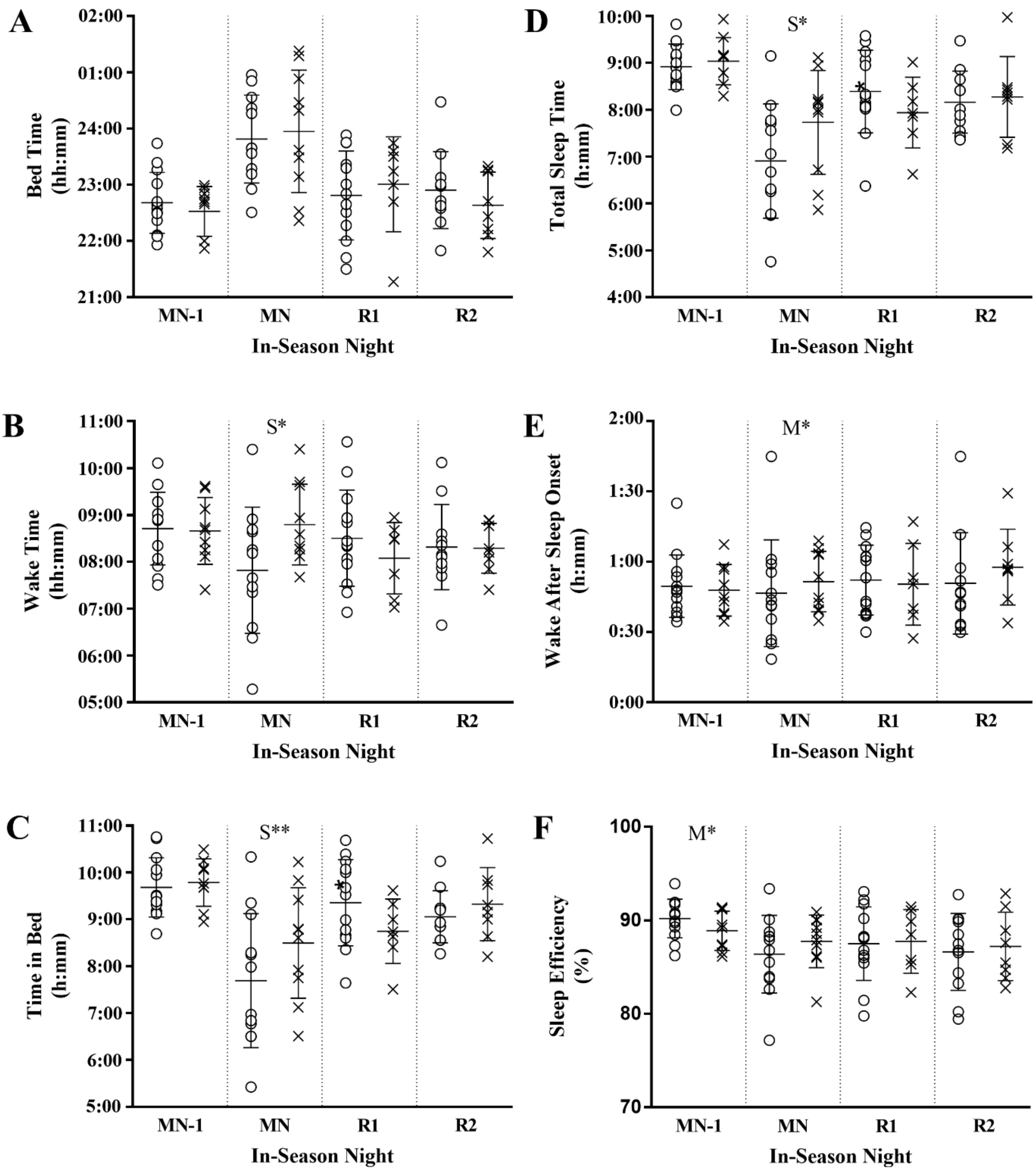


Figure 5.6. Sleep behaviours between AFL and VFL level matches of A) bed time, B) wake time, C) time in bed, D) total sleep time, E) wake after sleep onset, and F) sleep efficiency for the home matches (open circles) and away matches (crosses). Data are displayed as mean (long horizontal bar) ± standard deviation (short horizontal bars). Differences between pre-season and in-season periods are expressed as effect size magnitudes; S, Small; M, Moderate. Likelihood of effects being greater than 75% are expressed as *, likely; **, very likely.

5.4 Discussion

The present study revealed that individual chronotype, but not age, has a greater influence on the sleep behaviours of Australian Rules footballers. During the in-season period the athletes had later bed and wake times, spent a longer time in bed, and had greater total sleep time compared to the pre-season period. Competitive matches also influenced sleep behaviours, with players spending longer in bed and obtaining more sleep on the night before a match and on the two nights following a match compared to the pre-season period. Players spent less time in bed and obtained less sleep on the night of a match when compared to the night before a match and the two nights following a match; however, total sleep time was not different between the pre-season period and match nights as a result of reduced wakefulness. Whilst competition location had no substantial effect, competitive level showed that when playing in the National-level AFL competition, players spent less time in bed and obtained less sleep, compared to when playing in the State-level VFL competition. Together, these data reflect the importance of considering individual chronotype in the analysis of sleep behaviours, as well as the specific influences of seasonal period and competition factors on sleep behaviours in Australian Rules footballers.

The finding that individual chronotype influences the sleep behaviours of professional Australian Rules footballers indicates the importance of considering between-individual differences in drivers of sleep behaviour in the assessment of sleep. The present study found that earlier chronotypes contained older participants than later chronotypes, which supports previous evidence showing older athletes have a tendency for earlier sleep-wake schedules than younger athletes (Caia et al., 2017a), and that athlete populations tend to display earlier chronotype preferences (Kunorozva et al., 2012; Lastella et al., 2010; Lastella et al., 2016). The novel inclusion of chronotype in the analysis of sleep behaviours of professional Australian Rules is in support of previous findings showing that chronotype influences post-exercise sleep responses on team-sport athletes (Vitale et al., 2017). The results of this study provide greater clarity and confidence when interpreting findings related to the effect of seasonal period and competition-related factors on the sleep behaviours of Australian Rules footballers.

The present investigation demonstrated that Australian Rules footballers go to bed and wake later, spend more time in bed, obtain more sleep, and display higher sleep efficiency, during the in-season period compared to the pre-season period. Observed sleep durations of 7:20 ± 1:00 and 8:06 ± 1:09 hours during the pre-season and in-season periods, respectively, are above the 6:48 ± 1:06 hours previously reported in athletic populations (Lastella et al., 2014e), but lower than ‘habitual’ values, measured during pre-season training periods in Australian Rules footballers (8:53 ± 0:07 hours and 8:25 ± 0:16 hours) (Lalor et al., 2017; Richmond et al., 2004). Given the present study and the studies by Lalor et al. (2017) and Richmond et al. (2004) were undertaken at different professional organisations located in different states, the observed differences may be attributable to between-environment differences in the pre-season and in-season training and competition schedules, and travel demands. Early-morning training sessions (Sargent et al., 2014a; Sargent et al., 2014b), competition exposure (Richmond et al., 2004), and sleeping in unfamiliar environments (Chapter 3; Pitchford et al. (2017)) have been shown to reduce sleep quality and quantity in athletes, and between-organisation differences in sleep behaviours have previously been observed in rugby league (Caia et al., 2017b; Thornton et al., 2017a). The changes in sleep behaviours between the pre-season and in-season period observed in the present study may be due to differences in the training and competition demands (Ritchie et al., 2016) or training schedules (Kölling et al., 2016; Sargent et al., 2014b) that are experienced between pre-season and in-season periods. Early-morning scheduling of training sessions are often utilised during the pre-season period to facilitate greater training loads to prepare athletes for the upcoming competitive season. However, the presence of early-morning training leads to reduced sleep opportunity and altered sleep-wake behaviours in athletes (Kölling et al., 2016; Sargent et al., 2014b; Sargent et al., 2014a), which may explain the earlier sleep-wake times and reduced sleep duration observed during the pre-season period in the present study. These findings demonstrate the presence of within-sport differences in sleep behaviours that exist between environments, indicating the importance of appropriate training scheduling to reduce the potential for altered sleep behaviours influencing training or competition outcomes. Investigation as to the effects of training and competition loads on the sleep-wake patterns and sleep behaviours of athletes, and how this may influence competitive performance and training adaptation, are required.

Australian Rules footballers display increased sleep duration on the night before a match, reduced sleep duration on the night of a match, and a return to similar sleep duration on the recovery nights following a match, compared to pre-season sleep durations (Richmond et al., 2004; Shearer et al., 2015). The results of the present study support previous literature showing increased sleep duration on the night before a match. However, this study showed that on the night of a match sleep duration is not different to that experienced during the pre-season period, and that on the two nights following a match sleep duration exceeds that experienced during the pre-season. Lalor et al. (2017) found sleep duration to be shorter on the recovery nights following matches compared to pre-season values, whereas the present study found that sleep duration on recovery nights supersedes that observed during the pre-season period. This is possibly due to the lack of early morning training/recovery sessions undertaken in the current study following matches, unlike previous research where scheduling required the athletes to report early to the training facility (Caia et al., 2017b; Lalor et al., 2017). Training schedules that are restrictive to an athletes' opportunity for sleep may have a negative influence on athlete preparedness, further highlighting the impact of scheduling on sleep and fatigue (Kölling et al., 2016; Sargent et al., 2014b). The findings of this study suggest that in this group of Australian Rules footballers, sleep duration is increased pre- and post-match compared to pre-season values and match nights. Given that sleep has been rated as the most important recovery tool available to athletes (Venter, 2014), interventions to facilitate sleep and improve recovery should be prioritised on the night of and the morning following a match. Furthermore, the findings from this study suggest that pre-season sleep durations may be inadequate, and further attention should be given to how heightened training demands during the pre-season period influence sleep in Australian Rules footballers.

Travel is common in professional sport, yet is recognised to negatively affect sleep (Fowler et al., 2015). The present study found that matches played away, both in the presence and absence of time-zone changes, resulted in small changes in sleep onset latency on the night before and the night of matches, and poorer sleep efficiency on the night of a match, compared to when matches were played at home. The lack of difference in sleep duration, particularly on the night of the match, contrasts that of work by Richmond et al. (2004) and (Carriço et al., 2018) where it was reported that sleep duration is reduced on the night of away matches compared to home matches. These disparate findings may be explained by different post-match travel scheduling, whereby previous literature examined scenarios incorporating either westward air travel (Richmond et al., 2004) or 4-hour road travel (Carriço et al., 2018) immediately following all away matches, indicating that post-match sleep duration may have been hindered by travel following away matches . Unlike the current study where participants slept in a hotel of the same city as the away match location following matches before travelling home the next morning, eliminating the influence of post-match travel in the comparison between home and away matches. Furthermore, the present study showed that on the night before an away match spent in the away location, sleep efficiency is reduced compared to when athletes slept in their own home before a match. This supports the results of Chapter 4 that sleeping in an unfamiliar environment reduces sleep efficiency in Australian Rules footballers (Pitchford et al., 2017). However, sleep efficiency was not different between home and away matches on the night of a match, suggesting that the exposure to competition impairs sleep to a similar extent whether at home or away. The present investigation supports previous evidence suggesting sleep location is particularly important in relation to the sleep efficiency that athletes obtain (Pitchford et al., 2017). Furthermore, this study indicates that avoiding immediate post-match travel may prevent any additional post-match sleep loss associated with travel, but this does not reduce the post-match reduction in sleep duration that are observed following competition. In support of Fullagar et al. (2015a) there is a need for investigations into the effects of sleep interventions designed to enhance sleep quantity and quality have on post-match sleep and recovery outcomes.

The present study is the first to report the influence of competitive match level on the sleep behaviours of Australian Rules footballers. Whilst previous findings have shown that older (25.5 ± 3.7 years) rugby league athletes go to bed and wake earlier, compared younger players (18.8 ± 0.9 years) (Caia et al., 2017a), the current findings indicate that when playing AFL, players sleep less on the night of a match compared with when playing in the VFL competition. The reduced sleep duration on the night of AFL matches may have been influenced by heightened movement demands such as increased total and high-speed distance covered during matches, which have previously been reported in elite, compared to sub-elite, Australian Rules football competitions (Brewer et al., 2010). Increased total distance covered has a negative effect on sleep duration in rugby league (Thornton et al., 2017a; Thornton et al., 2016); however, evidence of load-induced alterations in sleep behaviour in Australian Rules football is lacking. The potential for locomotion-derived sleep disturbances as a result of higher-level competition is further supported by Fullagar et al. (2016b) who found that soccer players often reported strenuous matches, pain and post-match adrenaline as reasons for post-match sleep loss, although players who did not compete in matches also returned reduced sleep duration, likely due to social activities as opposed to locomotion-related influences (Fullagar et al., 2015b). The observed post-match sleep disturbances may also be a result of increased post-match media exposure in the AFL environment (Nédélec et al., 2013), increased prevalence of night-time matches (Fullagar et al., 2016b), and the subsequent later caffeine consumption (Dunican et al., 2018), which can increase night-time arousal levels and negatively influence sleep. The novel findings of this study suggest disparity in the sleep behaviours of Australian Rules footballers between elite AFL and sub-elite VFL competitions. However, further research is required to elucidate the potential relationships between later match times and the relationships between cognitive arousal or anxiety and the sleep behaviours of professional Australian Rules footballers before conclusive associations can be drawn.

Despite the novel observations in the present study, there are some limitations that should be acknowledged. The results of the present study may not be generalisable across all club environments. For example, whilst professional Australian Rules football clubs undertake similar training schedules, each club has unique contextual elements, such as the scheduling of post-match recovery interventions, that may restrict sleep opportunities. Unlike previous investigations (Caia et al., 2017b; Lalor et al., 2017; Richmond et al., 2004), the present study was conducted in an environment that did not schedule compulsory early-morning post-match recovery sessions or travel, allowing for increased sleep opportunity after matches. Furthermore, the present study did not collect information regarding caffeine consumption during matches or room-sharing scenarios during travel that may also influence the sleep behaviours of Australian Rules footballers.

The consideration of individual athlete and between environment factors appear crucial in the assessment of sleep in Australian Rules footballers. Indeed, when individual chronotype is accounted for, Australian Rules footballers obtain more sleep during the in-season period compared to the pre-season period and experience impaired post-match sleep behaviours, which are further altered depending on competition level. Reduced sleep efficiency but not duration on the night before away matches is in support of previous literature suggesting a detrimental effect of unfamiliar sleeping environments; however, this appears to be irrelevant in the presence of competition. Together, the sleep behaviours of Australian Rules footballers are influenced by numerous contextual factors including athlete-specific, i.e., individual chronotype, and environment specific, i.e., scheduling, post-match travel, and competition level, that must be considered in the preparation, performance, and recovery process. Further investigation is required to better understand if a relationship exists between physical activity demands and subsequent sleep outcomes and if enhanced sleep quantity and quality enhance performance and recovery outcomes following heavy physical activity.

CHAPTER 6. STUDY 3 – RELATIONSHIPS BETWEEN ACUTE AND CUMULATIVE LOAD WITH THE SLEEP BEHAVIOURS OF AUSTRALIAN RULES FOOTBALL PLAYERS

The results of Chapters 4 and 5 demonstrated that the sleep behaviours of professional Australian Rules footballers are influenced by variations in s-RPE Load and differ between the pre-season and in-season phases. Extending on the findings established in Chapter 4 and 5, there was a clear need to further examine the relationship between load and sleep - especially the role that season phase may play. This information is important for the athlete and practitioners to ensure that variations in load resulting in impaired, or improved, sleep can be better periodised to maximise the performance and recovery demands of team-sport athletes. Preliminary findings of this study have been presented as an Oral Presentation given at the Smartabase Users Conference, Queensland, Australia, 2017.

6.1 Introduction

To prepare for competition, team-sport athletes undertake robust training regimes that consists of technical, tactical, and physical training that, when combined with competition, can cause substantial fluctuations in sleep behaviours (Chapter 5; (Lastella et al., 2014a; Sargent et al., 2014b). Indeed, Chapter 5 indicated that sleep behaviours are different between the pre-season and in-season, and previous evidence indicates that changes in both volume and intensity load domains alter the sleep behaviours of individual-sport (Jürimäe et al., 2002; Jürimäe et al., 2004; Hausswirth et al., 2014) and team-sport athletes (Thornton et al., 2017a; Thornton et al., 2017b). As sleep plays an important role in the maintenance of immune function (Bollinger et al., 2010; Fondell et al., 2011), physiological and cognitive recovery (Rae et al., 2017), and physical performance (Mah et al., 2011), further investigation is warranted to better understand the effects that load has on the sleep behaviours of team-sport athletes across both the pre-season and in-season.

Athletes undertake a variety of training to develop speed, strength and power, agility, and aerobic capacity - all qualities required for competition (Reilly and Gilbourne, 2003). To achieve these physical qualities, athletes are exposed to varying volumes and intensities of field-based and gym-based load parameters, which form the fundamental components for quantifying load (Smith, 2003). Variables such as total distance covered, relative total distance ($m \cdot min^{-1}$), and the distance covered in certain speed zones (e.g. high-speed distance covered above 14.4 $km \cdot h^{-1}$; HSR), can be used for training periodisation and to quantify movement demands during training and competition (Kempton et al., 2014; Ritchie et al., 2016). Furthermore, session rating of perceived exertion, commonly referred to as internal training load (s-RPE Load = training duration x rating of perceived exertion; Foster et al. (2001)), is commonly used to monitor periodised load in Australian Rules footballers (Juhari et al., 2017; Ritchie et al., 2016). As a growing number of practitioners are monitoring the physical demands placed upon team-sport athletes over periodisation cycles of up to 4 weeks in duration (Gabbett, 2018), greater understanding and quantification of the impact that variations and accumulations in load parameters have on the sleep behaviours of team-sport athletes may help improve evidence-based monitoring, periodisation and recovery practises.

At present, there are contrasting findings concerning the association between load and sleep in athletes. Increased training volume during a 6-day period negatively influences mean sleep quality in rowers (Jürimäe et al., 2002; Jürimäe et al., 2004), and a 21-day period of training that induces a state of functional overreaching decreases mean sleep duration and sleep efficiency in triathletes (Hausswirth et al., 2014). In rugby league players, increased total distance covered during a 14-day pre-season camp is associated with reduced mean sleep duration (Thornton et al., 2017b). However, these studies do not directly consider the daily or cumulative effects of load variables on sleep behaviours. Daily increases in the acceleration-deacceleration demands leads to increased total sleep time and sleep efficiency in rugby league players (Thornton et al., 2017a). Furthermore, sleep efficiency is also increased when the acceleration-deacceleration and high-speed running demands were summated across the preceding 3-day and 7-day periods (Thornton et al., 2017a). However, the previous investigations by Thornton and associates (Thornton et al., 2017a; Thornton et al., 2017b) were conducted during the pre-season training period, and only incorporated cumulative training demands lasting up to 1 week. Hence, there appears to be a lack of literature investigating the sleep responses to increased physical demands during the in-season phase, which differ from the pre-season demands (Ritchie et al., 2016), and investigations have been short in duration. Therefore, to maximise physical preparation and performance and reduce athlete exposure to situations of compromised sleep, it is important to develop a better understanding of the relationship between the training demands and the sleep of athletes across shorter- (< 7-day) and longer-term (> 14-day) cumulative periods during both the pre-season and in-season.

Although increased training load has been shown to influence sleep behaviours, and lost sleep has negative effects on factors important for athletic preparation and recovery, the influence of varying load on subsequent sleep has not been widely investigated in team-sport athletes. Furthermore, consideration for the change in load exposure that is experienced between the pre-season and in-season (Ritchie et al., 2016) has not previously been accounted for in the assessment of the effect of load on sleep behaviours in team-sport athletes. As such, this study examined the two seasonal phases independently, to determine if any relationships exist between training load and sleep. To address the need for enhanced understanding of the role that load has on sleep behaviours in athletes, the aim of this investigation was to determine the influence of changes in load variables during both the pre-season and in-season across 1-, 7-, 14-, 21- and 28-day periods and their relationships with objectively measured sleep behaviours in Australian Rules footballers. It was hypothesised that heightened load demands over both short- and longer-term periods would negatively influence the sleep behaviours of Australian Rules footballers.

6.2 Methods

6.2.1 Participants

Participant information is detailed in Chapter 3 Section 3.1.1.

6.2.2 Sleep Assessment

Methods regarding the sleep assessment in this study are as previously described in Chapter 3, Sections 3.2.1 and 3.2.2. In brief, sleep behaviour data was collected using a wrist-watch activity device, the Actiwatch 2 (Philips Respironics, PA, USA) paired with subjective sleep diaries, and the same data was used for this study as that used in Chapter 5. Data was collected and analysed as individual mean values from data collected across 11 ± 2 consecutive days during the pre-season period incorporating both training and non-training days (December 2014 to January 2015), and across 8 ± 6 separate 4-consecutive-day collection periods during the in-season period (April to September 2015).

6.2.3 Training Load Measurement

Daily training and competition schedules during the pre-season and in-season are previously described in Chapter 3, Section 3.1.3. Internal raining load from all session types assessed using the session-RPE (s-RPE = session duration x RPE) method (Borgs CR-10 scale) – a valid measure of training load in team sports (Scott et al., 2013). External training load data was collected for all outdoor training/conditioning sessions and matches as per Chapter 3 Section 3.4.2. External training load measures were summed to calculate cumulative totals for each measure across 1-, 7-, 14-, 21- and 28-day periods of training preceding sleep-assessed nights during the pre-season (PS; December 2014 to January 2015) and in-season (IS; April to September 2015) phases. External training load measures included total distance; TD, TD per minute; $m \cdot min^{-1}$, high-speed running distance above 14.4 $km \cdot h^{-1}$; HSR, and running distance above 24.9 $km \cdot h^{-1}$; VHSR.

6.2.4 Statistical Analysis

Linear mixed models were used to investigate differences in sleep behaviours between the night following training and non-training days. These models appropriately handle repeated measurements on the same individuals by specification of random effects, where in the present study individuals were nested within each date. Q-Q plots were used to examine the normality of the dependant variable’s residuals using the Shapiro-Wilk test; if normality was violated the dependent variables were log-transformed and models were re-run. Differences in sleep behaviours between training versus non-training days and pre-season versus in-season periods were determined linear mixed models and standardised effect sizes. The least means square test obtained from the mixed model was used to calculate confidence limits (CL) for the standardised effect sizes. These effects were classified as; trivial; <0.2, small; 0.2-0.6, moderate; 0.6-1.2, large; 1.2-2.0, and very large; >2.0 (Hopkins et al., 2009). Following, a magnitude-based approach was adopted, where differences that are >75% likelihood of being greater than the smallest worthwhile difference (calculated as 0.2 x between subject SD) are reported using previously reported thresholds (Hopkins, 2007). Using the same random effect structure as described above, the effect of training loads on night-time sleep was determined by including the training load variables as fixed effects and using data from both training and non-training days collectively (except 1-day analyses), based on the results of the preceding analysis. Comparative differences in text are presented as mean difference, ES, and ±90% confidence limits, unless otherwise stated. All statistical analyses were performed using R statistical software (version number R.3.5, R foundation for Statistical Computing).

6.3 Results

6.3.1 Training versus Non-Training days

The comparison of sleep behaviours following training and non-training days is shown in Figure 6.2. Training days displayed later wake times compared to non-training days (0:22 h; ES = 0.30; ±0.15). There were no other substantial differences between training and non-training days.

6.3.2 1-Day changes in load

Relationships between 1-day loads and sleep behaviours are shown in Figure 6.3. During the pre-season, increased 1-day total distance was associated with earlier bed times (ES = -0.65; ±0.32), earlier wake times (ES = -1.08; ±0.50), reduced time in bed (ES = -0.58; ±0.48) and less total sleep time (ES = -0.85; ±0.40). Increased 1-day $m \cdot min^{-1}$ was associated with later wake times (ES = 1.04; ±0.85) and longer time in bed (ES = 0.82; ±0.86). Increased 1-day HSR was associated with earlier bed times (ES = -0.81; ±0.43), earlier wake times (ES = -1.29; ±0.64), shorter time in bed (ES = -0.50; ±0.60) and less total sleep time (ES = -0.61; ±0.48). Increased 1-day VHSR was associated with earlier bed times (ES = -0.42; ±0.50), earlier wake times (ES = -1.21; ±0.76), and shorter time in bed (ES = -0.69; ±0.60), total sleep time (ES = -0.85; ±0.66) and sleep onset latency (ES = -0.42; ±0.47). Increased 1-day s-RPE was associated with earlier bed times (ES = -0.91; ±0.28) and wake times (ES = -1.08; ±0.38).

During the in-season (Figure 6.3), increased 1-day total distance was associated with later bed times (ES = 0.80; ±0.27), earlier wake times (ES = -0.29; ±0.14), shorter time in bed (ES = -1.02; ±0.25), and shorter total sleep time (ES = -1.00; ±0.23). Increased 1-day $m \cdot min^{-1}$ was associated with later bed times (ES = 0.89; ±0.60), earlier wake times (ES = -0.49; ±0.25), and shorter time in bed (ES = -1.42; ±0.62) and total sleep time (ES = -1.35; ±0.59). Increased 1-day HSR was associated with later bed times (ES = 0.95; ±0.39), earlier wake times (ES = -0.36; ±0.15), and shorter time in bed (ES = -1.23; ±0.36) and total sleep time (ES = -1.16; ±0.34). Increased 1-day VHSR was associated with earlier wake times (ES = -0.49; ±0.42), and shorter time in bed (ES = -0.75; ±0.64), total sleep time (ES = -0.55; ±0.67) and wake after sleep onset (ES = -0.43; ±0.31). Increased 1-day s-RPE was associated with later bed times (ES = 0.84; ±0.21), and less time in bed (ES = -0.89; ±0.18) and total sleep time (ES = -0.91; ±0.17).

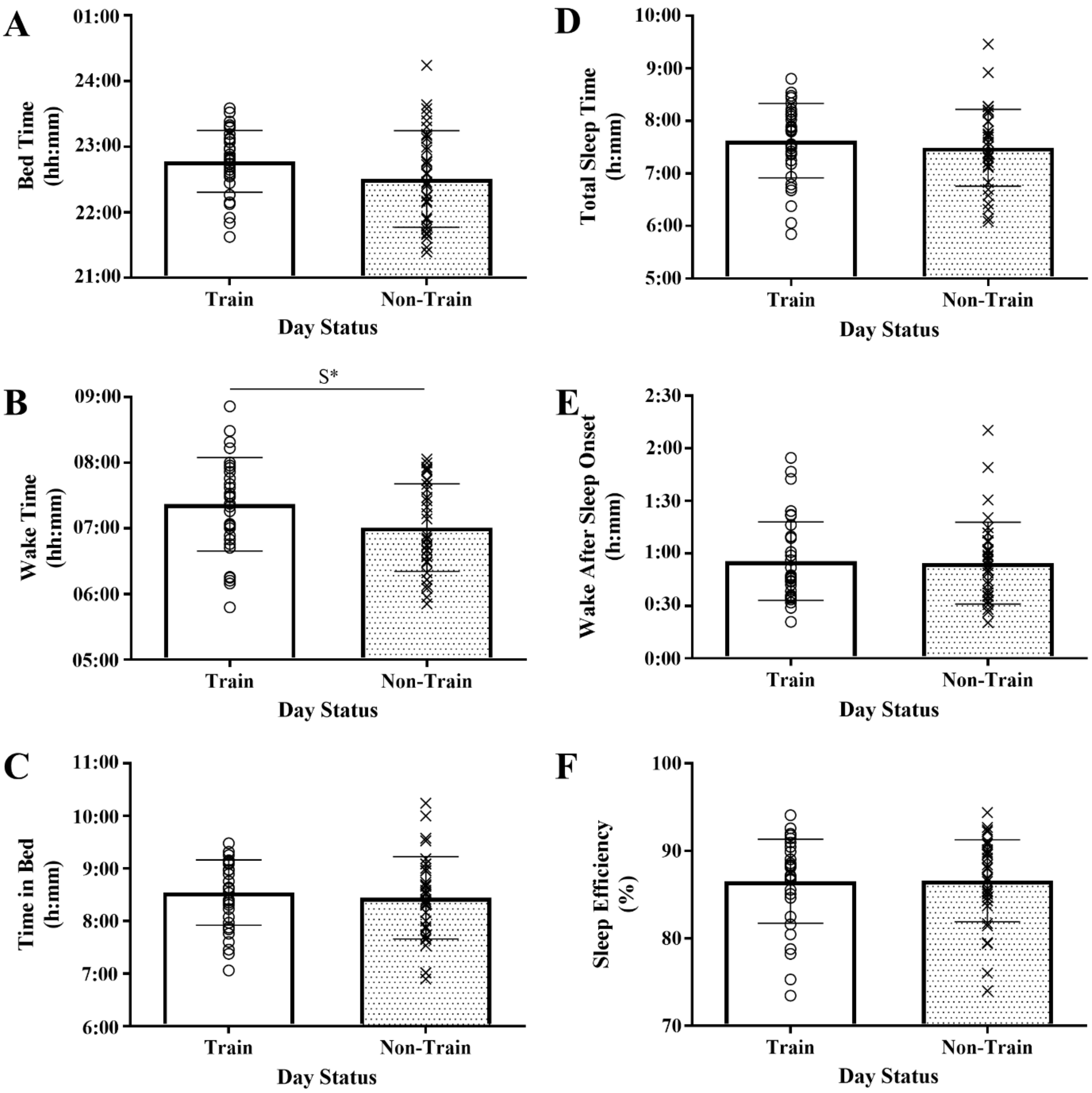


Figure 6.2. Differences in sleep behaviours A) bed time, B) wake time, C) time in bed, D) total sleep time, E) wake after sleep onset, and F) sleep efficiency between training and non-training days. Data displayed as mean ± standard deviation shown by horizontal bars. Differences between training and non-training days are expressed as effect size magnitudes; S, Small. Likelihood of effects being greater than 75% are expressed as *, likely.

6.3.3 7-Day changes in training load

Relationships between 7-day loads and sleep behaviours are shown in Figure 6.3. During the pre-season, increased 7-day total distance was associated with less total sleep time (ES = -0.48; ±0.27), whereas no substantial associations were observed between sleep behaviours and 7-day m·min^{-1}, HSR, VHSR or s-RPE during the pre-season.

During the in-season, increased 7-day total distance was associated with later bed times (ES = 0.46; ±0.31), and reduced time in bed (ES = -0.81; ±0.37) and reduced total sleep time (ES = -0.71; ±0.41). Increased 7-day m·min^{-1} was associated with earlier wake times (ES = -0.44;

±0.38), and shorter time in bed (ES = -0.64; ±0.65) and total sleep time (ES = -0.60; ±0.59). Increased 7-day HSR was associated with later bed times (ES = 0.44; ±0.35), and shorter time in bed (ES = -0.69; ±0.56) and total sleep time (ES = -0.62; ±0.53). Increased 7-day VHSR was associated with reduced time in bed (ES = -0.39; ±0.38) and total sleep time (ES = -0.44; ±0.33). Increased 7-day s-RPE was associated with later bed times (ES = 1.28; ±0.61), shorter time in bed (ES = -1.11; ±0.57), total sleep time (ES = -1.25; ±0.45) and sleep onset latency (ES = -0.50; ±0.44).

6.3.4 14-Day changes in training load

Relationships between 14-day loads and sleep behaviours are shown in Figure 6.4. During the pre-season, increased 14-day total distance was associated with earlier wake times (ES = -0.41; ±0.28), and shorter time in bed (ES = -0.66; ±0.34) and total sleep time (ES = -0.47; ±0.27). Increased 14-day $m \cdot min^{-1}$ was associated with later wake times (ES = 0.50; ±0.43), longer time in bed (ES = 0.43; ±0.53), shorter sleep onset latency (ES = -0.51; ±0.49), and higher wake after sleep onset (ES = 0.31; ±0.21). Increased 14-day HSR was associated with earlier wake times (ES = -0.49; ±0.31), and shorter time in bed (ES = -0.47; ±0.38) and total sleep time (ES = -0.43; ±0.31). Increased 14-day VHSR was associated with later bed times (ES = 0.37; ±0.33) and shorter time in bed (ES = -0.50; ±0.41). Increased 14-day s-RPE was associated with shorter total sleep time (ES = -0.52; ±0.33).

During the in-season, increased 14-day total distance was associated with shorter time in bed (ES = -0.44; ±0.31) and total sleep time (ES = -0.46; ±0.28). Increased 14-day $m \cdot min^{-1}$ was associated with earlier wake times (ES = -0.44; ±0.24), and shorter time in bed (ES = -0.58; ±0.47) and total sleep time (ES = -0.45; ±0.44). Increased 14-day HSR was associated with shorter time in bed (ES = -0.42; ±0.39) and total sleep time (ES = -0.37; ±0.30). Increased 14-day VHSR was associated with reduced total sleep time (ES = -0.49; ±0.39). Increased 14-day s-RPE was associated with later bed times (ES = 1.60; ±0.75), less time in bed (ES = -1.84; ±0.97), shorter total sleep time (ES = -2.26; ±0.92) and reduced wake after sleep onset (ES = -0.31; ±0.17).

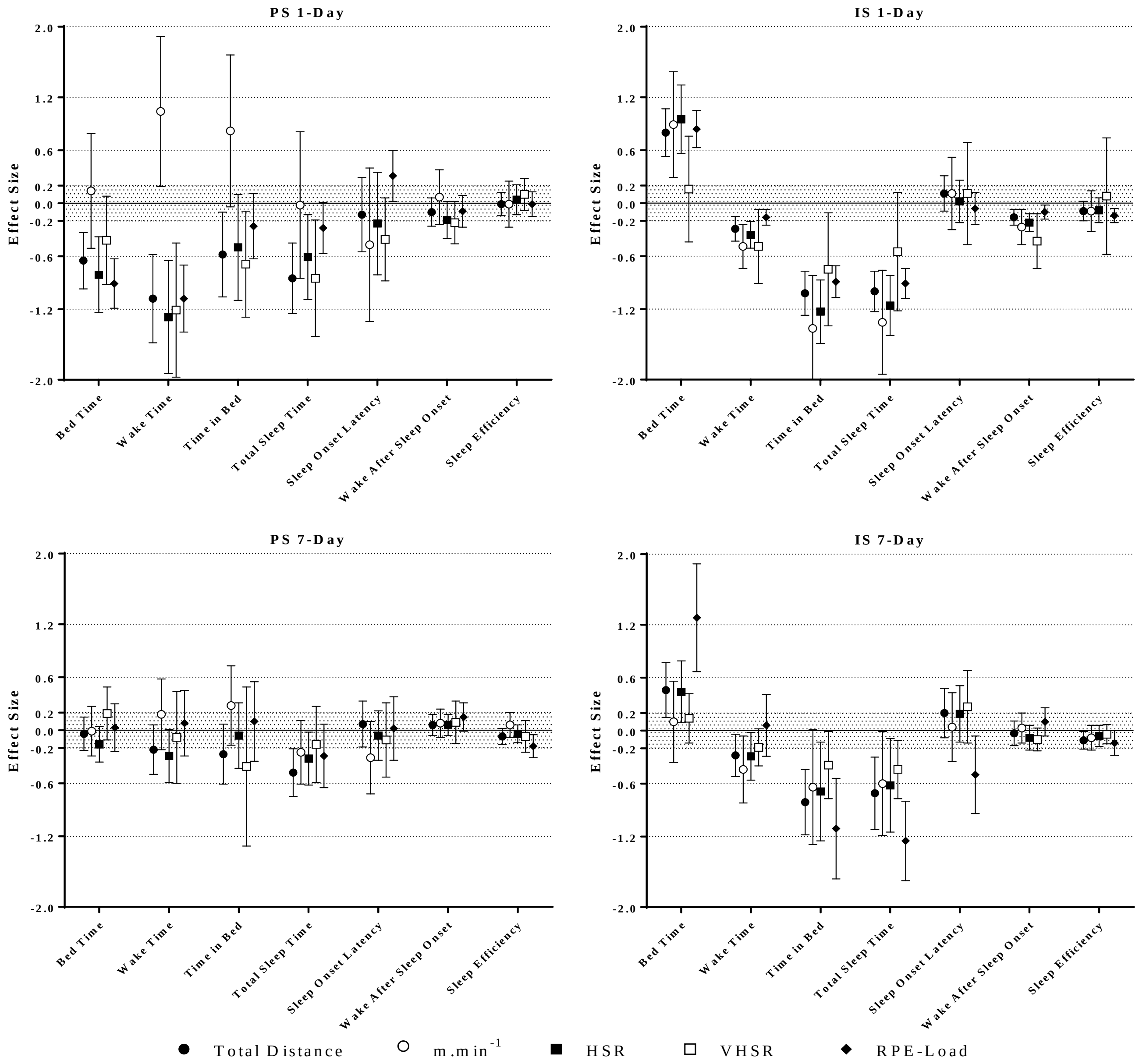


Figure 6.3. Effects of increased acute (1-day) and short-term (7-day) load parameters total distance, metres per minute; m·min-1, high-speed running; HSR, very high-speed running; VHSR, and rating of perceived exertion load; s-RPE Load on sleep behaviours, displayed as standardised effect size ± 90% confidence intervals, during the pre-season (PS) and in-season (IS) phases.

6.3.5 21-Day changes in training load

Relationships between 21-day loads and sleep behaviours are shown in Figure 6.4. During the pre-season, increased 21-day total distance was associated with earlier wake times (ES = -0.53; ±0.36), and shorter time in bed (ES = -0.90; ±0.41) and total sleep time (ES = -0.57; ±0.35). Increased 21-day $m \cdot min^{-1}$ was associated with later wake times (ES = 0.50; ±0.49), longer time in bed (ES = 0.44; ±0.56), reduced sleep onset latency (ES = -0.58; ±0.51) and greater wake after sleep onset (ES = 0.32; ±0.23). Increased 21-day HSR was associated with earlier wake times (ES = -0.56; ±0.35), and shorter time in bed (ES = -0.66; ±0.44) and total sleep time (ES = -0.48; ±0.37). Increased 21-day VHSR was associated with later bed times (ES = 0.42; ±0.30) and shorter time in bed (ES = -0.67; ±0.44). Increased 21-day s-RPE was associated with shorter total sleep time (ES = -0.47; ±0.31).

During the in-season, increased 21-day $m \cdot min^{-1}$ was associated with earlier wake times (ES = -0.45; ±0.26). Increased 21-day s-RPE was associated with later bed times (ES = 0.68; ±0.54), shorter time in bed (ES = -1.16; ±0.84) and total sleep time (ES = -1.59; ±0.95), increased sleep onset latency (ES = 0.50; ±0.61), and reduced sleep efficiency (ES = -0.39; ±0.21). Associations between sleep and 21-day total distance, HSR and VHSR were unclear.

6.3.6 28-Day changes in training load

Relationships between 28-day loads and sleep behaviours are shown in Figure 6.4. During the pre-season, increased 28-day total distance was associated with earlier wake times (ES = -0.50; ±0.41), shorter time in bed (ES = -0.68; ±0.41) and total sleep time (ES = -0.98; ±0.44). Increased 28-day $m \cdot min^{-1}$ was associated with later wake times (ES = 0.53; ±0.48), longer time in bed (ES = 0.65; ±0.53), shorter sleep onset latency (ES = -0.64; ±0.51), and increased wake after sleep onset (ES = 0.43; ±0.22). Increased 28-day HSR was associated with earlier wake times (ES = -0.47; ±0.38) and shorter total sleep time (ES = -0.68; ±0.42). Increased 28-day VHSR was associated with later bed times (ES = 0.38; ±0.32), and shorter time in bed (ES = -0.59; ±0.44) and total sleep time (ES = -0.55; ±0.61). Increased 28-day s-RPE was associated with shorter total sleep time (ES = -0.49; ±0.33), longer sleep onset latency (ES = 0.30; ±0.17) and reduced wake after sleep onset (ES = -0.29; ±0.14).

During the in-season, increased 28-day HSR was associated with shorter sleep onset latency (ES = -0.44; ±0.48). Increased 28-day s-RPE was associated with shorter time in bed (ES = -0.69; ±2.86), total sleep time (ES = -1.31; ±1.29) and wake after sleep onset (ES = -0.31; ±0.23). Associations between sleep and 28-day total distance, $m \cdot min^{-1}$ and VHSR were unclear.

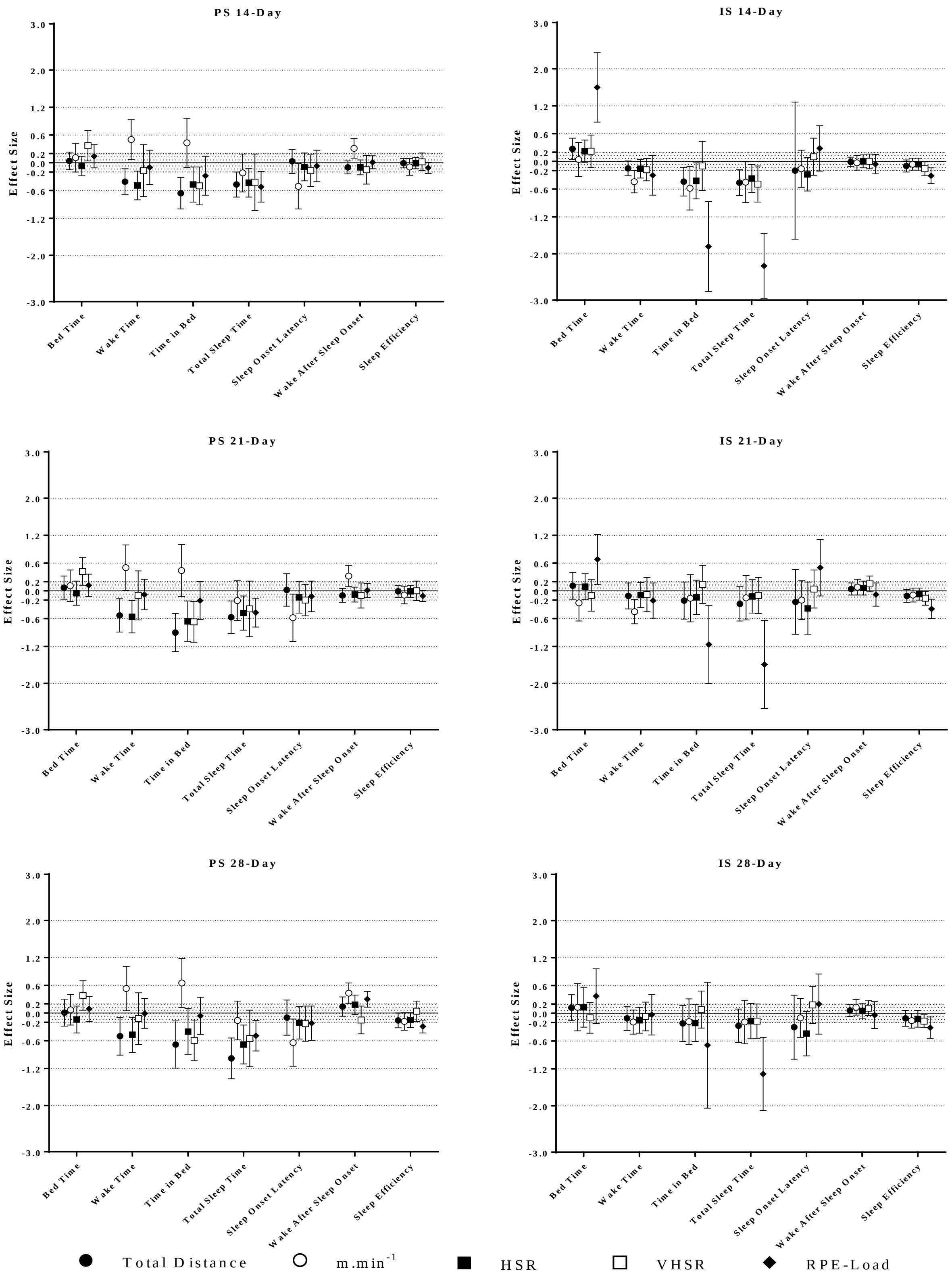


Figure 6.4. Effects of increased 14-, 21- and 28-day load parameters total distance, metres per minute; m·min-1, high-speed running; HSR, very high-speed running; VHSR, and rating of perceived exertion load; s-RPE Load on sleep behaviours, displayed as standardised effect size ± 90% confidence intervals, during the pre-season (PS) and in-season (IS) phases.

6.4 Discussion

The aim of this investigation was to determine the association between changes in load variables across 1-, 7-, 14-, 21- and 28-day periods and objectively measured sleep behaviours in Australian Rules footballers. Overall, the findings of the present study show that increased load during both the pre-season and in-season periods was associated with detrimental effects on sleep duration and sleep-wake behaviours of Australian Rules footballers. Irrespective of seasonal period, increased measures of both volume (total distance and s-RPE) and intensity ($m \cdot min^{-1}$, HSR and VHSR) both have negative associations with sleep behaviours the same night (i.e. 1-day), whilst cumulative 7-day loads during the pre-season have minimal associations with sleep behaviours. In contrast, sleep duration was negatively associated with higher 7-day cumulative loads during the in-season period. Load measures during the pre-season display consistent detrimental associations with sleep behaviours over 14-day, 21-day and 28-day cumulative periods, whereas during the in-season, higher loads had less detrimental effects on sleep behaviours as the cumulative period becomes longer. Together, these findings support the notion that heightened loads over both short- and longer-term periods negatively influence the sleep behaviours of Australian Rules footballers. The results of this study extend those of Chapter 5 indicating that practitioners should consider the season period in the assessment of sleep behaviours in Australian Rules footballers.

Previous evidence suggests that a complex and intricate relationship exists between physical demands and subsequent sleep in athletes (Dumortier et al., 2018; Thornton et al., 2017a; Thornton et al., 2017b). Consistent with this notion, the present study identified that during both the pre-season and in-season increased total distance and s-RPE Load negatively influences sleep duration and bed and wake times on the following night. This study also found that measures of intensity, including that of high-speed and very-high speed running distances, have a detrimental effect on total sleep time and bed and wake times during both the pre-season and in-season periods. This is similar to previous work in young gymnasts who display a negative relationship between s-RPE load and total sleep time the same night (Dumortier et al., 2018), and rugby league players where increased total distance and training duration have negative relationships with total sleep time during a training camp (Thornton et al., 2017b). Further work by Thornton et al. (2017a) found that the number of accelerations and decelerations performed during training was associated with increased sleep duration and sleep efficiency that night. Collectively, these findings suggest that exposure to high-volume sessions (total distance and s-RPE Load) that also result in increased high-speed running distances reduces the sleep duration of athletes, whereas sessions that expose athletes to high acceleration and deacceleration demands may generate a greater drive for increased sleep duration and sleep efficiency. Given that vast differences in accelerations and deaccelerations, total distance, and high-speed and very high-speed running between sports such as rugby league, soccer and Australian Rules football (Kempton and Coutts, 2015; Kempton et al., 2014; Bangsbo et al., 2006), knowledge of the differences in expected sleep outcomes as a result of daily load exposures may enhance periodisation to better facilitate sleep, recovery and performance. Further research is required to investigate the differential effects of load variables in a more controlled environment to better understand the role that load-variation has on the sleep behaviours of athletes.

Appropriate scheduling provides athletes with sufficient sleep opportunities to minimise sleep loss, which aids recovery and performance (Mah et al., 2011; Fullagar et al., 2015c). Early-morning training commitments present as a substantial barrier to obtaining adequate sleep durations in athletic populations. Early-morning training sessions have been shown to reduce the amount of sleep obtained by swimmers and rowers compared to the night preceding training-free days or days where early-morning commitments were removed (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b). Although, the present study did not evaluate the sleep behaviours of participants on the nights preceding training and non-training days, this may have influenced the results of the present study. Figure 6.1 demonstrates a clear shift to later start times during the in-season compared to the pre-season. These later start times may have provided increased sleep opportunities and increased in-season sleep duration, as reported in Chapter 5. Increased sleep has been shown to improve mood, facilitate neuromuscular function, and improve physical performance (Arnal et al., 2016; Mah et al., 2011), which may reduce the detrimental influence of increased load variables on sleep behaviours during the in-season and explain the discrepancies in associations between cumulative load and sleep observed across the pre-season and in-season periods. Therefore, the results of this study and Chapter 5 support previous evidence from individual sport athletes of a detrimental effect of early-morning scheduling on training days, especially during the pre-season period, on the sleep behaviours of Australian Rules footballers.

Team-sport training plans are typically broken down to 7-day microcycles during both the pre-season and in-season phases (Issurin, 2010). This cyclic nature of both training and competition exposure justifies the need to develop an understanding of how this periodisation process influences the sleep behaviours of athletes. In rugby league, Thornton et al. (2017a) showed that cumulative high-speed running distances and summed acceleration and deacceleration efforts across 3- and 7-day periods resulted in earlier bed times and increased sleep efficiency but had no influence on total sleep time during the pre-season period. In contrast, the present study found that increased cumulative 7-day total distance reduced total sleep time during the pre-season, yet intensity domains such as $m \cdot min^{-1}$ and high-speed running distance had no effect during the pre-season. The disparity in findings suggests that although sleep duration is enhanced with greater training intensity in rugby league athletes, increased total distance appears to impair sleep duration in Australian Rules footballers, which provides additional evidence to Chapter 4 (Pitchford et al., 2017) that found that increased s-RPE-Load during an 8-day pre-season camp impairs sleep efficiency. These findings may suggest that sports involving shorter, higher-intensity intermittent activities increase the need and/or drive for sleep during the pre-season period, whereas sports involving longer duration, higher volume activities lead to impaired sleep duration and sleep efficiency. This notion is somewhat supported by previous literature that has found high-intensity sports reduce wake after sleep onset, without impacting total sleep time (Suppiah et al., 2015; Myllymäki et al., 2012). However, comparisons between badminton and ten-pin bowling (Suppiah et al., 2015), and using continuous 30-min exercise sessions at 45%, 60% and 75% max heart-rate (Myllymäki et al., 2012) do not provide comprehensive information from which to make strong conclusions regarding the influence of intensity and volume on the sleep behaviours of athletes. Thus, further research that the influence of sport-specific demands has on the sleep behaviours of athletes is required, to ensure that training can be periodised and planned appropriately to minimise the detrimental influences of lost sleep that may occur as a result.

Australian Rules footballers experience substantial reductions in total distance and high-speed running during the in-season period, with most of this load coming by way of competitive matches instead of training sessions (Ritchie et al., 2016). The present study found that during the in-season, increases in both 7-day cumulative volume (total distance and s-RPE Load) and intensity ($m \cdot min^{-1}$, HSR and VHSR) demands resulted in altered bed and wake times and reduced total sleep time, which was not observed during the pre-season phase. These findings are in support of the results of Chapter 5, and previous literature (Lalor et al., 2017; Richmond et al., 2004), suggesting a competition-centred detrimental influence of load on the sleep behaviours of Australian Rules footballers. Indeed, the present study collected in-season sleep behaviour data on the days surrounding competitive matches, which may have influenced the results of the present study given the large contribution of matches to the 7-day load summation during the in-season period. This may also suggest that a more even distribution of daily loads across a 7-day period, as seen during the pre-season, has less influence on sleep behaviours than uneven or sudden load increases, observed during the in-season. Furthermore, matches are accompanied by factors such as pain and post-match adrenaline (Fullagar et al., 2016b), post-match media exposure (Nédélec et al., 2013), increased prevalence of night-time matches (Fullagar et al., 2016b), and later caffeine consumption (Dunican et al., 2018), which may detrimentally influence sleep duration, irrespective of preceding load exposure. Therefore, further investigation incorporating additional days during the in-season period and the consideration of whether days involving competition, training or neither are required to better understand the influence of in-season load on the sleep behaviours of Australian Rules footballers.

During the pre-season period, Australian Rules footballers undertake training that involves larger volumes and repeated exposure to high-intensity load, compared to the in-season (Ritchie et al., 2016). Training periodisation of this manner is designed to improve the physical attributes of players and enhance performance during the in-season. However, exposure to periods of sustained high load, may expose athletes to increased risk of unfavourable outcomes such as non-functional over-reaching. Non-functional over-reaching involves a sustained elevation in training and other stress, coupled with insufficient recovery, leading to impaired performance outcomes and function of biological mechanisms (Meeusen et al., 2013). Periods of increased training volume and intensity over 14 days have been shown to result in reduced average sleep duration in rowers and cyclists (Kölling et al., 2016; Teng et al., 2011). Furthermore, Hausswirth et al. (2014) showed that exposing triathletes to a 21-day over-training period, where training duration was increased by 30%, reduces sleep duration, reduces efficiency and increases prevalence of upper respiratory tract infections, with suppressed immune function linked to impaired sleep (Imeri and Opp, 2009). This also suggests a potential reciprocal relationship between load, illness and sleep, as reduced sleep duration has also been associated with increased incidence of illness within the next 7 days in Australian Rules footballers (Fitzgerald et al., 2019). This is somewhat supported by the present study, with higher cumulative 14-, 21- and 28-day total distance, high-speed running, very-high speed running, and s-RPE Load associated with reduced total sleep time during the pre-season. Heightened s-RPE load also showed a detrimental effect on total sleep time across 14-, 21- and 28-day periods during the in-season. Given recent support for the use of sleep as an indicator of over-reaching in athletes (Lastella et al., 2018), the results of the present study provide additional evidence suggesting that periods of sustained high load, in particular volume measures such as total distance and s-RPE Load, have detrimental effects on the sleep duration of athletes and should be closely monitored to prevent a negative flow-on effect to markers of recovery, illness and performance. However, further research is required to evaluate the effect of season phase and the presence of a threshold for change in load variables, within which, sleep behaviours may remain unaffected.

In conclusion, the present study found that the physical loads undertaken by Australian Rules footballers have substantial detrimental effects on sleep behaviours during both the pre-season and in-season periods. Furthermore, cumulative 7-day loads during the pre-season period have less influence on sleep behaviours compared to the in-season period, with total distance, $m \cdot min^{-1}$, HSR and VHSR having stronger effects on sleep during short term (1- and 7-day) time periods compared to longer time periods, which may be a result of the load distribution pattern differential between the pre-season and in-season. Increased total distance for 1-day and cumulative 14-, 21- and 28-day periods during the pre-season period and increased s-RPE load for 1-day and cumulative 7-, 14- and 21-day cumulative periods causes consistent reductions in bed time, time in bed and total sleep time. Collectively, sleep is negatively influenced by increased training demands and restrictive training schedules more so during the pre-season, except 7-day load demands, and that periods of sustained high-volume lasting 14-days or longer has detrimental effects on the sleep duration of athletes. These findings may explain the previously observed reduced sleep durations observed in Chapter 5 and supports the need for the utilisation of sleep monitoring in athlete populations to accompany load monitoring practises and prevent load- and schedule-induced impairments in the sleep and performance outcomes of team-sport athletes.

CHAPTER 7. STUDY 4 – A SINGLE NIGHT OF SLEEP EXTENSION DOES NOT INFLUENCE MARKERS OF RECOVERY

Chapters 4, 5 and 6 demonstrate a range of influencing factors that negatively impact the sleep of team-sport athletes. Given the role that sleep plays in recovery from exercise, it may be speculated that increasing the total amount of sleep will expedite recovery and exercise performance. Therefore, this study was designed to investigate the effects of increased sleep duration on markers of recovery following a heavy bout of intermittent exercise, resembling competition. Preliminary findings have been presented as a poster presentation at the Exercise and Sport Science Australia – Research to Practice Conference, Brisbane, Australia 2018.

7.1 Introduction

Team-sport competitions are characterised by periods of submaximal activity interspersed by bursts of high-intensity efforts (Coutts et al., 2010). In this regard, team-sport activity resembles that of high-intensity interval exercise (HIIE), which has detrimental effects on sleep duration compared to non-competition nights (Fullagar et al., 2015b; Shearer et al., 2015; Lalor et al., 2017; Richmond et al., 2004). Sleep loss and HIIE both display similar transient effects on markers of recovery, such as the production of a catalytic environment and dysregulation of inflammatory, hormonal and immunological function (Obal and Krueger, 2004; Santos et al., 2007; Vgontzas et al., 2004; Croft et al., 2009; Fragala et al., 2015; Nieman, 1997; Ascensão et al., 2008), impaired neuromuscular function (Skein et al., 2013; Arnal et al., 2016; Skein et al., 2011), decreased muscle force generating capacity (Ispirlidis et al., 2008; Thorlund et al., 2008), increased perceptual fatigue (Cormack et al., 2008a; McLean et al., 2010; Ispirlidis et al., 2008), and reduced subjective ratings of wellbeing (McLean et al., 2010; Mohr et al., 2016). The combined effects of HIIE and subsequent reduced sleep may have detrimental effects on key physical and physiological factors relevant to recovery, which may limit exercise participation and impair subsequent physical performance.

To enhance the process of recovery following HIIE, team-sport athletes implement a range of recovery strategies, such as cold-water immersion (CWI), active recovery, and the use of massage and compression garments, with overall positive effects (Dupuy et al., 2018). For example, massage techniques reduce perceived soreness, fatigue, and inflammation (Torres et al., 2012; Ogai et al., 2008; Crane et al., 2012), and compression garments and CWI improve ratings of perceived soreness and fatigue (Delextrat et al., 2014; Kraemer et al., 2010; Rowsell et al., 2011; Machado et al., 2016), whilst active recovery improves ratings of soreness and force production following-exercise (Zainuddin et al., 2006). However, not all techniques impact all aspects of recovery, as cryotherapy and active recovery have minimal effects on neuromuscular function (Andersson et al., 2008; Guilhem et al., 2013; Vieira et al., 2015), and compression garments do not benefit inflammatory or perceptual responses (Marqués-Jiménez et al., 2018). In Australian Rules footballers, players who completed a combination of CWI, floor stretching, compression garments, and no active recovery displayed an increased probability of reporting greater perceptual recovery across the following week (Bahnert et al., 2013). Therefore, evidence suggests mixed and incomplete effects of currently utilised recovery interventions on markers of recovery and function following exercise, supporting the need for further investigation of more effective methods to enhance post-exercise recovery.

Further investigation as to the effectiveness of interventions designed to enhance or increase sleep to improve recovery have received strong support (Halson, 2008), especially given the importance placed upon sleep for recovery by athletes (Venter, 2014). Despite this, the effect that sleep extension and improved sleep hygiene have on markers of recovery following heavy exercise or competition has received limited investigation. Sleep hygiene interventions are designed to enhance the effectiveness of time spent in bed, whereas sleep extension is the process by which normal or habitual sleep durations are increased through increasing time spent in bed, both of which have direct application for athletic populations. Previous investigations have found beneficial effects of sleep extension on time to exhaustion, perceived effort and wellbeing, sprint performance, and basketball shooting accuracy (Arnal et al., 2016; Mah et al., 2011), however these protocols lasted several days to weeks. Furthermore, single-night sleep extension investigations and sleep hygiene interventions have been successful at increasing sleep duration in athletic populations (Caia et al., 2018a; Fullagar et al., 2016a; O'Donnell and Driller, 2017; Sargent et al., 2014a). However, these single-night protocols did not examine post-exercise recovery outcomes. Therefore, the use of sleep extension to increase sleep duration on a single night and enhance measures of physical recovery and athletic performance over prolonged periods of time is promising, meaning there is a clear need for further research investigating the exposure to a single night of sleep extension on post-exercise recovery.

Activities consisting of high-intensity intermittent exercise, such as team-sport competition, induce substantial physiological and physical impairments that are exacerbated when accompanied by post-exercise sleep loss. Given the prevalence of post-match sleep loss in athletic populations, the aim of the present study was to investigate the effect of a single night of sleep extension on physiological, physical, and perceptual recovery following a demanding HIIE session. It was hypothesised that a single night of sleep extension, by increasing time in bed overnight to 10 h, would have a beneficial effect on recovery outcomes compared to a control condition spending 8 hours in bed overnight, following high-intensity interval running.

7.2 Methods

7.2.1 Participants

Participant information is detailed in Chapter 3 Section 3.1.2.

7.2.2 Data Collection

In a randomised, repeated-measures design, participants completed two trials. Following a session of High Intensity Interval Exercise (HIIE) participants slept in a sleep laboratory on two occasions, which consisted of 1 night of 8 h time in bed (CON; 12:00am – 8:00am) and 1 night of 10 h time in bed (EXT; 10:00pm – 8:00am). Participants were familiarised to the HIIE session, recovery assessments (excluding blood sampling procedures), and the sleeping environment, at least 7 days prior to the beginning of the experimental procedures by completing each component and spending a single night in the controlled laboratory conditions. During the experimental procedures, participants were assessed for maxmimal voluntary contraction (MVC) peak torque, countermovement jump (CMJ) performance, submaximal heart-rate response and heart-rate variability (HRV), and subjective recovery. Blood samples were also obtained for measurement of circulating markers relevant to hormonal, immune and inflammatory status (interleukin-6; IL-6, insulin-like growth factor-1; IFG-1, and growth hormone; GH).

7.2.3 High-Intensity Interval Exercise

Participants arrived 2 h prior to beginning the HIIE session to consume a standardised pre-exercise meal (see Section 7.2.7). Participants were asked to abstain from consuming caffeine and alcohol, and from partaking in exercise for 24 h prior to the HIIE bout. The 58-minute HIIE session is as described previously in Chapter 3, Section 3.5.3. All participants completed the HIIE for both trials.

7.2.4 Recovery Assessments

Recovery assessments in this study are as previously described in Chapter 3, Section 3.3.3. Measurements for MVC and CMJ were taken at Pre, 0 h, 1 h, 2 h and 16 h post-HIIE, HRV was measured Pre, 1 h, 2 h and 16 h post-HIIE, subjective recovery was measured at Pre and 16h post-HIIE, and blood was obtained at Pre, 0 h, 1 h, 2 h and 16 h post-HIIE. In this way, the 0 h, 1 h and 2 h time points assessed the magnitude of immediate post-exercise fatigue and the 16-h post-HIIE assessment was following the single night of sleep extension or control sleep.

7.2.5 Blood Analysis

Blood analysis procedures in this study are as previously described in Chapter 3, Section 3.3.4.

7.2.6 Sleep Assessment

The sleep assessment in this study was as previously described in Chapter 3, Sections 3.2.1 and 3.2.2. In brief, baseline sleep assessment (BL) took place prior to the experimental procedures across a 14-day period in free-living conditions. During the experimental conditions bed time, out of bed time and time in bed were controlled for, as lights were turned out at 10:00 pm (EXT) or 12:00 am (CON) and turned on at 8:00 am, whilst also adhering to sleep hygiene guidelines outlined in Chapter 3, Section 3.2.1.

7.2.7 Dietary Standardisation

Participants were supplied with a standardised diet throughout the duration of the study, as described in Chapter 3 Section 3.5.4.

7.2.8 Statistical Analysis

Changes in sleep variables relative to baseline were analysed using paired two-tail t-tests ($P<0.05$) and differences in absolute sleep variables between conditions and baseline were analysed using repeated measures one-way ANOVA and Tukey's HSD ($P<0.05$). Multiple linear mixed models were constructed to examine individual differences in recovery markers relative to pre-HIIE (0 h) values between CON and EXT, whilst sleep behaviours were analysed relative to baseline sleep values. Q-Q plots were used to examine the uniformity of the dependant variables; if uniformity was violated the dependent variables were log-transformed and models were re-run. To account for error associated with individual repeated measures and differences in baseline values between conditions, participants and condition were included in the model as random effects; this allowed different within-individual standard deviations. The condition*timepoint interaction and order of condition were included as a fixed effect in the models, which described the relationship between the dependent variable and covariates (West et al., 2014). Pairwise fixed-effect comparisons were completed using the Least Squares mean test and were expressed as standardised effect sizes (ES) using pooled standard deviation, categorised according to Hopkins et al. (2009): <0.20 trivial, 0.21 – 0.60 small, 0.61 – 1.20 moderate, 1.21 – 2.0 large and > 2.1 very large, with only moderate or above effects reported. The likelihood of the observed effect was established using a non-clinical magnitude-based approach, where effects were considered clear at the 95% level (Hopkins et al., 2009). The moderate level effect size and 95% clearance level was chosen to reduce the chance of Type I error (Sainani, 2018). Comparative differences in text are presented as mean difference, ES, and ±90% confidence limits, unless otherwise stated. Descriptive statistics in figures are presented as individual mean values, and group means ± standard deviation, unless otherwise stated. Statistical analyses were performed using R statistical software (R 3.5.0, R foundation for Statistical Computing).

7.3 Results

7.3.1 Sleep

Descriptive data and results of one-way repeated measures ANOVA comparing between-condition sleep behaviours can be seen in Table 7.1. Bed time was later in EXT compared to BL, but no difference was observed between CON and BL. Compared to BL, time in bed was longer in EXT but not CON. Total sleep time was longer in both CON and EXT compared to CON, and was longer in EXT compared to CON. Compared to BL, wake after sleep onset was longer in both CON and EXT, but not between CON and EXT. Compared to BL, sleep efficiency was higher in CON, but no differences between EXT and BL nor EXT and CON were observed. No between-condition differences in wake time and sleep onset latency were observed.

Changes in sleep behaviours relative to BL data are shown in Figure 7.1. The EXT experienced a greater increase in bed time (1:29 ± 0:53 h), compared to CON (0:29 ± 0:53 h; $p<0.0001$, ES = 2.23; ±1.05), whereas no between-condition difference in change of wake time was observed. The EXT resulted in a greater increase in TIB (2:19 ± 0:44 h), compared to CON (0:18 ± 0:44 min; $p>0.0001$, ES = 2.71; ±1.14), and a greater increase in TST (2:21 ± 0:55 h) compared to CON (0:51 ± 0:37 h; $p<0.0001$, ES = 1.90; ±1.05). No substantial between-condition difference in changes of sleep onset latency, wake after sleep onset nor sleep efficiency were observed.

Table 7.1. Descriptive data detailing the sleep behaviours observed during baseline sleep assessment (BL), and the control (CON) and extension (EXT) conditions. Comparisons between conditions are expressed as p-value and standardised effect sizes; ±90% confidence interval. Likelihoods are expressed as; *, likely; **, very likely; ***; most likely. Results of one-way repeated measures ANOVA are signified as p-value.

Sleep Characteristic	**Condition**			**Comparison**		
	BL	**CON**	**EXT**	**BL v CON**	**BL v EXT**	**CON v EXT**
Bed Time (AM/PM)	11:28 ± 0:56 PM	12:00 AM	10:00 PM	p = 0.0655 ES = 0.80; ±0.89*	***p<0.0001 ES = -2.18; ±1.06****	n/a
Wake Time (AM/PM)	7:22 ± 1:00 AM	8:00 AM	8:00 AM	p = 0.048 ES = 0.89; ±0.70*	p = 0.048 ES = 0.89; ±0.70*	n/a
TIB (h:mm)	7:41 ± 0:44	8:00	10:00	p = 0.2262 ES = 0.53; ±0.87	***p<0.0001 ES = 4.31; ±1.52****	n/a
TST (h:mm)	6:45 ± 0:43	7:28 ± 0:12	9:07 ± 0:32	***p = 0.0072 ES = 1.27; ±0.98***	***p<0.0001 ES = 3.53; ±1.37****	***p<0.0001 ES = 3.88; ±1.48****
SOL (h:mm)	0:15 ± 0:13	0:04 ± 0:04	0:11 ± 0:10	p = 0.0255 ES = -1.24; ±0.98*	p = 0.6506 ES = -0.36; ±0.88	p = 0.1378 ES = 1.01; ±0.95*
WASO (h:mm)	0:45 ± 0:22	1:32 ± 0:04	1:28 ± 0:06	***p<0.0001 ES = 4.18; ±1.56****	***p<0.0001 ES = 3.77; ±1.42****	p = 0.6684 ES = -0.85; ±0.94
SEF (%)	88.1 ± 5.0	93.5 ± 2.4	91.2 ± 5.3	***p = 0.085 ES = 1.45; ±1.00***	p = 0.1961 ES = 0.59; ±0.89	p = 0.2558 ES = -0.67; ±0.92

h:mm = time of day in hours and minutes, TIB = time in bed, TST = total sleep time, SOL = sleep onset latency, WASO = wake after sleep onset, SEF = sleep efficiency, % = percentage, BL = baseline, CON = control condition, EXT = extension condition, ES = standardised effect size, and n/a = result not available due to lack of within-group standard deviation.

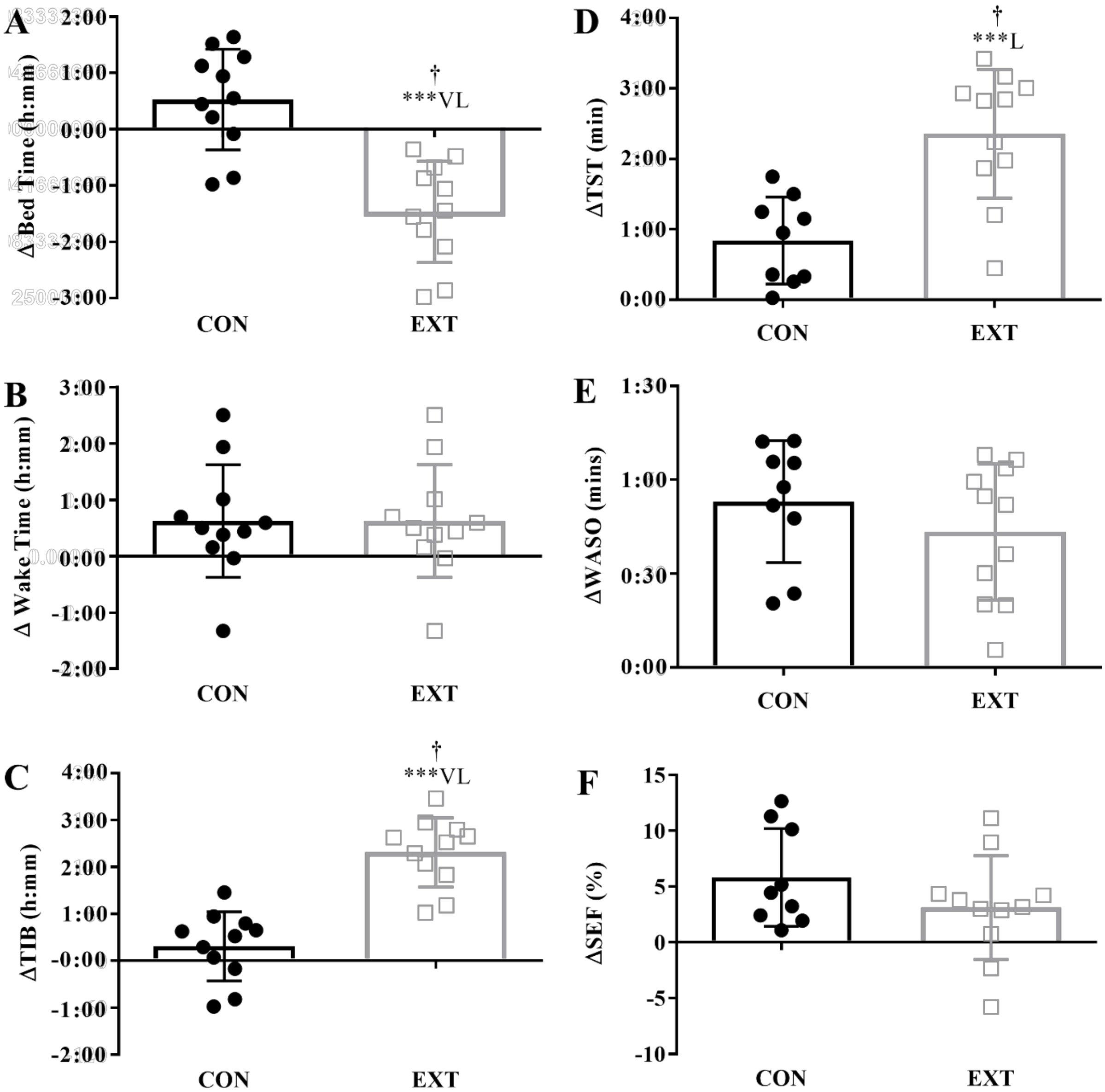


Figure 7.1. Individual and group changes in A) bed time, B) wake time, C) time in bed (TIB), D) total sleep time (TST), E) wake after sleep onset (WASO), and F) sleep efficiency (SEF) relative to baseline sleep assessment (CON; black bar and closed circles) and (EXT; grey bar and open squares). Group change values relative to baseline are displayed as mean ± standard deviation. Differences between groups are expressed as effect size magnitudes; L, large; VL, very large. Likelihoods are expressed as; ***; most likely. † signifies statistical between-group difference ($p<0.05$).

7.3.2 Subjective

Changes in ratings of subjective wellness are shown in Figure 7.2. No main effects of HIIE on subjective ratings of fatigue, sleep quality, stress, mood or total wellbeing were observed. Both the CON and EXT conditions displayed reductions in soreness ratings at 16 h post-HIIE. There were no substantial between-condition differences in subjective wellbeing scores (Figure 7.2).

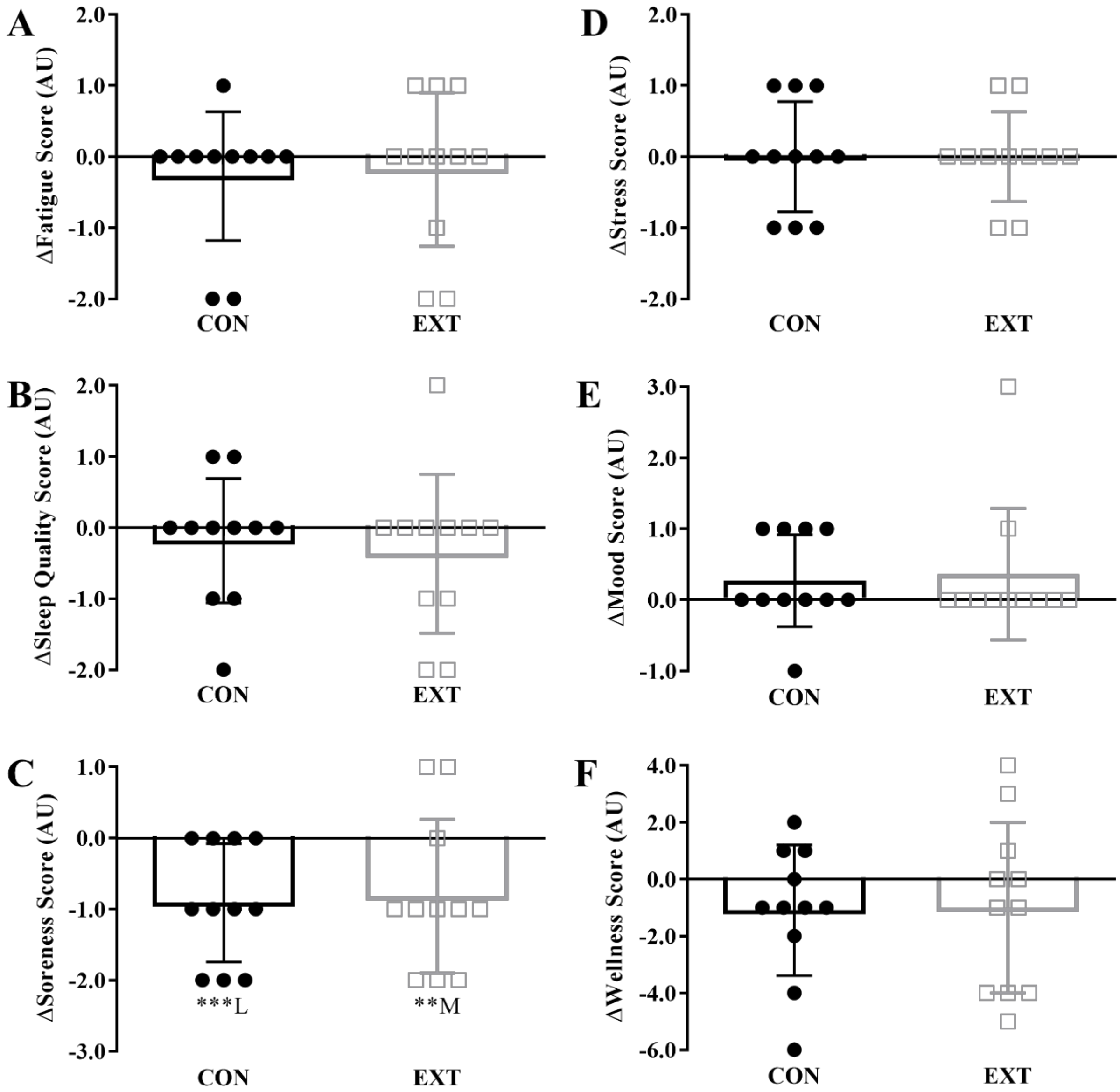


Figure 7.2. Individual and group changes in subjective ratings of Fatigue, Sleep Quality, Muscle Soreness, Stress, Mood and Total Wellbeing from pre-HIIE to 16 h between the (CON, black bar and closed circles) and (EXT, Grey bar and open squares) groups. Group change values relative the pre-HIIE are displayed as mean ± standard deviation. Differences between pre-HIIE and 16 h timepoints are noted below the data points and expressed as effect size magnitudes; M, moderate; L, large; VL, very large. Likelihoods are expressed as; **, very likely; ***; most likely.

7.3.3 Neuromuscular

The HIIE session had substantial effects on measures of neuromuscular function (Figure 7.3). Main effects of time revealed that peak jump height was reduced at 0 h (-3.3 ± 2.0 cm, ES = -2.25; ±0.70) and at 2 h (-1.8 ± 3.6 cm, ES = -0.69; ±0.39). Peak jump velocity was reduced at 0 h (-0.08 ± 0.11 $m \cdot s^{-1}$, ES = -0.97; ±0.54). Peak jump force was reduced at 1h (-56.3 ± 89.8 N, ES = -0.89; ±0.46), 2h (-62.2 ± 120.6 N, ES = -0.73; ±0.34) and 16h (-43.2 ± 95.0 N, ES = -0.64; ±0.44). Peak jump power was reduced at 2h (-115.0 ± 258.9 W, ES = -0.63; ±0.43) and

16 h (-161.0 ± 305.0 W, ES = -0.75; ±0.36). Concentric time was increased at 1 h (0.01 ± 0.02 ms, ES = 0.90; ±0.49). Peak MVC torque was reduced at 0 h (-19.1 ± 21.8 Nm, ES = -1.24; ±0.53), 1h (-19.1 ± 19.9 Nm, ES = -1.35; ±0.58), 2 h (-18.8 ± 28.0 Nm, ES = -0.95; ±0.42) and 16h (-28.5 ± 24.5 Nm, ES = -1.65; ±0.48). There were no substantial between-condition effects on measures of neuromuscular function (Figure 7.3).

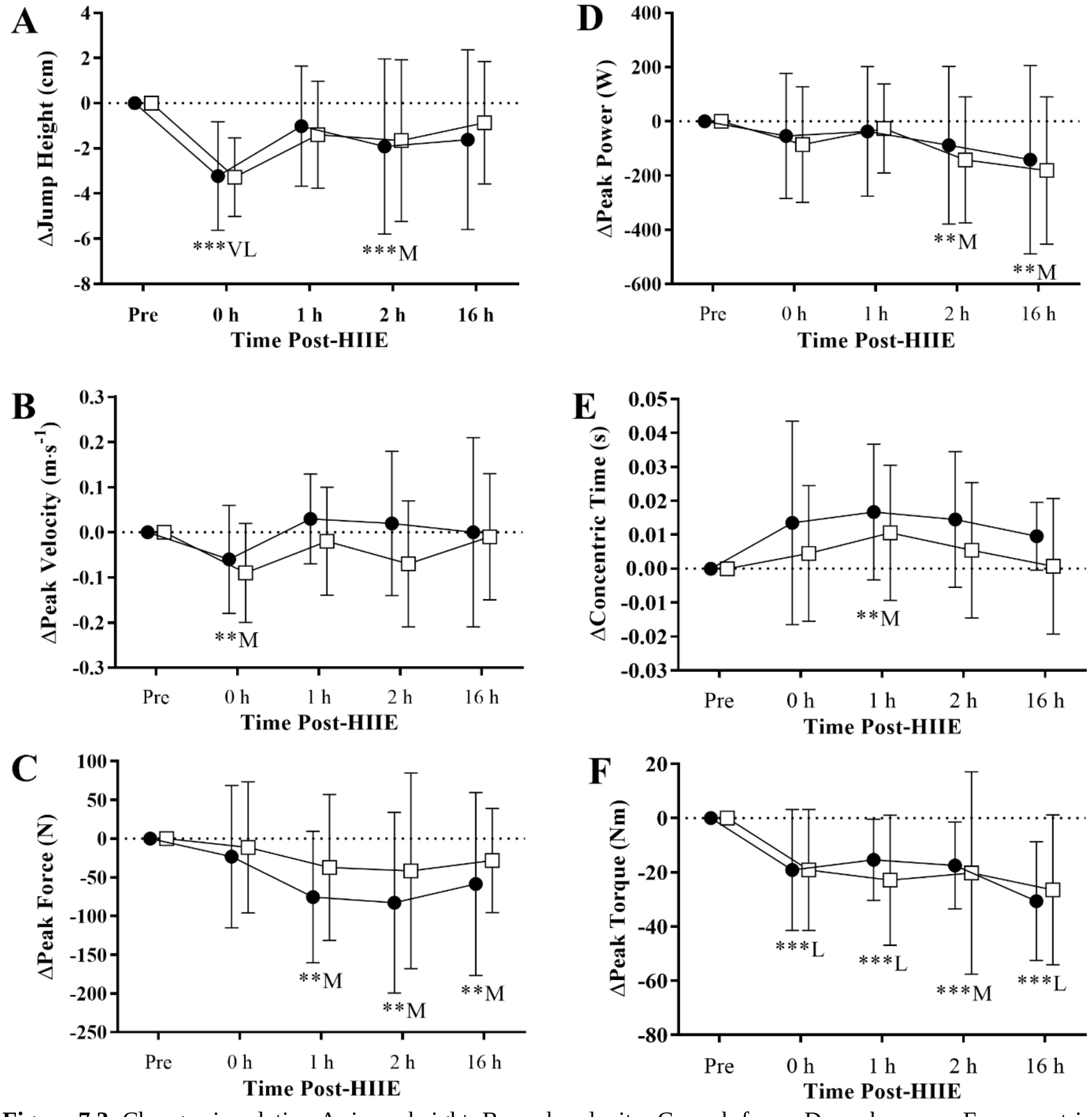


Figure 7.3. Changes in relative A; jump height, B; peak velocity, C; peak force, D; peak power, E; concentric time, and F; peak knee extension torque over time between the (CON, closed circles) and (EXT, open squares) groups following HIIE. Change values relative the pre-HIIE are displayed as mean ± standard deviation. Differences between pre-HIIE and post-HIIE timepoints are noted below the data points, whereas differences between condition are noted above the data points, and are expressed as effect size magnitudes; M, moderate; L, large; VL, very large. Likelihoods are expressed as; **, very likely; ***; most likely.

7.3.4 Autonomic

A main effect of time was observed following HIIE, as seen by increased RPE, RHR and HRex, and reduced log-rMSSD and %HRr at all timepoints post-HIIE (Figure 7.4). SDNN was also reduced at 1 h (-13.6 ± 25.4 AU, ES = -0.76; ±0.51) and at 16 h post-HIIE (-23.3 ± 23.6 AU, ES = -1.42; ±0.58). There were differences between CON and EXT for %HRr such that EXT showed less reductions in %HRr at 1 h (ES = 0.93; ±0.65) and at 2 h (ES = 1.30; ±1.07). There were no substantial between-condition effects on RPE, HRV, RHR and HRex (Figure 7.4).

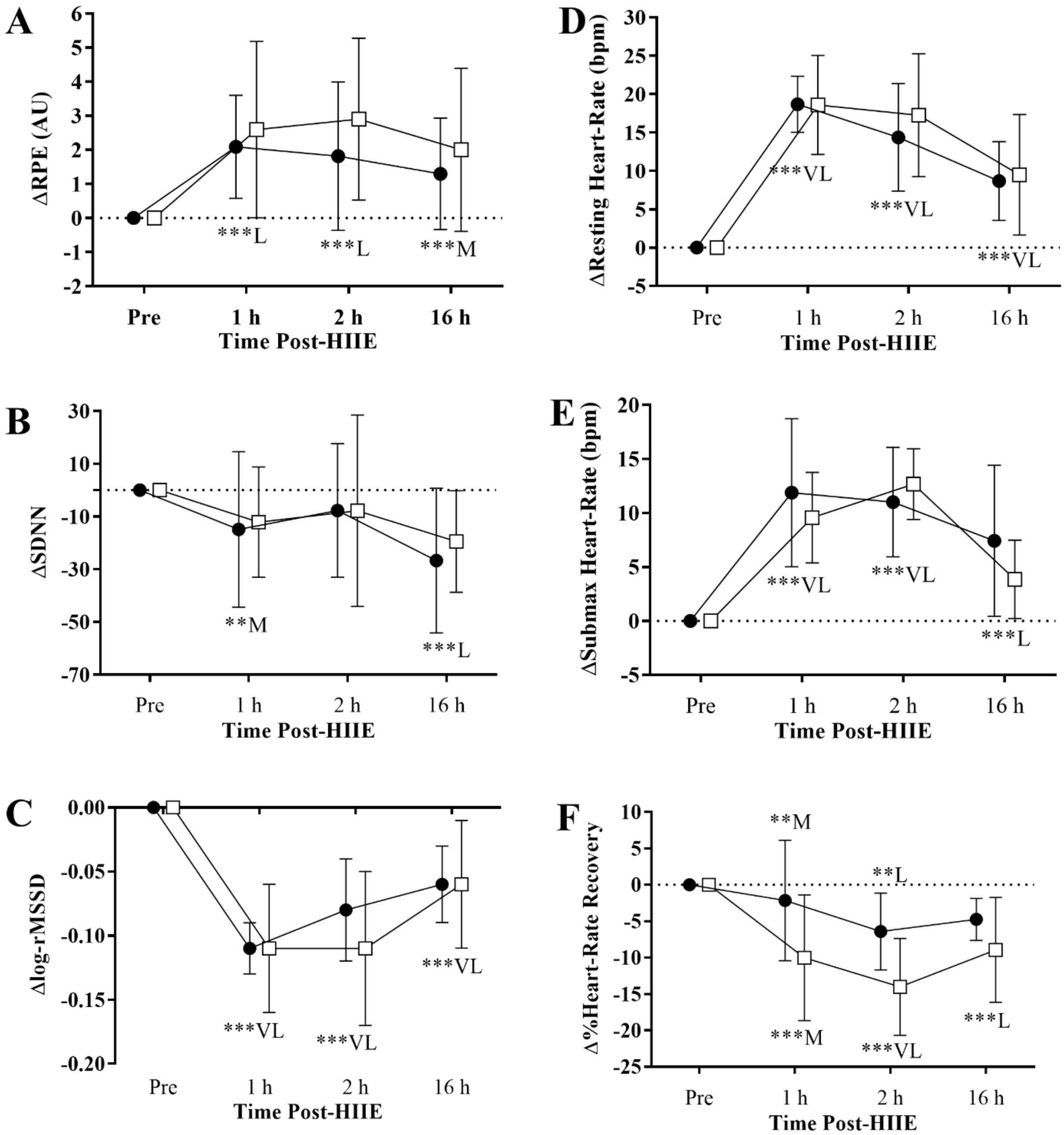


Figure 7.4. Changes in relative A; RPE, B; SDNN, C; log-rMSSD, D; RHR, E; HRex and F; %HRr over time between the (CON, closed circles) and (EXT, open squares) groups following high-intensity interval exercise (HIIE). Change values relative the pre-HIIE are displayed as mean ± standard deviation. Differences between pre-HIIE and post-HIIE timepoints are noted below the data points, whereas differences between condition are noted above the data points, and are expressed as effect size magnitudes; M, moderate; L, large; VL, very large. Likelihoods are expressed as; **, very likely; ***; most likely.

7.3.5 Blood-markers

A main effect of time on blood-based recovery markers was observed following HIIE, with IL-6 showing an increase at 0 h (5.61 ± 3.02 pg·mL^{-1}, ES = 2.63; ±0.76) and GH concentrations showing an increase at 0 h (2.56 ± 2.55 ng·mL^{-1}, ES = 1.42; ±0.53). The HIIE session had no substantial effect on IL-6 and GH at 16 h, and no substantial effect on IGF-1 at any time-point. There were no substantial between-condition effects on IL-6, GH and IGF-1.

7.4 Discussion

This study is the first to investigate the effects of a single night of sleep extension (increased sleep duration) on markers of recovery following a session of high-intensity interval exercise in a laboratory-controlled environment. The key findings were that providing the opportunity for increased sleep duration substantially increases post-exercise sleep duration; however, this does not alter subjective, neuromuscular, autonomic, or blood-based measures of recovery at 16 h following a single session of high-intensity interval exercise.

The present study found substantial reductions in ratings of muscle soreness and total wellbeing, markers of neuromuscular function, countermovement jump performance, maximal voluntary force production, and autonomic recovery, following HIIE. These responses are all consistent with previous literature that has explored the time course of recovery following HIIE. For example, muscle soreness increases and total wellbeing declines following a session of HIIE (McLean et al., 2010; Mohr et al., 2016; Skein et al., 2013), whilst measures of neuromuscular function, countermovement jump performance, maximal voluntary contraction force production, and autonomic recovery, are also detrimentally impacted by HIIE (Cormack et al., 2008a; Johnston et al., 2013; Rowell et al., 2016; Thorlund et al., 2008; Mann et al., 2015; Buchheit et al., 2015) and healthy populations (Bailey et al., 2007). Even though the HIIE session utilised in the present study did not incorporate the changes of direction and impacts inherent in competition, given the high repeatability of recovery outcome measures, the observed changes in overall responses to wellbeing, neuromuscular function, countermovement jump performance, maximal voluntary force production, and autonomic recovery, it would appear appropriate to study the effects of a single night of extended sleep on markers of recovery.

The primary finding of this study demonstrates that a single night of sleep extension has no substantial effect on markers of subjective, neuromuscular, autonomic, and hormonal recovery. Previous observations have shown that sleep restriction and deprivation have negative effects on perceptual (Martin and Gaddis, 1981; Arnal et al., 2016), neuromuscular (Arnal et al., 2016), autonomic (Mougin et al., 1991), and hormonal (Abedelmalek et al., 2013; Dattilo et al., 2011) markers of recovery. In addition, prolonged periods of sleep extension have beneficial effects on physical performance and recovery outcomes (Arnal et al., 2016; Mah et al., 2011; Famodu et al., 2017). Therefore, it was hypothesised that a single night of increased sleep duration following exercise would positively affect these recovery markers, compared to habitual sleep durations. The results of the present study do not support this hypothesis, which may be due to the increase in total sleep time experienced by both conditions relative to habitual sleep conditions, resulting in a situation where the increased total sleep time in both the control and extension conditions may have impacted the post-exercise recovery responses, reducing any between-condition effects. The increase in total sleep time, without a concomitant increase in time in bed, in the control condition relative to habitual sleep assessments is a somewhat unexpected finding. However, this finding provides support for the benefits of adhering to sleep hygiene guidelines on the night following demanding HIIE. Indeed, adherence to sleep hygiene guidelines, such as the removal of electronic devices and excessive light exposure 30 min prior to bed and sleeping in a cool and quiet environment, improves sleep duration (Caia et al., 2018a; Duffield et al., 2014; O'Donnell and Driller, 2017). Furthermore, Fullagar et al. (2016a) found that the implementation of sleep hygiene strategies improves sleep quantity, but not physical performance or recovery, following soccer competition. Notwithstanding, despite no effect of sleep extension on markers of recovery, compared to control, the present study showed that both sleep quantity (increased total sleep time) and markers of sleep quality (reduced sleep onset latency and improved sleep efficiency) are enhanced, compared to baseline, by adhering to sleep hygiene strategies, both with (extension condition) and without (control condition) increased sleep opportunity. Hence, further research is required to better understand the efficacy of multiple nights of increased sleep durations, whilst adhering to sleep hygiene guidelines, on post-exercise recovery outcomes.

The present study also found that further increases in time in bed in the extension condition substantially increased total sleep time compared to both the baseline assessment and control condition, with no substantial differences in measures of wakefulness observed. Together, this suggests that obtaining at least 8 h of time in bed, following demanding HIIE, provides adequate opportunity for recovery. This is in support of previous reports indicating that obtaining >8 hours per night of sleep is required to optimise performance (Mah et al., 2011; Roberts et al., 2019; Schwartz and Simon, 2015). However, in the context of recovery from exercise, it is unclear in terms of how much sleep, above that of baseline/habitual, is deemed sufficient to 'accelerate' recovery. The current study shows that obtaining ~7:28 h of sleep (~45 min more than baseline) resulted in comparable recovery to that obtained in the extension group (>9:00 h of sleep). Unfortunately, the current study did not assess recovery in the context of baseline sleep, which means it is not possible to specifically determine what the lowest dose of increased sleep, above that of baseline, is required for improved recovery. However, it is evident from the current study that to ensure recovery is not impaired by sleep, that at least 8 h time in bed and adopting typical sleep hygiene guidelines is followed. For practitioners involved in designing and coordinating athletes' weekly schedules, this is also important as increasing time in bed to 10 h for one night does not further accentuate recovery from a single session of HIIE. This means that when time is limited there may not be a desperate need to further increase sleep opportunities up to 10 h. However, future research should therefore examine the efficacy of multiple nights of sleep extension, following a session of demanding HIIE and 'baseline' sleep, to determine how effective extended sleep is for accentuating recovery.

In conclusion, the present study developed a novel high-intensity interval exercise session that induces substantial decrements in markers of recovery. Adhering to sleep hygiene guidelines enhanced post-exercise sleep quantity and quality in healthy adults. However, one single night of sleep extension (spending 10 hours in bed) does not modulate markers of post-exercise recovery when compared to a control condition (spending 8 hours in bed). Further investigation is required to determine whether longer-term exposure to sleep extension enhances post-exercise recovery and whether a dose-response relationship exists between sleep duration and recovery when sleep hygiene guidelines are followed.

CHAPTER 8. STUDY 5 – INFLUENCE OF SLEEP EXTENSION ON RECOVERY FOLLOWING HIGH-INTENSITY EXERCISE

The results of Chapter 7 indicate that recovery from a session of high-intensity intermittent exercise, designed to resemble the physical demands of team-sport competition, was not substantially improved by a single night of sleep extension. Given that team-sport athletes typically lose sleep on the night following competition, and there are 2 to 3 days/nights of subsequent recovery sleep, this study aimed to replicate this scenario and investigate the effects of multiple nights of sleep extension on markers of recovery. Preliminary findings have been presented at the 22nd Congress of the European College of Sport Science in Essen, Germany.

8.1 Introduction

Measures of perceived wellbeing, neuromuscular function, and physical performance are negatively impacted by bouts of high-intensity interval exercise (HIIE) (Chapter 7; (McLean et al., 2010; McLean et al., 2012; Rowell et al., 2016), which is a common activity pattern also observed during team-sport competitions (Coutts et al., 2010). Recovery from HIIE may be further impacted by reduced total sleep time post-exercise, which is common-place within team-sport environments (Fullagar et al., 2016a; Fullagar et al., 2016b; Lalor et al., 2017; Richmond et al., 2004). It has been reported that team-sport athletes experience reduced sleep duration – often regarded as sleep loss, on the night immediately following competition, which is followed by a return to habitual sleep durations on subsequent recovery nights (Lalor et al., 2017; Richmond et al., 2004). The reduced sleep duration following competition may be the result of a range of variables, including pre-match caffeine consumption (Dunican et al., 2018) and pain (Halson, 2014; Shearer et al., 2015), which are not as prevalent on subseqent recovery nights. Despite previous evidence showing that when given the opportunity athletic populations will extend sleep duration on single nights (Sargent et al., 2014a; Sargent et al., 2014b), the influence of increased sleep opportunities to extend sleep over multiple nights during the post-exercise recovery period on markers of recovery warrants further investigation.

Sleep deprivation following team-sport match-play impairs neuromuscular performance. Indeed, sleep deprivation results in greater declines in peak power, peak force, and mean power during a 30 s maximal cycling effort (Souissi et al., 2003). Furthermore, Skein et al. (2013) found that countermovement jump height declines, without a significant decline in maximal voluntary contraction (MVC) force as a reuslt of sleep deprivation following rugby league match-play. However, total sleep deprivation may not represent typical post-exercise behaviours of athletes, with evidence suggesting athletes suffer from sleep restriction following competition (Fullagar et al., 2016a; Fullagar et al., 2016b; Lalor et al., 2017; Richmond et al., 2004). Sleep restriction may impair post-exercise recovery, due it's detirmental effects on the physiological responses to endurance exercise, power production and strength (Mougin et al., 1991; Souissi et al., 2008; Souissi et al., 2013; Knowles et al., 2018). Given that post-exercise declines in recovery markers may be prevalent for extended periods of time following HIIE (Doeven et al., 2018), and the importance placed on neuromuscular recovery following team sport competition (Johnston et al., 2013), multiple days of sleep intervention may be required to enhacne recovery outcomes. Therefore, further investigations replicating the post-match sleep behaviours of team-sport athletes to investigate the potential benefits of increasing sleep duration to enhance post-exercise recovery are required.

Prolonged periods of sleep extension have been shown to benefit measures of recovery and physical performance. In basketball, increasing time in bed by 110 min, to 10 h a night over a 7-week period, improves sprint performance, shooting accuracy, and overall ratings of wellbeing (Mah et al., 2011). In contrast, however, increasing time in bed by one hour, which resulted in 21 min of increased sleep duration, over a 1-week period has no effect on power, fatigue, or reaction times in female sprinters (Famodu et al., 2017). In the context of sleep loading, where sleep duration was extended by 96 minutes per night for six consecutive nights preceding a night of sleep deprivation has been shown to increase time to exhaustion and lower perceived effort during isolated knee extension exercise (Arnal et al., 2016). However, sleep extension took place preceding a night of total sleep deprivation and subsequent exercise (Arnal et al., 2016), which does not provide evidence regarding the effects on sleep extension during the recovery period following exercise. Therefore, despite initial evidence suggesting that sleep extension can enhance performance and markers relevant to recovery (Arnal et al., 2016; Mah et al., 2011), there has been no study of the influence of increased post-exercise recovery sleep duration on the recovery of measures such as neuromuscular function, subjective wellbeing and physical performance, especially when a session of HIIE is paired with sleep loss, thus resembling the post-match sleep behavious of team-sport athletes.

The ability for athletes to obtain increased overnight sleep opportunities may be limited due to training schedules, family commitments, feelings of worsening sleep quality with increased time in bed, and other lifestyle restrictions. However, the use of daytime naps may be an alternative method to increase sleep duration. The use of naps is becoming more prevalent in athletic populations and has recently been identified as an area in need of further investigation (Watson, 2017). Dinges et al. (1987) reported that a 2 h sleep opportunity at any point during prolonged wakefulness improves reaction time performance and ratings of subjective sleepiness. Furthermore, following a night of sleep restricted to 4 hours, a 30 min nap opportunity improved vigilance, reduced sleepiness, and improved decision-making accuracy (Dinges et al., 1987; Waterhouse et al., 2007). This was also accompanied by faster 2 m and 20 m sprint performance, despite no improvements in neuromuscular function measured via grip strength (Waterhouse et al., 2007). However, despite some of the aforementioned contextual factors affecting the ability to increase night time sleep duration, Thornton et al. (2017b) reported that short daytime naps do not impact night-time sleep behaviours in rugby league players, indicating that daytime naps may be useful to supplement night-time sleep, to increase total daily sleep duration, if sleep cannot be readily obtained during the night.

Given the prevalence of reduced sleep in athletic populations following exercise, and the detrimental effects of sleep loss on markers of recovery, further investigation as to the potential benefits of increased sleep duration is required. Therefore, this study was designed to replicate the previously-observed post-exercise sleep behaviours of athletic populations (Chapter 5) and investigate the influence of sleep extension, by way of increased multiple overnight sleep opportunities or daytime napping, on physiological and psychometric measures of recovery and physical performance outcomes following high-intensity intermittent running exercise (HIIE). It was hypothesised that increasing daily sleep duration over 3 days would enhance measures of recovery and physical performance compared to a control condition exhibiting similar sleep behaviours to those observed in athletic populations following HIIE.

8.2 Methods

8.2.1 Participants

Participant information is detailed in Chapter 3 Section 3.1.2.

8.2.2 Data Collection

In a randomised, repeated-measures design, participants completed three trials. Following a session of High Intensity Interval Exercise (HIIE), participants slept in laboratory conditions on three occasions. Each trial consisted of 1 night (N0) of restricted sleep (6 h in bed, bedtime = 02:00 am) followed by 3 intervention nights (N1, N2, N3) of either 8 h time in bed (CON; 12:00 am – 8:00 am), 10 h time in bed (EXT; 10:00 pm – 8:00 am) or 8 h time in bed plus a 2-h nap each afternoon (NAP; in bed 12:00 am – 8:00 am and a nap 2:00 pm – 4:00 pm). Participants were familiarised to the HIIE session, recovery assessments (excluding blood sampling procedures), and sleeping environment at least 7 days prior to the beginning of the experimental prcoedures by completing each component and spending a single night in the controlled laboratory conditions. During the experimental procedures, participants were assessed for maxmimal voluntary contraction (MVC) peak torque, countermovement jump (CMJ) performance, submaximal heart-rate response and heart-rate variability (HRV), sprint performance (5 m, 10 m and 20 m splits), endurance (YoYo IR1) performance, subjective recovery and profile of mood states (POMS).

8.2.3 High Intensity Interval Exercise

Participants arrived 2 h prior to beginning the HIIE session to consume a standardised pre-exercise meal (Section 8.2.8). Participants were asked to abstain from consuming caffeine and alcohol, and from partaking in exercise, for 24 h prior to the HIIE session. The 58-minute HIIE sesion was described previously in Chapter 3, Section 3.5.3.

8.2.4 Recovery Assessments

Recovery assessments in this study were as per previously described in Chapter 3, Section 3.3.3. Measurements for MVC and CMJ were taken at Pre, and 0 h, 1 h, 2 h, 12 h, 36 h, 60 h and 84 h post-HIIE; subjective recovery was measured at Pre, and 12 h, 36 h, 60 h and 84 h post-HIIE; HRV was measured Pre, and 1 h, 2 h, 12 h, 36 h, 60 h and 84 h post-HIIE; POMS was measured at Pre and 84 h post-HIIE.

8.2.5 Performance Testing

Sprint and endurance (YoYo IR1) performance testing were taken at baseline, Pre, and 84 h post-HIIE, as described in Chapter 3 Section 3.3.2.

8.2.6 High Intensity Interval Exercise

Participants arrived 2 h prior to beginning the HIIE session to consume a standardised pre-exercise meal (Section 7.2.7). Participants were asked to abstain from consuming caffeine and alcohol, and from partaking in exercise for 24 h prior to the HIIE session. The 58-minute HIIE session is as described previously in Chapter 3, Section 3.5.3.

8.2.7 Sleep Assessment

Methods regarding the sleep assessment in this study are as previously described in Chapter 3, Sections 3.2.1 and 3.2.2. In brief, sleep behaviour data was collected using a wrist-watch activity device, the Actiwatch 2 (Philips Respironics, PA, USA) paired with subjective sleep diaries. Baseline sleep assessment (BL) took place prior to the experimental procedures, with participants undertaking a 14-day period of sleep assessment in free-living conditions. During the experimental conditions bed time, wake time and time in bed were controlled for, as lights were turned out at 10:00 pm (EXT) or 12:00 am (CON and NAP) and turned on at 8:00am for the overnight sleep periods. Wake time remained constant to allow for a consistent exercise time and to maintain the post-exercise assessment timing between conditions. In the NAP condition (Foundation, 2019), participants were also in bed between 2:00 pm and 4:00 pm in the afternoon preceding night-time sleep on N1, N2 and N3. The nap was performed under the same environmental conditions and the same place as the night time sleep.

8.2.8 Dietary Standardisation

Participants were supplied with a standardised diet for the duration of the study, as described in Chapter 3 Section 3.5.4.

8.2.9 Statistical Analysis

Differences in absolute sleep variables between timepoints during the afternoon nap opportunities were analysed using repeated measures one-way ANOVA and Tukey's HSD ($P<0.05$). Multiple linear mixed models were constructed to examine individual differences in recovery, sprint, and endurance performance between CON, EXT and NAP conditions. All recovery assessment data was analysed relative to pre-HIIE (0 h) values, whereas sleep behaviours, sprint and endurance performance were analysed relative to baseline values. Q-Q plots were used to examine the uniformity of the dependant variables; if uniformity was violated the dependent variables were log-transformed and models were re-run. To account for error associated with individual repeated measures, participants were included in the model as a random effect; this allowed different within-individual standard deviations. The condition*timepoint interaction and order of condition were included as a fixed effect in the models, which described the relationship between the dependent variable and covariates (West et al., 2014). Pairwise fixed-effect comparisons were completed using the Least Squares mean test and were expressed as standardised effect sizes (ES), categorised according to Hopkins et al. (2009): <0.20 trivial, 0.21 – 0.60 small, 0.61 – 1.20 moderate, 1.21 – 2.0 large and > 2.1 very large, with only moderate or greater effects reported. The likelihood of the observed effect was established using a magnitude-based approach, where effects were considered clear at or above the *very likely* 95% level (Hopkins et al., 2009) to reduce the chance of chance of Type I error (Sainani, 2018). Importantly, these statistical constraints were kept consistent with Chapter 7, therefore, permitting comparisons between single and multiple nights of sleep extension. Comparative differences in text are presented as mean difference, ES, and ±90% confidence limits, unless otherwise stated. Descriptive statistics in figures are presented as individual mean values, and group means ± standard deviation, unless otherwise stated. Statistical analyses were performed using R statistical software (R 3.5.0, R foundation for Statistical Computing).

8.3 Results

8.3.1 Baseline Sleep Comparisons

At baseline participants went to bed at 11:35 ± 0:49 pm, got out of bed at 7:10 ± 0:30 am, spent 7:35 ± 0:45 h time in bed, and obtained 6:43 ± 0:39 h total sleep time. Participants' sleep onset latency was 0:16 ± 0:14 h, wake after sleep onset was 0:35 ± 0:13 h and sleep efficiency was 89 ± 5%. Descriptive data and between condition x night comparisons with baseline sleep behaviours can be seen in Table 8.1.

8.3.2 Changes to sleep during intervention sleep relative to baseline

The changes in sleep behaviours relative to baseline during each night of the experimental sleep extension protocols can be seen in Figure 8.1. There was no substantial differences between conditions for change to time in bed at N0. Compared to CON, the change in total time in bed was increased in both EXT and NAP for N1, N2 and N3 (ES = 2.70; ±0.23). The change in total sleep time at N0 was not different between conditions. Compared to CON, change in total sleep time was increased in both EXT at N1 (ES = 2.69; ±0.42), N2 (ES = 1.79; ±0.28) and N3 (ES = 2.35; ±0.37), and NAP at N1 (ES = 1.92; ±0.30), N2 (ES = 2.11; ±0.33) and N3 (ES = 1.53; ±0.24), but not between EXT and NAP. Compared to CON, change in sleep onset latency was increased in EXT at N2 (ES = 1.36; ±0.80) and night-time NAP sleep at N3 (ES = 1.45; ±0.54). Change in sleep onset latency was increased at N3 for night sleep in NAP compared to EXT at N3 (ES = 1.34; ±0.56). Compared to CON, change in wake after sleep onset increased at N2 in EXT (ES = 1.24; ±0.57) and NAP (ES = 0.84; ±0.48). Change in sleep efficiency was increased in CON compared to EXT at N2 (ES = 1.52; ±0.76), and compared to NAP it was increased at N2 (ES = 1.63; ±0.98) and increased at N3 (ES = 1.20; ±0.53). Compared to EXT, change in sleep efficiency was reduced in NAP at N1 (ES = -0.88; ±0.67) and N3 (ES = -1.17; ±0.65).

Table 8.1. Descriptive data detailing the sleep behaviours observed during baseline sleep assessment (BL), and the control (CON), extension (EXT) and nap (NAP) conditions across between-condition pooled N0, and individual condition N1, N2 and N3. Data are presented as mean ± standard deviations and differences between night and baseline are expressed as (effect size; ±90% confidence interval). Substantial between condition differences are expressed using †; BL v CON, *; BL v EXT, and €; BL v NAP.

Sleep Characteristic	BL	N0	CON			EXT			NAP		
			N1	N2	N3	N1	N2	N3	N1	N2	N3
Bed Time (AM/PM)	11:28±0:56 PM	***2:00 AM (4.17; ±0.70†*€)***		***12:00 AM (0.71; ±0.50†)***			***10:00 PM (2.75; ±0.50*)***			***12:00 AM (0.71; ±0.50€)***	
Out of Bed Time (AM/PM)	7:22±1:00 AM	***8:00 AM (2.27; ±0.49†*€)***		***8:00 AM (2.27; ±0.49†)***			***8:00 AM (2.27; ±0.49*)***			***8:00 AM (2.27; ±0.49€)***	
TIB (h:mm)	7:41±0:44	***6:00 (3.04; ±0.51†*€)***		***8:00 (0.78; ±0.50†)***			***10:00 (4.59; ±0.76*)***			***10:00 (4.59; ±0.76€)***	
TST (h:mm)	6:45±0:43	***5:37±0:08 (-3.26; ±1.21†*€)***	***7:24±0:14 (1.42; ±0.60†)***	***7:26±0:09 (1.49; ±0.59†)***	***7:20±0:17 (1.23; ±0.59†)***	***9:16±0:12 (5.36; ±0.89*)***	***8:55±0:33 (3.67; ±0.61*)***	***9:02±0:21 (4.46; ±0.74*)***	***9:04±0:30 (4.03; ±0.67€)***	***9:02±0:11 (4.76; ±0.80€)***	***8:43±0:33 (3.35; ±0.65€)***
SOL (h:mm)	0:15±0:13	***0:04±0:03 (-1.56; ±1.12†*€)***	0:09±0:09 (1.09; ±1.50)	0:08±0:05 (0.74; ±0.90)	0:09±0:08 (0.65; ±0.90)	0:17±0:12 (0.06; ±0.80)	0:28±0:28 (0.54; ±0.50)	0:14±0:11 (0.19; ±0.90)	0:10±0:07 (0.52; ±1.00)	0:21±0:21 (0.26; ±0.60)	***0:42±0:30 (1.14; ±0.47€)***
WASO (h:mm)	0:45±0:22	***0:20±0:08, (-1.55; ±0.47†*€)***	0:27±0:08 (1.13; ±0.90)	0:29±0:09 (0.46; ±0.40)	0:33±0:14 (0.08; ±0.40)	0:34±0:11 (0.01; ±0.50)	0:43±0:20 (0.49; ±0.30)	0:46±0:13 (0.83; ±0.40)	0:32±0:11 (0.47; ±1.10)	0:40±0:10 (0.10; ±0.30)	0:33±0:11 (0.76; ±0.90)
SEF (%)	88.1±5.0	***94 ± 2 %, (1.64; ±0.64†*€)***	***92 ± 2 %, (0.99; ±0.54†)***	***93 ± 2%, (1.18; ±0.54†)***	***92 ± 3 %, (0.70; ±0.51†)***	***93 ± 2 %, (1.13; ±0.58*)***	89±6 (0.10; ±0.40)	90±4 (0.38; ±0.50)	91±5 (0.37; ±0.70)	90±2 (0.63; ±0.90)	87±5 (-0.07; ±0.10)

h:mm = time in hours and minutes, TIB = time in bed, TST = total sleep time, SOL = sleep onset latency, WASO = wake after sleep onset, SEF = sleep efficiency, and ES = standardised effect size. BL = baseline, N0, N1, N2, N3 = night following exercise, CON = control condition, EXT = extension condition, and NAP = nap condition.

8.3.3 Afternoon Naps

There was no difference in bed time, out of bed time, and time in bed during naps in the afternoon preceding N1, N2 nor N3. Total sleep time was shorter at pre-N3 (1:39 ± 0:08 h) than pre-N1 (1:49 ± 0:04 h, ES = 1.52; ±0.81). Sleep onset latency was longer at pre-N3 (0:28 ± 0:22 h) than pre-N1 (0:10 ± 0:06 h, ES = 1.09; ±0.57). There were no substantial differences in wake after sleep onset between naps in the afternoon preceding N1, N2 nor N3. Sleep efficiency was lower at pre-N3 (82.62 ± 6.81 %) than pre-N1 (90.83 ± 3.48 %, ES = 1.52; ±0.81).

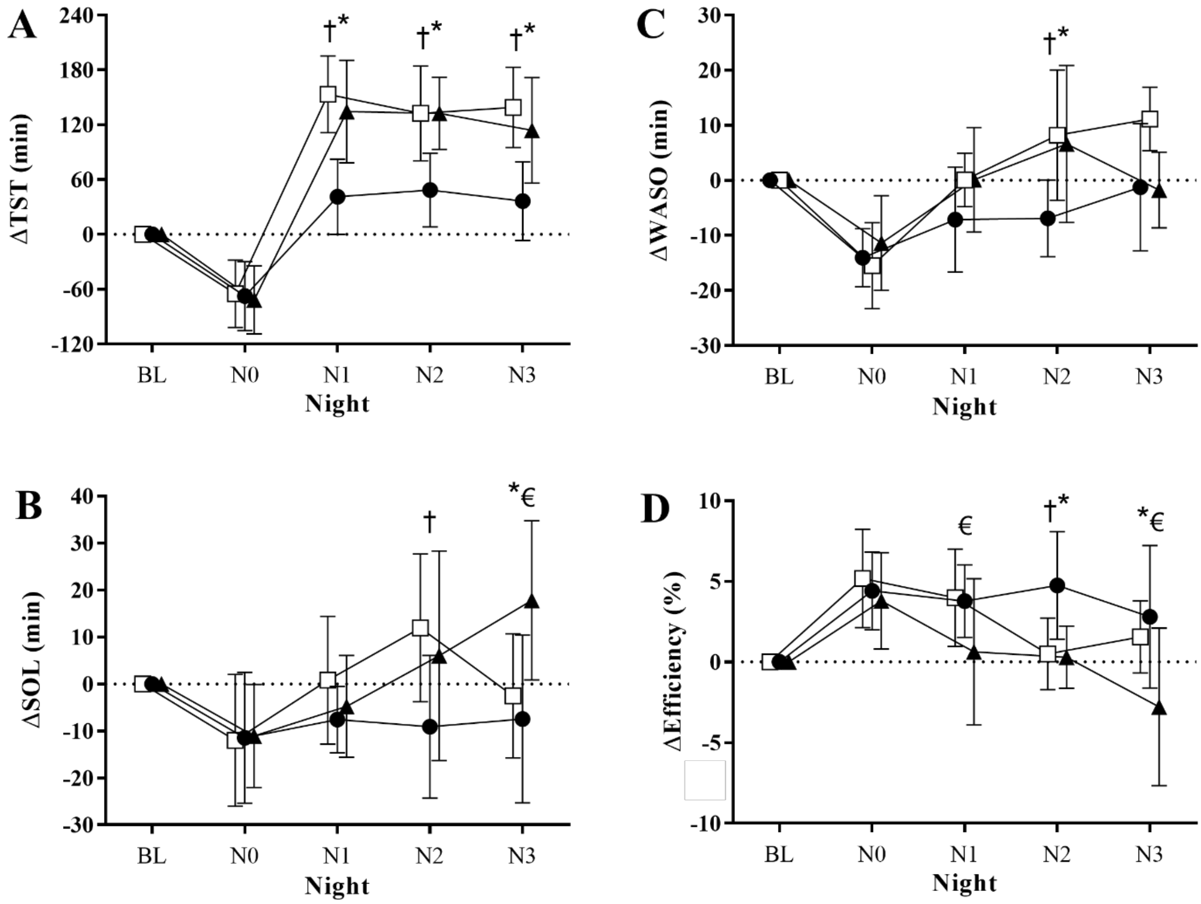


Figure 8.1. Changes in A) total sleep time, B) night-time sleep onset latency, C) wake after sleep onset, and D) sleep efficiency relative to baseline between the CON (closed circles), EXT (open squares) and NAP (closed triangles) conditions following HIIE. Change values relative to pre-HIIE are displayed as mean ± standard deviation. Substantial between condition differences are expressed using †; CON v EXT, *; CON v NAP, and €; EXT v NAP.

8.3.4 Subjective Wellness

Relative changes in ratings of subjective wellness from pre-HIIE values are shown in Figure 8.2. Changes in ratings of fatigue were increased in EXT compared to NAP at 36 h (EXT; 0.88 ± 0.99 vs. NAP; -0.25 ± 1.04 AU, ES = 1.11; ±0.55), and increased at 84 h (EXT; 1.00 ± 1.31

vs. NAP; 0.25 ± 0.46 AU, ES = 0.76; ±0.55). Changes in ratings of sleep quality were reduced in NAP compared to EXT at 36 h (NAP; -0.63 ± 0.74 vs. EXT; 0.25 ± 0.71 AU, ES = -1.21; ±0.96). There were no substantial between-condition differences in changes of muscle soreness or stress. There were greater reductions in mood in CON compared to EXT at 12 h (CON; -0.50 ± 0.76 vs. EXT; 0.00 ± 0.53 AU, ES = -0.76; ±0.50), and EXT displayed increased changes of ratings of mood compared to NAP at 36 h (EXT; 0.38 ± 0.52 vs. NAP; 0.00 ± 0.54 AU, ES = 0.71; ±0.52). The EXT displayed greater changes in ratings of total wellness compared to NAP at 36 h (EXT; 1.38 ± 2.88 vs. NAP; -1.50 ± 2.33 AU, ES = 1.10; ±0.60).

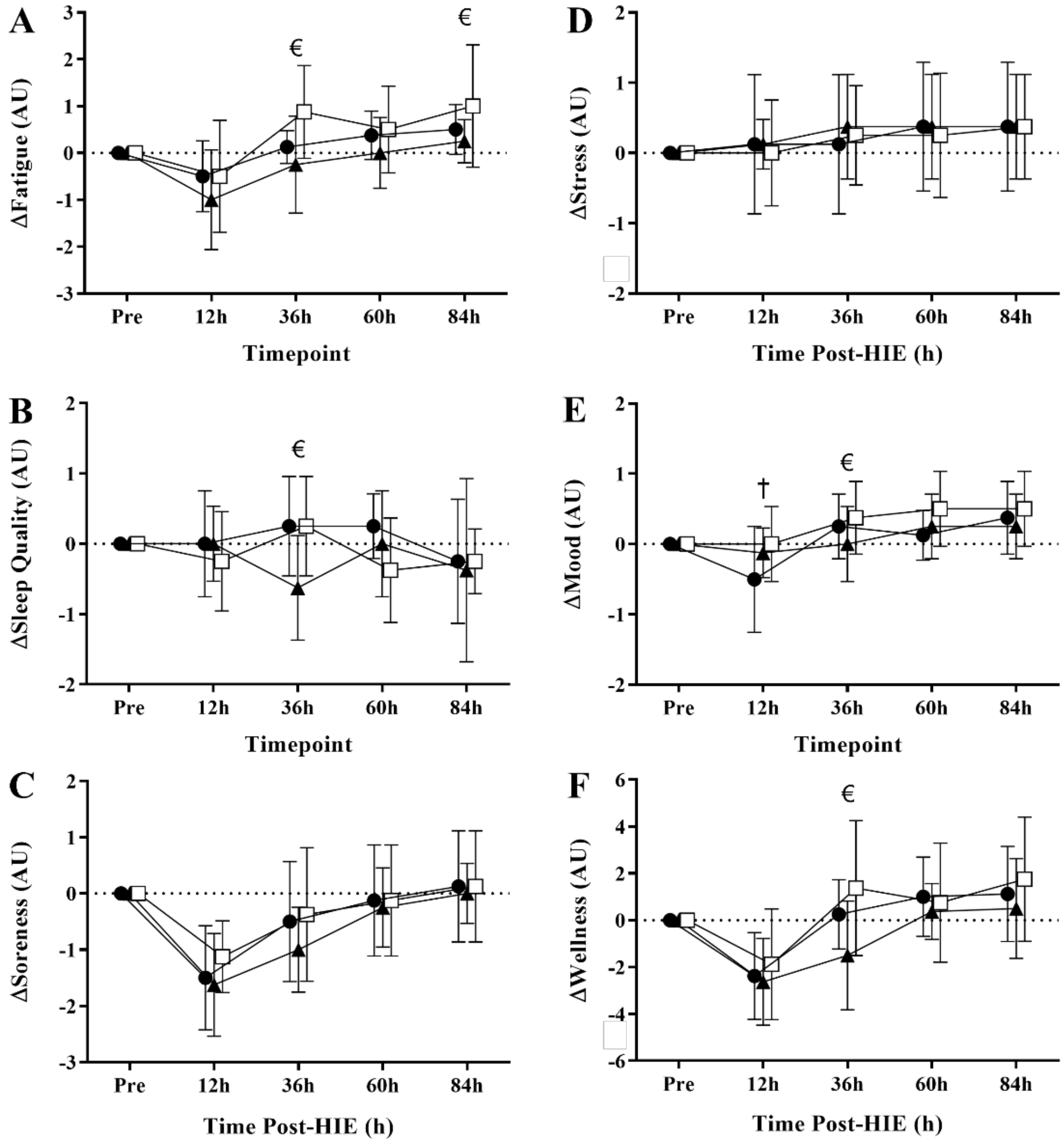


Figure 8.2. Changes in ratings of perceived A) fatigue, B) sleep quality, C) soreness, D) stress, E) mood, and F) total wellbeing between the CON (closed circles), EXT (open squares) and NAP (closed triangles) conditions following HIIE. Change values relative the pre-HIIE are displayed as mean ± standard deviation. Substantial between condition differences are expressed using †; CON v EXT, and €; EXT v NAP.

8.3.5 Profile of Mood States

Subcomponents relating to tension, depression, fatigue, confusion and vigour of the profile of mood states questionnaire, and total mood disturbance were not substantially different between conditions at pre-HIIE or 84 h. Anger was reduced in NAP (3.9 ± 2.9 AU) compared to CON at 84 h (7.1 ± 5.1 AU, ES = 0.79; ±0.63). Changes in subcomponents and total mood disturbance from pre-HIIE to 84 h and comparisons between conditions are shown in Table 8.2.

8.3.6 Neuromuscular

The HIIE session resulted in a reduction in MVC peak torque production at 12 h (Pre; 250 ± 44 vs. 12 h; 213 ± 43 N, ES = 0.67; ±0.15). There were no other substantial effects of time on measures of neuromuscular function. Changes in measures of neuromuscular function relative to pre-HIIE between conditions are shown in Figure 8.3. No substantial differences were observed between conditions for changes in peak countermovement jump height, peak force, peak power, and concentric time. NAP displayed increased peak velocity compared to CON at 60 h (NAP; 0.12 ± 0.09 vs. CON -0.02 ± 0.11 $m \cdot s^{-1}$, ES = 1.33; ±1.15), and compared to EXT at 36 h (NAP; 0.03 ± 0.13 vs. EXT; -0.15 ± 0.15 $m \cdot s^{-1}$, ES = 1.28; ±0.64), 60 h (NAP; 0.12 ± 0.09 vs EXT; -0.06 ± 0.09 $m \cdot s^{-1}$, ES = 1.89; ±0.97) and increased at 84 h (NAP; 0.10 ± 0.13 vs. EXT; -0.05 ± 0.13 $m \cdot s^{-1}$, ES = 1.19; ±0.77). Compared to CON, the NAP resulted in increased peak torque at 36 h (CON; -24.6 ± 22.7 vs. NAP; -4.6 ± 19.3 Nm, ES = 0.95; ±0.64), 60 h (CON; -15.6 ± 16.0 vs. NAP 1.2 ± 19.2 Nm, ES = 0.94; ±0.70) and 84 h (CON; -1.9 ± 11.9 vs. NAP; 14.7 ± 24.3 Nm, ES = 0.83; ±0.59).

Table 8.2. Change in profile of mood state scores from pre-HIIE to 84 h for the control (CON), extension (EXT) and nap (NAP) condition are expressed as mean ± standard deviation. Comparisons between conditions are expressed as standardised effect sizes and; ± 90% confidence intervals. Likelihoods are expressed as; *, likely; **, very likely; ***; most likely.

	Condition			Comparison		
POMS Component	**CON Change (AU)**	**EXT Change (AU)**	**NAP Change (AU)**	**CON V EXT**	**CON V NAP**	**EXT V NAP**
Tension	-1.6 ± 2.1	-2.6 ± 2.3	-0.8 ± 3.9	-0.45; ± 0.55*	0.28; ± 0.99	0.59; ± 0.64*
Depression	-2.6 ± 3.2	-0.5 ± 3.6	-3.4 ± 3.9	0.62; ± 0.72*	-0.21; ± 0.44	-0.75; ± 0.66*
Anger	0.9 ± 3.4	-2.3 ± 3.4	-1.9 ± 3.7	***-0.92; ± 0.57***	-0.77; ± 0.79*	0.11; ± 0.43
Fatigue	0.0 ± 4.2	-1.6 ± 3.9	-1.3 ± 2.5	-0.40; ± 0.66	-0.36; ± 0.58	0.11; ± 0.96
Confusion	-0.4 ± 1.9	-0.9 ± 2.4	-0.5 ± 1.6	-0.23; ± 0.51	-0.07; ± 0.27	0.19; ± 0.91
Vigour	-0.9 ± 3.6	-0.2 ± 2.5	-0.4 ± 3.7	0.86; ± 0.74*	0.14; ± 0.70	-0.70; ± 0.66
Total	-2.9 ± 10.6	-3.7 ± 9.5	-7.4 ± 13.5	-0.71; ± 0.74*	-0.37; ± 0.34	0.22; ± 1.57

POMS = profile of mood states, CON = control, EXT = extension, NAP = nap, v = versus

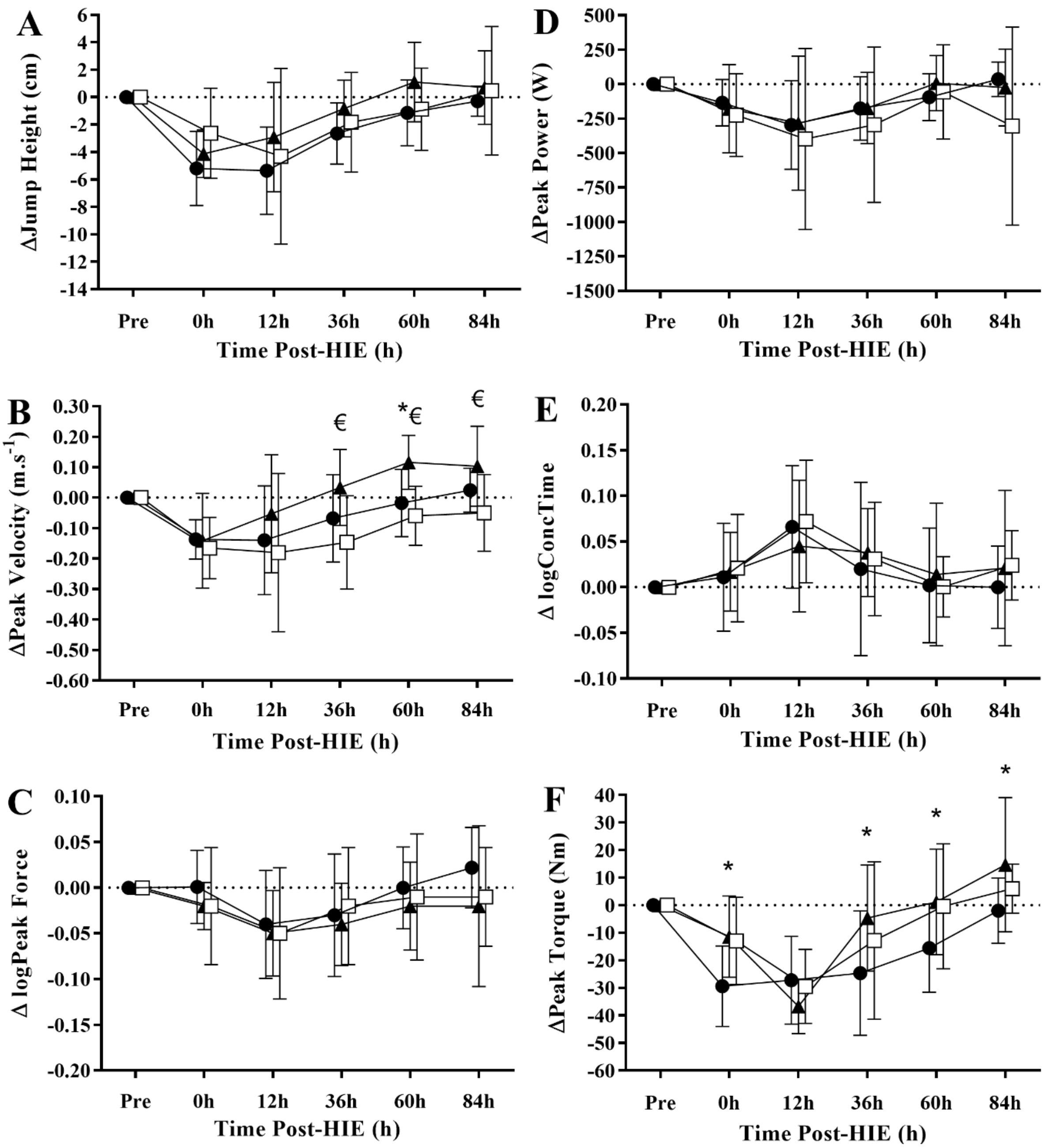


Figure 8.3. Changes in relative A) CMJ height, B) peak velocity, C) log peak force, D) peak power, E) log ConcTime, and F) peak torque over time between the CON (closed circles), EXT (open squares) and NAP (closed triangles) conditions following HIIE. Change values relative to pre-HIIE are displayed as mean ± standard deviation. Substantial between condition-differences are expressed using *; CON v NAP, and €; EXT v NAP.

8.3.7 Autonomic

The HIIE session had no substantial effect on SDNN and log-rMSSD. Compared to pre-HIIE (12.7 ± 1.37 AU), the HIIE resulted in increased RPE at 1 h (15.3 ± 1.8 AU, ES = 1.66; ±0.32), 2 h (15.5 ± 2.0 AU, ES = 1.62; ±0.29), 12 h (15.2 ± 1.7 AU, ES = 1.65; ±0.33) and 36 h (13.8 ± 1.3 AU, ES = 0.83; ±0.37). Compared to pre-HIIE (77 ± 9 bpm), the HIIE also resulted in increases in RHR at 1 h (95 ± 9 bpm, ES = 1.86; ±0.33), 2 h (92 ± 9 bpm, ES = 1.65; ±0.29), 12 h (83 ± 8 bpm, ES = 0.65; ±0.24) and 84 h (83 ± 9 bpm, ES = 0.62; ±0.26). Compared to pre-HIIE (169 ± 6 bpm), HRex was increased at 1 h (181 ± 9 bpm, ES = 1.55; ±0.39), 2 h (182 ± 8 bpm, ES = 1.74; ±0.42), and 36 h (175 ± 9 bpm, ES = 0.83; ±0.52). Compared to pre-HIIE (61 ± 10 bpm) HRr was reduced at 1 h (52 ± 10 bpm, ES = 1.03; ±0.36) and reduced at 12 h (56 ± 8 bpm, ES = 0.63; ±0.31). Between condition differences in changes of autonomic measures of recovery are shown in Figure 8.4. No substantial differences in change of log-rMSSD, resting heart rate and peak heart-rate during submaximal exercise were observed between conditions (Figure 8.4). Changes in RPE during submaximal exercise was increased in CON compared to NAP at 60 h (CON; 1.4±1.6 vs. NAP; -0.5±0.8 AU, ES = 1.50; ±1.20). Change in SDNN was increased in CON compared to NAP at 36 h (CON; 21.5±15.1 vs. NAP -18.0±30.0 ms, ES = 1.66; ±1.46). Change in HRr following exercise was increased in NAP compared to CON at 60 h (NAP; 5.5±7.9 vs. CON; -10.8±8.5 bpm, ES = 1.98; ±1.35) and 84 h (NAP; -0.4±9.4 vs. CON; -12.4±6.2 bpm, ES = 1.51; ±1.32).

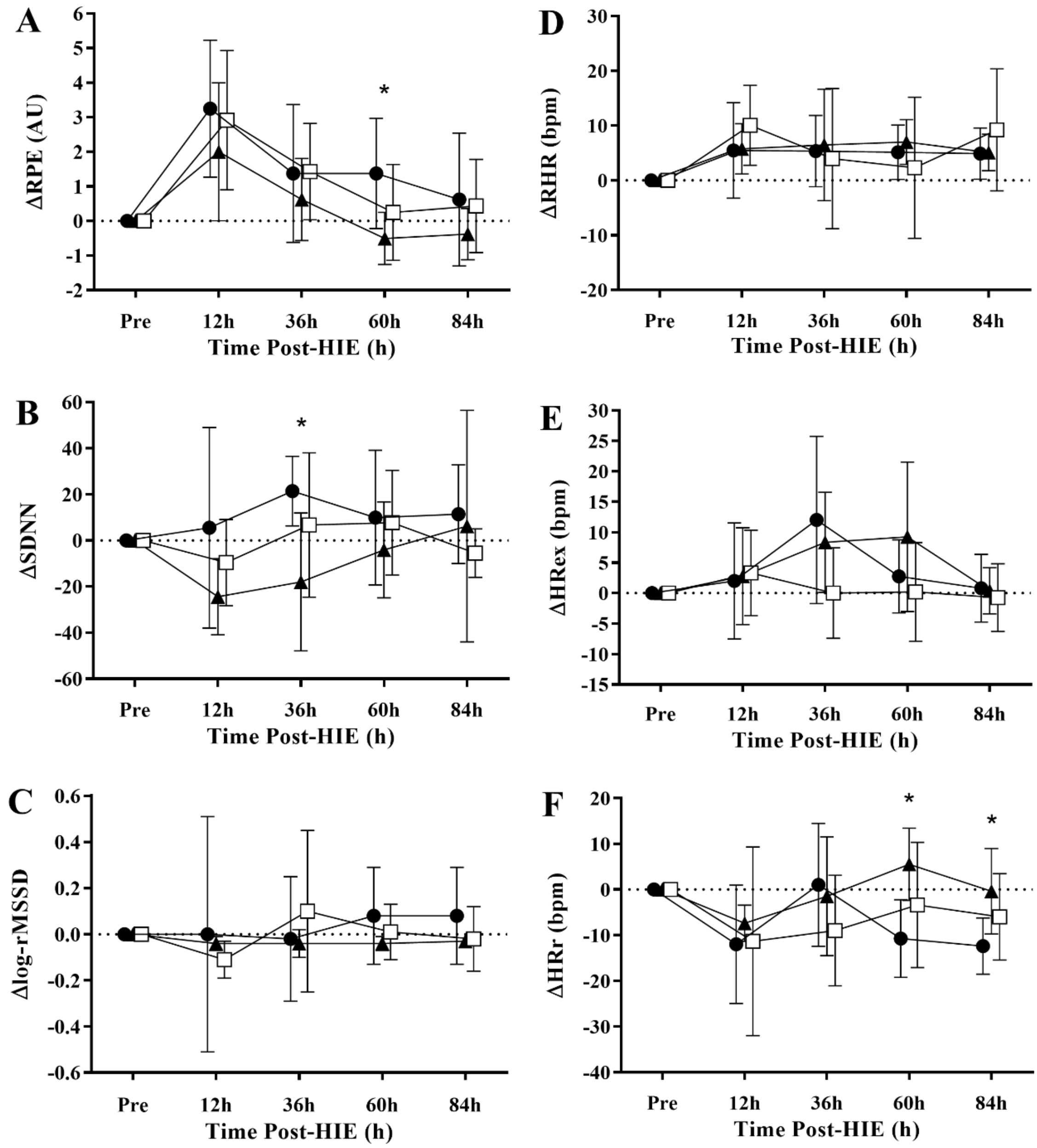


Figure 8.4. Changes in A) ratings of perceived exertion (RPE); B) standard deviation of R-R intervals (SDNN) C) log root mean square of the successive R-R intervals (log-rMSSD) D) resting heart-rate (RHR), E) maximal exercise heart-rate (HRex), and F) heart-rate recovery (HRr) during the 5 min submaximal heart-rate test between the CON (closed circles), EXT (open squares) and NAP (closed triangles) conditions following HIIE. Change values relative to pre-HIIE are displayed as mean ± standard deviation. Substantial between condition-differences are expressed using *; CON v NAP.

8.3.8 Performance

Absolute sprint and endurance performance were not substantially different from BL or between conditions. However, compared to CON, changes in performance from BL were improved in EXT for 5 m (CON; 0.04 ± 0.06 vs. EXT; -0.04 ± 0.07 s, ES = -1.17; ±0.79), 10 m (CON; 0.02 ± 0.08 vs. EXT -0.05 ± 0.07 s, ES = -0.91; ±0.70) and 20 m (CON; 0.02 ± 0.08 vs. EXT; -0.05 ± 0.08 s, ES = -0.89; ±0.66) sprint distances. Changes in YoYo IR1 performance were not substantially different between conditions (Figure 8.5).

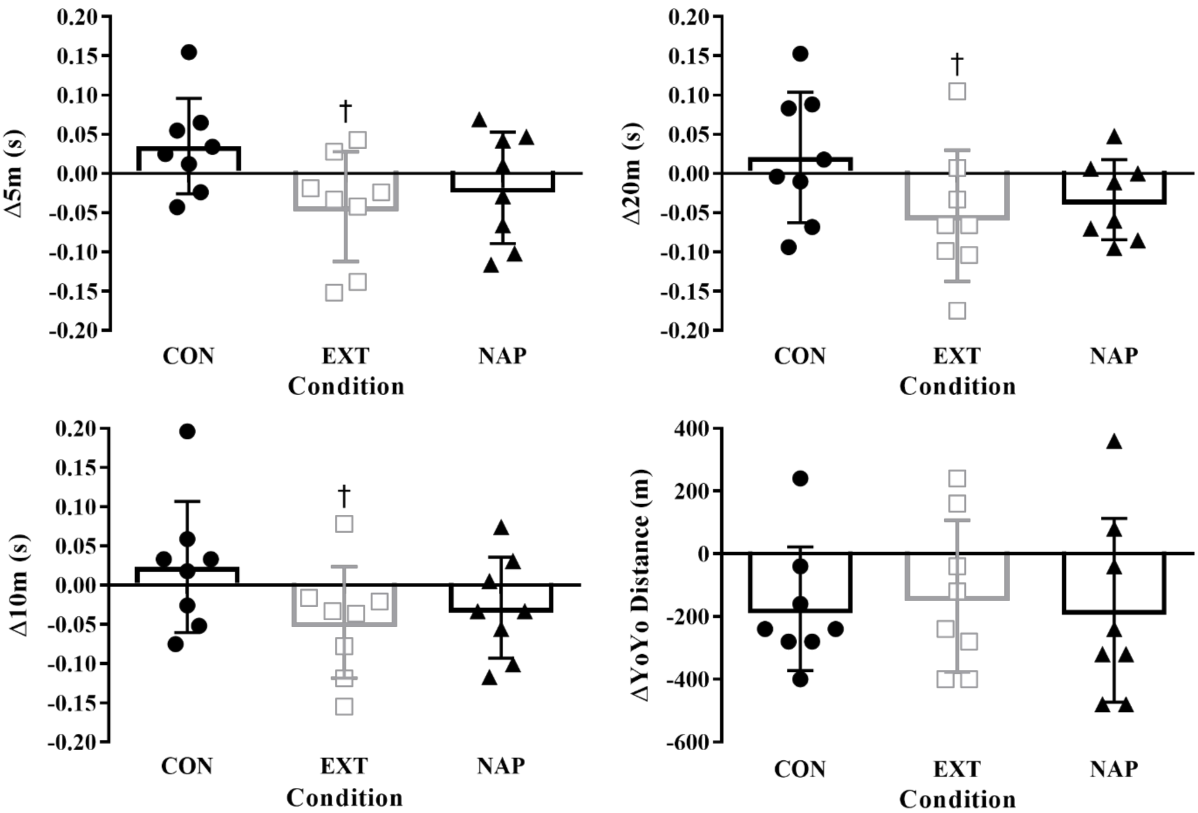


Figure 8.5. Individual changes in A) 5 m, B) 10 m and C) 20 m sprint performance, and D) YoYo IR1 performance from baseline to 84h-post HIIE. Individual data points for CON (black bar, closed circles), EXT (grey bar, open squares) and NAP (black bar, closed triangles) conditions are shown with group mean (long horizontal bars) and standard deviation (short horizontal bars). Substantial between condition-differences are expressed using †; CON v EXT.

8.4 Discussion

The aim of this study was to investigate the influence of multiple nights of sleep extension on physiological and psychometric measures of recovery and physical performance following a demanding session of HIIE. Afternoon naps resulted in enhanced recovery of neuromuscular function, and both overnight sleep extension and afternoon napping improved the recovery of sprint performance following a session of HIIE that was followed by a night of mild sleep restriction. These results were accompanied by enhanced recovery of perceptual wellbeing measures after sleep extension compared to afternoon naps. Collectively, the results suggest an overall positive effect of sleep extension, both by way of overnight extension and afternoon napping, on post-exercise recovery. As such, when presented with the opportunity, sleep time can successfully be increased following HIIE; however, afternoon naps may increase sleep onset latency and wake after sleep onset, and reduce sleep efficiency of night-time sleep on successive days.

Sleep duration was successfully increased in both the overnight sleep extension and afternoon nap opportunity conditions, compared to the control condition. These results are in support of previous investigations demonstrating that increased sleep opportunities lead to increased sleep duration (Sargent et al., 2014a; Sargent et al., 2014b) and that experimental attempts to achieve sleep extension can be successful in athletic and healthy adult populations (Arnal et al., 2016; Mah et al., 2011). Furthermore, the control condition obtained increased sleep duration compared to the baseline sleep behaviours. This finding provides further evidence in support of the results of Chapter 7, and previous investigations (Caia et al., 2018a; Duffield et al., 2014; O'Donnell and Driller, 2017; Fullagar et al., 2016a), to suggest that when sleep interventions are conducted in sleep-enhancing conditions; sleep duration can be improved without requiring additional sleep opportunity. Hence, a priority for practitioners in the provision of sleep-based interventions should be to ensure that sleep opportunities are maximised through the implementation of ongoing sleep hygieine education and support, to ensure athletes are givenresources and skills to ensure that their sleeping environments are as conducive for sleep as possible.

This study found that multiple days of mid-afternoon naps substantially increases sleep onset latency and wake after sleep onset, and reduces sleep efficiency, during subsequent 8 h night-time sleep opportunities. This suggests that consecutive days of increased sleep duration through napping may increase the difficulty of getting to sleep, which may impair sleep quality. However, as shown by the perceptual sleep quality ratings, this was not observed in the present study. Contrasting the current study, Thornton et al. (2017b) reported that daytime nap opportunities do not impair night-time sleep duration in rugby league athletes across 13 nights. Unlike the present study, the participants in the study by Thornton et al. (2017b) were undertaking an intensified training camp where overall daily sleep duration was less compared to habitual home-based sleep behaviours. Together this indicates that when sleep duration is increased relative to habitual levels, subsequent days of mid-afternoon napping impairs measures of sleep. Furthermore, the detrimental effects of subsequent days of sleep extension on sleep onset latency, wake after sleep onset, and sleep efficiency are not observed when sleep duration is extended through increased overnight sleep opportunities. Collectively, this study indicates that overnight sleep extension may be a preferred method of sleep extension compared to napping, in the context of not influencing sleep behaviours, in healthy physically-active populations.

Consecutive nights of sleep extension preceding exercise can enhance maximal voluntary force production (Arnal et al., 2016), which appears to be advantageous, comapred to a single night of sleep extension, as both Chapter 4 and previous evidence found no effect of a single-night of increased post-exercise sleep duration on countermovement jump height (Fullagar et al., 2016a). In the present study, countermovement jump metrics were not influenced by three consecutive nights of overnight sleep extension relative to the control condition. However, afternoon naps improved peak jump velocity compared to overnight sleep extension and improved peak torque production during maximal voluntary isometric contraction compared to the control condition. This study supports previous findings that short 20 min naps improve peak jump velocity preceding a netball match (O'Donnell et al., 2018). However, the present study is the first to examine the effects of sleep extension during the recovery period following exercise. The present study provides novel findings to suggest a beneficial effect of sleep extension, by way of afternoon napping, on maximal voluntary isometric force production and movement velocity during a countermovement jump following exercise. Further to this, the combined results of the present study and those from Skein et al. (2011) suggest a potential dose-response relationship between sleep duration and isometric force production. Indeed, sleep deprivation (i.e., 30 hours of wakefullness) impairs quadriceps voluntary activation force following exercise compared to a control (8:30 ± 1:42 h) condition (Skein et al., 2011), whereas the present study showed the sleep extension by way of afternoon naps improves maximal voluntary contraction force of the quadriceps.

Subjective ratings of perceived wellness are considered an integral part of the training monitoring process and have the ability to accurately reflect the training demands of athletic populations (Saw et al., 2015). This study displayed similar post-HIIE subjective responses to previous literature (McLean et al., 2010; Bailey et al., 2007), in that overnight sleep extension displayed greater improvements in ratings of fatigue, sleep quality, and mood and total wellness, after the first night (i.e., at 36 h post HIIE) of experimental sleep extension, and improved ratings of anger compared to afternoon naps. Despite this, the influence of sleep extension on the profile of mood states contrasts with previously-reported findings (Mah et al., 2011; Kamdar et al., 2004). This may be due to previous observations having utilised longer periods of sleep extension (1 to 10 weeks) compared to the present study (3 nights), suggesting that longer sleep extension periods may be required to enhance profile of mood states. Furthermore, the time-course of recovery appears accentuated in the present study even though it was not influenced by sleep extension, which may be due to the likely increase in time in bed experienced by the CON condition in the present study compared to habitual sleep durations of athletes. Therefore, overnight sleep extension appears to enhance post-HIIE fatigue, sleep quality, and mood and total wellness responses, compared to extending sleep by way of an afternoon nap, which may be connected with the reduced sleep efficiency observed at N1 in the nap condition compared to overnight extension.

Indices of autonomic nervous system function form an important part of the post-exercise recovery process (Plews et al., 2013; Thorpe et al., 2015) and are typically measured following a bout of short-duration submaximal exercise to monitor adaptive training responses and/or recovery status of athletic populations (Buchheit et al., 2015; Buchheit et al., 2013b). The perceived effort of completing submaximal exercise also provides insight into the recovery and training status (Mann et al., 2015), which may be influenced by sleep duration (Arnal et al., 2016). The present study found that RPE is lower following two days of afternoon naps, and HRr appears to be enhanced following two and three days of afternoon naps compared to the control condition. Sleep deprivation increases RPE during submaximal exercise compared to unrestricted sleep opportunities (Martin and Gaddis, 1981), and sleep extension preceding maximal exercise has been shown to reduce subsequent RPE compared to habitual sleep opportunities (Arnal et al., 2016). However, the present study is the first to show a beneficial effect of sleep extension, by way of afternoon naps, on submaximal exercise-RPE following a session of HIIE. Furthermore, this is the first study to indicate that HRr is improved after undertaking consecutive days of afternoon naps, compared to a control condition. Importantly, HRr is positively linked with an individual's training status (Daanen et al., 2012), which can be evaluated during recovery from exercise. Together, reduced perceived exertion and faster return of autonomic nervous system function to baseline levels following exercise may facilitate a quicker return to training or allow individuals to train at higher intensities sooner, leading to enhanced performance potential.

Power, speed, and endurance are important attributes for team-sport athletes. The faster restoration of these components may enable athletes to return to higher levels of performance sooner, reducing the detrimental impact of schedule congestion and tournament-like competitions (Barnett, 2006). Although absolute sprint performance was not substantially improved by sleep extension, sprint times returned to baseline quicker within the recovery time course that was investigated. Previous evidence has shown that afternoon naps can improve 20 m sprint performance following a single night of sleep restriction (Waterhouse et al., 2007). In contrast, a 1-week period of sleep extension does not appear to influence anaerobic exercise performance (Famodu et al., 2017). The extended sleep duration in the present study, however, is more than the 60 min overnight sleep extension opportunity provided by Famodu et al. (2017), and the nap opportunity provided by Waterhouse et al. (2007) took place immediately prior to sprint testing. These results suggests that increases in sleep duration of >1 h may be required to improve anaerobic performance outcomes and that napping may be of benefit to sprint performance when performed in the hours preceding testing under sleep restriction conditions.

Sleep may play an important role in endurance performance outcomes. Total sleep deprivation has been shown to reduce endurance performance (Oliver et al., 2009), whilst a 6-night period of overnight sleep extension, preceding a night of sleep deprivation, enhanced time-to-fatigue during an isolated knee extension task (Arnal et al., 2016). The present study found no effect of sleep extension on endurance performance, with all groups showing a trend towards impaired YoYo IR1 performance following the intervention period. Endurance performance is the product of a number of factors, including endurance capacity and anaerobic threshold (Bassett and Howley, 2000), and remains relatively constant over short periods of time, such as those experienced in the present study. Athletes also report that, despite losing sleep on the night preceding competition, performance is not negatively influenced (Erlacher et al., 2011). Although sleep loss may lead to reduced endurance performance, the present study indicates that increasing sleep duration above 8 hours does not modulate the recovery of endurance performance. However, further work investigating the duration-response relationship between sleep and endurance performance is warranted to better understand if sleep modulates endurance performance.

Following a session of HIIE that is followed by a night of sleep restriction, similar to that seen following team-sport competition, sleep extension results in improvements to common measures of recovery. Whilst overnight sleep extension appears to enhance subjective measures, isometric force production, and sprint performance; afternoon naps appear to affect recovery of countermovement jump outcomes and autonomic nervous system function. The inconsistent pattern of recovery between overnight sleep extension and mid-afternoon naps, despite similar increases in total sleep duration, may be indicative of an inter-individual preference of sleep extension protocols. Furthermore, consecutive days of mid-afternoon naps has a decay effect on sleep onset latency, wake after sleep onset, and sleep efficiency, which may contribute to the lack of positive effect on subjective measures of wellness. The present study also found that the provision of a sleep-enhancing environment, but following sleep hygiene guidelines, enhances sleep duration without increasing sleep opportunity. Collectively, sleep extension, via either overnight sleep extension or mid-afternoon naps, improves measures of recovery and performance, which may be of particular benefit to athletes involved in tournament-like competition and/or multiple games in a week, where the emphasis is on recovery. Given the potential for the presence of an individual preference for or against napping, both methods of sleep extension may be successfully utilised to improve recovery and performance in the 4-day period following post-HIIE that is accompanied with sleep loss.

CHAPTER 9 – DISCUSSION, CONCLUSIONS AND FUTURE DIRECTIONS FOR RESEARCH

9.1 Introduction

The annual training and competition process of team-sports is characterised by a pre-season and in-season, where athletes undergo a period of intensified training during the pre-season to prepare themselves for the rigors of in-season competition. During both the pre- and in-season phases, recovery is a critical feature of an athlete's periodisation plan in order to prepare for subsequent training and competition. Recently there has been increased interest in the role of sleep in the recovery process. Accordingly, this thesis began by expanding on previous knowledge of the sleep behaviours of athletes. Three studies were completed to develop a deeper understanding of the factors influencing sleep between the pre-season and the in-season, which are specifically relevant to team-sport athletes, to provide greater insights that may assist to develop individualised sleep interventions. The final two studies of this thesis then provided novel information regarding the efficacy of sleep interventions to improve post-exercise recovery, and how these findings could be used to improve the sleep and recovery of athletic populations. The present Chapter addresses each individual aim of the thesis and provides a general discussion of how these findings contribute to the current literature. Discussion is then presented on the practical applications and conclusion of the thesis, before providing insight into the potential limitations of the findings and some suggestions for future research directions.

9.2 Discussion of Thesis Aims

The aim of this thesis was to develop a better understanding of the sleep behaviours of, and factors that impact, the sleep of professional team-sport athletes - specifically Australian Rules football players. A further aim was to investigate the effects of increased sleep duration on factors important for athlete recovery and performance.

Aim 1 – Investigate the influence of physical sleep environment during a pre-season training camp on the sleep behaviours of professional Australian Rules football players (Study 1).

This objective was addressed via the completion of Study 1 (Chapter 4). Professional Australian Rules footballers frequently travel and sleep in new and unfamiliar environments to participate in pre-season training and for in-season competition. This study was designed to better understand how exposure to new sleeping environments alters sleep behaviours, which would then enable practitioners to be able to implement sleep strategies specific to the individual players who need them most. Thus, helping to reduce the potential detrimental effects of sleep loss through changing sleeping environments on subsequent performance and recovery, especially during camp-like scenarios where training demands are high, and recovery may be limited. This study found that players went to bed earlier and spent longer in bed during Camp, however wakefulness was higher and sleep efficiency was lower compared to Home. This study also identified that players who spent less time in bed at Home increased time in bed to a greater extent on Camp, compared to those who spent longer in bed at Home. These results occurred independently of changes in mean daily s-RPE Load, however, when changes in the individual daily training load are accounted for, alterations in daily training load on Camp resulted in greater changes in TST compared to Home. Together this provides new evidence for the need of practitioners to implement individualised sleep intervention strategies to overcome the negative effects of changes in sleep environment.

Aim 2 – Investigate the role that individual contextual factors; age and chronotype, and environmental factors; competitive matches, competition level, and competition location have on the sleep behaviours across the pre-season training and in-season competition periods in professional Australian Rules football players (Study 2).

This objective was addressed via the completion of Study 2 (Chapter 5). Although involved in team-sports, athletes are individuals that display unique behaviours, traits and preferences, which extends to sleep. To improve the understanding of the sleep behaviours and requirements of team-sport athletes, this study was designed to consider these unique individual and environmental factors and determine their influence on sleep behaviours. As a result, Study 2 (Chapter 5) expanded on previous findings, ascertaining the importance of considering individual chronotype in the assessment of the sleep behaviours Australian Rules footballers. Whereas although chronotype varied with age, age itself had little to no effect. This study also found that sleep behaviours differ between the pre-season and in-season, and revealed that restrictive scheduling during the may play an important role in the shifting sleep behaviours between these season periods. In support of current knowledge of sleep behaviours surrounding competition, time in bed and sleep duration was reduced on match nights compared to the night before and the two nights following a match. However, no difference in sleep duration between the pre-season and the night of competition was observed. This finding provides new information to suggest that pre-season sleep durations may be sub-optimal to support recovery and adaptation during the pre-season, which may not facilitate adequate preparation for the in-season, and lead to impaired competition performance outcomes. Furthermore, despite the findings of Study 1, which showed a detrimental effect of changing sleep environment during the pre-season, sleep did not differ between Home and Away matches during the in-season. This suggests that the stresses of competition may counteract the benefits of sleeping in the habitual home environment during the in-season, and that the large physical demands of matches may negatively influence sleep. When comparisons were made between playing levels, AFL-level players spent less time in bed and obtained less sleep, compared to when playing in the State-level VFL competition. This novel finding provides additional information to suggest that factors, such as increased physical demands of match-play in higher-level competitions, may have a negative influence on sleep behaviours. Together, this study demonstrates the importance of considering individual chronotype in the analysis of sleep behaviours, and that environmental factors such as the seasonal period, and competing at higher-levels of competition impairs the sleep behaviours of Australian Rules footballers, which may be driven by the vastly different physical demands of training and competition scenarios.

Aim 3 – Determine the influence of changes in load variables during both the pre-season and in-season across 1-, 7-, 14-, 21- and 28-day periods and their relationships with objectively measured sleep behaviours in Australian Rules football players (Study 3).

This objective was addressed via the completion of Study 3 (Chapter 6). Study 1 (Chapter 4) and Study 2 (Chapter 5) demonstrated that the sleep behaviours of professional Australian Rules footballers are influenced by variations in s-RPE Load and differ between the pre-season and in-season phases. Despite existing evidence indicating that 1) sleep behaviours are influenced by load changes in rugby league athletes, 2) load varies substantially between the pre-season and in-season in Australian Rules footballers, and 3) periods of increased training loads lasting >14-days lead to a state of over-training, which is associated with impaired sleep durations, there is a paucity of information pertaining specifically to the relationship between sleep and load in team-sport athletes. As the monitoring of team sport athlete loads considers different time-courses, this study was designed to understand the effects of both short-term (1- and 7-day) and longer-term (14-, 21- and 28-day) periods of cumulative load on the sleep behaviours of Australian Rules footballers. It was demonstrated that the loads undertaken by Australian Rules footballers have different effects on sleep behaviours during both the pre-season and in-season periods, with cumulative loads during the in-season period having less influence on sleep behaviours compared to the pre-season period. Furthermore, periods of increased volume over 4-days or longer has detrimental effects on the sleep duration of athletes. These findings may explain the observed reduced sleep durations in Study 2 (Chapter 5) and supports the need for the utilisation of sleep monitoring in athlete populations to accompany load monitoring practises and prevent load- and schedule-induced impairments in the sleep and performance outcomes of team-sport athletes. Furthermore, given the role that sleep plays in physiological functions relevant for physical adaptation, increased investigation of the role that sleep plays in modulating the adaptative training response is required. Information regarding training status and training adaptation is invaluable for the athlete and practitioner to ensure that variations in load resulting in impaired, or improved, sleep can be better periodised to maximise the performance, recovery and adaptation outcomes of team-sport athletes.

Aim 4 – Determine the effect of a single night of sleep extension on physiological, physical, and perceptual recovery.

This objective was addressed via the completion of Study 4 (Chapter 7), which revealed that despite its reported potential, a single night of sleep extension did not enhance subjective, neuromuscular, autonomic or blood-based markers of recovery 16 h following high-intensity interval exercise, compared to a control condition. However, the key findings showed that sleep duration can be increased, without a substantial increase in sleep opportunity, as observed in the control condition. In Study 4 (Chapter 7), the control condition replicated similar time in bed to participants' habitual sleep behaviour, however sleep duration increased. This finding may have been a result of implementing common sleep hygiene guidelines and the facilitation of optimal sleep environments. Given previous evidence to support the utilisation of sleep hygiene education in athlete populations, this study provided further support to suggest that, even when no more time is spent in bed, increased post-exercise sleep duration can be achieved. However, the practical challenges of implementing sleep hygiene interventions in applied field environments are very different to those experienced in controlled laboratory scenarios, such as those experienced in Study 4 (Chapter 7). Furthermore, the implementation of sleep hygiene practices may also explain the lack of between-condition differences in markers of recovery, given that both conditions exhibited increased sleep duration, compared to habitual amounts. As team-sport athletes typically experience reduced sleep durations on the night following competitive matches, further work should investigate the effects of sleep extension, compared to sleep restriction, whilst adhering to sleep hygiene protocols and its effects on the sleep behaviours of team-sport athletes following matches.

Aim 5 – Determine the effects of post-exercise sleep extension on the status of physiological, physical, and perceptual recovery and physical performance.

This objective was addressed via the completion of Study 5 (Chapter 8). Study 4 showed that a single night of sleep extension does not influence post-exercise recovery markers. However, previous investigations indicate that multiple successive nights of sleep extension may be more effective at improving neuromuscular function and physical performance. Furthermore, in order to replicate ecologically valid scenarios for athletic populations, who may experience reduced sleep opportunities following matches due to a number of contextual factors identified in Studies 1 and 2 (Chapters 4 and 5), the implementation of sleep extension in the recovery period following exercise, and subsequent sleep loss, was warranted. In addition, to account for the potential presence of restrictive scheduling processes that may reduce sleep opportunities, as identified in Studies 2 and 3 (Chapters 5 and 6), sleep extension by way of both increased overnight sleep duration and mid-afternoon nap opportunities were compared. This study found that afternoon naps improved the recovery rate of neuromuscular function, and both overnight sleep extension and afternoon napping improved the recovery of sprint performance. Overnight sleep extension also enhanced the recovery of perceptual wellbeing measures, compared to afternoon naps. Overall, sleep extension, both by way of overnight extension and afternoon napping, has a positive effect on post-exercise recovery. However, caution must be taken when undertaking successive days of afternoon naps, due to the gradual development increased sleep onset latency and wake after sleep onset, and reduced sleep efficiency during the subsequent night-time sleep period.

9.3 General Discussion

Investigation of the sleep behaviours of athletic populations is now a popular and developing field, especially within professional sporting environments. Indeed, previous research has identified that athletes sleep worse than non-athletic populations (Leeder et al., 2012), and that there is variation in the sleep behaviours between and within athletes of individual and team-sport populations (Lastella et al., 2014e), and between environments within the same sport (Caia et al., 2017b; Thornton et al., 2017a). Furthermore, sleep is negatively impacted by competitive matches (Fullagar et al., 2016b; Lalor et al., 2017; Richmond et al., 2004; Shearer et al., 2015), which has long been thought to expose athletes to increased risk of impaired recovery of physiological and physical function and impair subsequent physical performance outcomes, due to the detrimental impact of sleep deprivation and restriction on these factors (Mougin et al., 1991; Oliver et al., 2009; Souissi et al., 2013; Souissi et al., 2003; Souissi et al., 2008; Zhong et al., 2005).

The exposure of athletes to situations where sleep opportunities are limited is troubling, especially given the physiological and physical detriments that can result from reduced sleep. However, the changes in physical training and competition environments are an unavoidable component of professional Australian Rules football. The role that changes in the physical sleep environment, as a result of travel, have on the sleep behaviours of athletes have traditionally been investigated whilst undertaking transmeridian travel, resulting in either advances or delays in the sleep-wake cycle (Fullagar et al., 2015b; Lastella et al., 2014b). The presence of altered sleep-wake cycles makes it difficult to separate the effects of travel from the effects of changes in the sleeping environment and their influence on athlete sleep behaviours. Study 1 provides novel data indicating that sleeping in a different physical sleeping environment to home, detrimentally influences sleep efficiency, and highlights that those who sleep more in their home environment are more likely to experience reduced sleep duration in a new environment. Furthermore, sleep duration shows greater sensitivity to changes in training load whilst sleeping in a new environment, compared when sleeping at home. Together, these findings support the notion for an individualised approach to athlete sleep interventions (Fullagar and Bartlett, 2015), and provides a framework from which practitioners can identify individuals who may be more susceptible to impaired sleep duration when sleeping in new environments, such as when travelling for training camps and competition.

The presence of post-match travel and restrictive next-day recovery schedules have detrimental effects on sleep (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b; Youngstedt and O'Connor, 1999). However, previous investigations have not accounted for those factors in their investigation of the sleep behaviours of Australian Rules footballers (Richmond et al., 2004; Lalor et al., 2017). Although Study 2 (Chapter 5) found similar post-match sleep behaviours to those previously observed after home matches (Lalor et al., 2017; Richmond et al., 2004), it indicates that when post-match travel and early-morning schedules are removed, there is no substantial effect of away matches on the post-competition sleep behaviours of Australian Rules footballers. This finding, in conjunction with the results of Study 1, suggest that a change in sleeping environment when competing in away matches does not have the same detrimental effect on sleep duration as changes in sleep environment during pre-season training, relative to the home sleeping environment. This may suggest that athletes make a conscious decision to place greater importance on sleep during the in-season period, especially following competition. This is further supported by the increased mean sleep duration observed during the in-season period, compared to the pre-season period in Study 2, and previous evidence rating sleep as the most highly-rated recovery measure in athletes (Venter, 2014). The disparate effects of changing sleep environments between the pre-season and in-season may also be due to the substantial increase in daily loads on competition days, compared to the more consistent distribution of daily loads experienced during the pre-season. Collectively, these results support the need for greater education on the importance of sleep, and provides justification for the implementation of sleep interventions during pre-season, when training demands are highest (Ritchie et al., 2016), to facilitate recovery and enhance training outcomes. Furthermore, sleep interventions should be implemented around competition nights to reduce the effect of match-driven reductions in sleep duration, and influence of increasing competitive level, on markers of recovery. Although, sleep hygiene education has been shown to be successful to increase sleep duration in rugby league and soccer athletes (Caia et al., 2018a; Fullagar et al., 2016a), this type of intervention has not been attempted in team-sport athletes during the pre-season period or specifically around competition where, it seems, it may be most important.

Rugby league athletes playing in the National-level competition (National Rugby League; NRL) display longer sleep duration during the in-season compared to their sub-elite counterparts playing in State-level competition (Caia et al., 2017a). This thesis showed that when playing in the National-level AFL competition, players spent less time in bed and obtained less sleep, compared to when playing in the State-level VFL competition. However, the previous investigation did not evaluate individual nights surrounding competition, instead taking an average of sleep across a 7-day period (Caia et al., 2017a). Given the variation in sleep duration between competition and non-competition nights during the in-season, as reported in Study 2 and previous literature (Fullagar et al., 2016b; Lalor et al., 2017; Richmond et al., 2004; Shearer et al., 2015), the findings of this thesis support the evaluation of sleep behaviours relative to the daily demands (i.e. presence of competition or training). Together, these data suggest that playing in higher-level competitions has a detrimental influence on sleep duration, specifically on the night of competition. This suggests that athletes can be targeted with sleep education when transitioning to National-level competition in order to minimise the competition-level induced changes in sleep behaviour.

Previous investigations of the sleep behaviours of team-sport athletes have not considered factors such as chronotype or age and their role in observed sleep behaviours. This thesis provides the novel finding that individual chronotype influences the sleep behaviours of Australian Rules footballers. Whilst Study 2 found that age did not influence sleep independently, chronotype did vary as a function of age, which is in support of previous findings of earlier-chronotypes with older age during adulthood in athletes (Hagenauer and Lee, 2012; Caia et al., 2017a). These findings provide valuable information that the use of a simple morningness-eveningness questionnaire (Horne and Ostberg, 1976) facilitates better interpretation of sleep behaviours across large cohorts of athletes where chronotype (and age) may vary.

The physical demands that are placed on team-sport athletes vary during the pre-season and in-season periods, with training providing the most load during the pre-season, and competition being the main form of load during the in-season (Ritchie et al., 2016). During the pre-season, exposure to increased daily acceleration/deacceleration loads increases sleep duration and sleep efficiency, whereas increased daily total distance reduces sleep duration in rugby league athletes (Thornton et al., 2017a; Thornton et al., 2017b). Furthermore, periods of increased training loads across 6-, 14- and 21-day periods result in reduced sleep duration and sleep efficiency (Jürimäe et al., 2002; Jürimäe et al., 2004; Hausswirth et al., 2014; Thornton et al., 2017b). However, based on the results of Studies 1 and 2, and previous evidence (Thornton et al., 2017a; Thornton et al., 2017b), it can be postulated that not only are the sleep behaviours of team-sport athletes sensitive to changes in load, the relationship between them may be influenced by the season phase and the cumulative load of the preceding days, which has not been previously considered in Australian Rules footballers. Therefore, Study 3 was designed to investigate the effects of both short-term (1- and 7-day) and long-term (14-, 21- and 28-day) changes in load parameters and the influence this has on sleep behaviours. In support of previous findings, Study 3 (Chapter 6) showed that increased s-RPE Load across a 7-day period is associated with reduced sleep duration. Study 3 (Chapter 6) also presented novel information to suggest that increased daily loads have similar effects between the pre-season and in-season. However, sleep behaviours are more sensitive to increases in 7-day loads during the in-season, and more sensitive to increases in 14-, 21- and 28-day loads during the pre-season. The heightened change to increases in 7-day cumulative loads during the in-season is likely due to the weekly distribution of load, with the majority of load being contributed by competition. This is in opposition to the typical load distribution during the pre-season, where multiple sessions contribute more evenly to the weekly load demands. When combined with the findings of Study 2, this finding signifies the substantial influence that weekly competition has on the sleep behaviours of Australian Rules footballers, and the need for greater implementation of individualised sleep intervention to prevent impaired sleep duration. The findings of Study 3 (Chapter 6), in relation to the heightened sensitivity of sleep behaviours to cumulative pre-season loads over the preceding 14-, 21- and 28-day periods, suggest that during the pre-season where loads are regular increased to achieve progressive overload and training adaptations; sleep duration is impaired. Hence, in order to prevent the potential sleep-loss induced restriction of training adaptation and facilitate greater performance benefits; Study 3 provides further support to the findings of Study 2 and the need for greater athlete education on the importance of sleep, and the utilisation of sleep interventions to prevent impaired sleep during the pre-season.

Shifts to earlier morning commitments, whether for training or recovery, leads to reduced sleep duration in individual-sport athletes (Kölling et al., 2016; Sargent et al., 2014a; Sargent et al., 2014b). This thesis provides novel information in team-sport athletes, indicating that earlier schedules may contribute to the observed reductions in sleep duration during the pre-season period, compared to the in-season period (Study 2). The schedule-based facilitation of increased sleep duration during the in-season may also contribute to the reduced detrimental influences of increased cumulative load on sleep behaviours, and explain the discrepancies in associations between cumulative load and sleep observed between the pre-season and in-season periods. Furthermore, given the exposure to higher loads during the pre-season, compared to the in-season (Ritchie et al., 2016), and the increased risk of over-training that occurs with sustained periods of increased load (Meeusen et al., 2013), this thesis provides further support that sleep can be used as an indicator or symptom of over-training (Lastella et al., 2018).

Therefore, given that increased sleep duration improves mood, facilitates neuromuscular function, and improves physical performance (Arnal et al., 2016; Mah et al., 2011), further implementation of sleep interventions, including less-restrictive scheduling, during the pre-season period are recommended to potentially improve recovery and performance that, although speculative, may enhance training adaptations and reduce the risk of over-training.

Sleep is a natural human process designed to preserve and restore physical, physiological and cognitive function (Gordijn and Beersma, 2007), and therefore should facilitate post-exercise recovery when obtained in sufficient or increased amounts. However, this thesis (Study 2) and other others (Lalor et al., 2017; Richmond et al., 2004; Shearer et al., 2015) have shown that sleep is reduced following heavy exercise, such as competition, which may impair recovery. Therefore, athletes turn to other recovery interventions, such as active recovery, cold-water immersion, compression, and massage to provide recovery following heavy bouts of exercise (Torres et al., 2012; Ogai et al., 2008; Crane et al., 2012; Zainuddin et al., 2006), which are most effective when a combination of these interventions are utilised (Duffield et al., 2014; Bahnert et al., 2013). Study 4 of this thesis shows that increasing sleep duration by spending 10:00 h in bed (Extension condition), compared to 8:00 h in bed (Control condition) on a single night, does not reduce the detrimental effect of high-intensity intermittent exercise on markers of subjective and perceptual, neuromuscular, hormonal, and autonomic recovery the next day. As sleep duration was increased by 43-minutes in the Control condition, compared to mean habitual sleep duration, the results of Study 4 indicate that spending longer than 8 h in bed following a bout of high-intensity exercise does not provide further benefits for recovery. However, the influence of sleep extension on cognitive performance factors that are important to team-sport performance, such as decision-making and reaction times, was not investigated in Studies 4 or 5. Hence, future research should consider cognitive performance benefits when investigating sleep and team-sport athletes. Furthermore, the benefits of spending 8:00 h in bed, compared to a night of reduced sleep duration such as that experienced by team-sport athletes following competition, on markers of recovery is unknown and requires further investigation to make more definitive conclusions regarding the presence of a dose-response relationship between sleep duration and markers of recovery.

The beneficial effects of sleep extension for markers of physical performance and neuromuscular function, key aspects of post-exercise recovery, may only be apparent following consecutive nights of increased sleep duration (Mah et al., 2011; Arnal et al., 2016). As Study 2, and others (Lalor et al., 2017) showed post-match declines in sleep duration is followed by a rebound increase in sleep duration; Study 5 replicated this scenario (albeit in a laboratory environment) to investigate how increased sleep duration on the nights following high-intensity intermittent exercise influenced recovery. Unlike a single night of increased sleep duration, it was found that 3-nights of increased sleep duration enhances the recovery of perceptual wellbeing, neuromuscular function, and sprint performance. A unique element of this thesis was the utilisation of mid-afternoon naps to increase total daily sleep duration as an alternative method to overnight sleep extension, to counteract the restrictive nature of training and recovery schedules that limit the opportunity of athletes to obtain increased overnight sleep duration. These novel findings suggest that increasing sleep duration, through mid-afternoon naps, can enhance the recovery of peak jump velocity compared to overnight sleep extension, and improves recovery of peak torque production compared to a control condition. The observed improvements in neuromuscular function may help facilitate faster return to training levels that are required for optimal performance and training outcomes. Hence, the results of Study 5 (Chapter 8) indicated that the implementation of sleep extension interventions following competition may help improve recovery and subsequent performance in athlete populations.

The utilisation of subjective measures to monitor the wellbeing of athletes has received recent support (Saw et al., 2015), including the recording and reporting of perceived sleep quality and sleep duration. Self-reported time in bed ($r = 0.82 – 0.86$) and sleep duration ($r = 0.82 – 0.86$) have been shown to have good agreement with objective measures of sleep behaviour in student populations (Kölling et al., 2015). However, despite the commonality of subjective reporting of sleep quality and quantity, there is little evidence evaluating the accuracy of this method in athletic populations, compared objective measurement devices such as wrist-worn activity monitors. In rugby league players, some evidence of limited precision has been found between subjective sleep duration and that from a wrist-watch activity device, with mean bias of approximately 18 minutes and TEE of 48 minutes (Caia et al., 2018b). Furthermore, there is little available evidence to guide the interpretation of what the acceptable limits of agreement should be between subjective and objective measurement tools. Previous evidence suggests that differences of less than 60 minutes between are reliable (Van Den Berg et al., 2008), however shorter differences of less than 30 minutes have been suggested as acceptable (Werner et al., 2008). Therefore, as previously reported by Caia et al. (2018b), the utilisation of subjective reporting for sleep quality and quantity helps to ensure that information encompassing a number of sleep-related issues including difficulty falling asleep, fragmented sleep, insufficient sleep duration and poor sleep efficiency can be collected. However, this information should be accompanied by clear and consistent conversations between practitioners and clients when objective information is unavailable, and that a combination of both subjective and objective measures and sleep quality and quantity should be implemented where possible to ensure a full-analysis of sleep behaviours can be conducted.

9.4 Summary

This thesis furthers the understanding of how the sleep behaviours of team-sport athletes vary under the influence of individual and environmental factors, and how increased sleep duration interacts with post-exercise recovery. Specifically, Studies 1 – 3 (Chapters 4 – 6) show that changes in physical sleeping environment, individual chronotype, competitive level, and acute and cumulative loads alter the sleep behaviours of Australian Rules footballers in a variable manner. Expanding on these findings, the results of Studies 4 and 5 (Chapters 7 and 8) revealed that three consecutive nights, but not a single night, of increased sleep duration has a beneficial effect on markers of recovery and performance following a single session of high-intensity interval exercise.

9.5 Conclusions and Practical Applications

The practical applications of this thesis are:

1. Individual chronotype, using a simple questionnaire such as the Morningness-Eveningness Questionnaire, should be measured to provide greater understanding of the sleep behaviours of athletes.
2. Greater attention should be played to athletes undertaking an increase in competitive playing level to prevent such an increase having a detrimental influence on sleep behaviours following competition.
3. Sleep interventions, such as sleep hygiene education, should be targeted to the individual and in times of greatest need, such as pre-season camps and new sleeping environments (especially during the pre-season), and during prolonged periods of planned increased load.
4. Increasing time in bed above 8 h appears to have no increased benefits for recovery on the night following high-intensity intermittent exercise, whereas, multiple nights of sleep extension using both overnight sleep extension and afternoon naps totalling 10 h in bed per day can enhance markers of recovery.
5. Inter-individual preferences for sleep extension protocols exist and practitioners should ensure that individualised approaches are taken to increase the effectiveness of sleep interventions.
6. Implementation of less-restrictive training schedules provides greater opportunity for sleep, which positively influences recovery.

9.6 Limitations

The potential limitations of this thesis are:

1. No data or information was collected relating to travel time and/or social dynamics and how they may have influenced the observed changes in sleep behaviour between Home and Camp environments. Therefore, insight regarding the influence of daily commute-related travel time, changes social interaction during camp environment, and room-sharing driven alterations to sleep behaviours were not considered as modifiers of sleep behaviour.
2. The recording of sleep behaviours over relatively short timeframes during the pre-season and in-season phases may not provide a comprehensive representation of how the sleep behaviours of athletes vary across those periods, nor as a consequence of increased load.
3. Given the importance of subjective sleep behaviours and perceptual sleep quality for athlete populations, the lack of comprehensive subjective sleep quality information, particularly in Studies 2 and 3, present as a limitation to the ability to provide widespread practical applications for athlete populations.
4. During the in-season period, the sleep behaviours were examined on the night before, the night of, and the two nights following competition. Therefore, in the assessment of the influence that load has on sleep behaviours during the in-season, the majority of load during this period was a result of competition.
5. Study 4 showed that both the Control and Extension conditions increased sleep duration relative to habitual levels. The lack of a group undertaking reduced or habitual sleep durations limits the ability to make definitive conclusions of the role that increased sleep duration has on recovery following high-intensity intermittent exercise.

9.7 Future Research Directions

The following directions for further research are recommendations that will help facilitate improved understanding of the interactions and benefits of sleep on the preparation, performance, and recovery of athlete populations.

Direction 1

Does adherence to sleep hygiene guidelines improve the sleep behaviours of team-sport athletes following competition?

Sleep hygiene education results in transient increases of sleep duration in athletic populations (Caia et al., 2018a; Fullagar et al., 2016a). However, the implementation of individualised sleep interventions, based on the results of objective sleep monitoring, has not been attempted. In support of Fullagar et al. (2015a), there is also a need for investigations into the effects that individualised sleep interventions, designed to enhance sleep quantity and quality, have on post-match sleep and recovery outcomes.

Direction 2

Are cumulative load-induced alterations in sleep behaviours related to physiological and psychological symptoms of over-training in team-sport athletes?

Over-training is caused by an accumulation of training volume or intensity, coupled with insufficient recovery, which leads to neurochemical disturbances, upper respiratory tract infections, increased stress and anxiety, disturbed mood that results prolonged periods of impaired adaptation to training and reduced performance outcomes (Meeusen et al., 2013). Indeed, periods of over-training have been related to reduced sleep duration (Hausswirth et al., 2014), and poor sleep quality is commonly reported in over-trained athletes (Wall et al., 2003). However, the relationship between sleep, following periods of high cumulative load, and the presentation of physiological and psychological symptoms of over-training have not been thoroughly investigated. In support of recent calls (Lastella et al., 2018), future research should investigate the presence of sleep disturbances and symptoms of over-training following periods of increased cumulative load.

Direction 3

Is sleep extension beneficial for recovery following exercise, compared to habitual and restricted sleep durations?

Sleep restriction impairs cognitive function and physiological markers of recovery compared to habitual sleep (Knutson et al., 2007; Leproult et al., 2014; Mougin et al., 1991; Patel, 2009; Walker, 2008). This thesis found that multiple nights of sleep extension improves physiological markers of recovery (Chapter 8). It is yet to be determined if sleep extension improves post-exercise recovery when compared to habitual or restricted sleep, across either a single-night or multiple-nights, and whether sleep extension can enhance cognitive performance outcomes relevant for athletic performance, which warrants further investigation.

CHAPTER 10 – REFERENCES

Abedelmalek S, Souissi N, Chtourou H, et al. (2013) Effects of partial sleep deprivation on proinflammatory cytokines, growth hormone, and steroid hormone concentrations during repeated brief sprint interval exercise. *Chronobiology International* 30: 502-509.

Adan A, Archer SN, Hidalgo MP, et al. (2012) Circadian Typology: A Comprehensive Review. *Chronobiology International* 29: 1153-1175.

Andersson HM, Raastad T, Nilsson J, et al. (2008) Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Medicine & Science in Sports & Exercise* 40: 372-380.

Anothaisintawee T, Reutrakul S, Van Cauter E, et al. (2016) Sleep disturbances compared to traditional risk factors for diabetes development: Systematic review and meta-analysis. *Sleep Medicine Reviews* 30: 11-24.

Antic NA, Weeks R, McEvoy D, et al. (2013) Prevalence Of Sleep Disorders And Excessive Daytime Sleepiness In An Elite Australian Rules Football Team. *B70. Sleep Disordered Breathing. Epidemiology and Outcomes: Bench to Bedside* 187.

Arnal PJ, Lapole T, Erblang M, et al. (2016) Sleep Extension before Sleep Loss: Effects on Performance and Neuromuscular Function. *Medicine And Science In Sports And Exercise*.

Ascensão A, Rebelo A, Oliveira E, et al. (2008) Biochemical impact of a soccer match—analysis of oxidative stress and muscle damage markers throughout recovery. *Clinical biochemistry* 41: 841-851.

Baehr EK, Revelle W and Eastman CI. (2000) Individual differences in the phase and amplitude of the human circadian temperature rhythm: with an emphasis on morningness-eveningness. *Journal Of Sleep Research* 9: 117-127.

Baekeland F and Lasky R. (1966) Exercise and sleep patterns in college athletes. *Perceptual And Motor Skills* 23: 1203-1207.

Bahnert A, Norton K and Lock P. (2013) Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players. *Journal Of Science And Medicine In Sport / Sports Medicine Australia* 16: 151-156.

Bailey DM, Erith SJ, Griffin PJ, et al. (2007) Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. 1163-1170.

Bangsbo J, Mohr M and Krustrup P. (2006) Physical and metabolic demands of training and match-play in the elite football player. *Journal Of Sports Sciences* 24: 665-674.

Barnett A. (2006) Using recovery modalities between training sessions in elite athletes. *Sports Medicine* 36: 781-796.

Bassett DR and Howley ET. (2000) Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine And Science In Sports And Exercise* 32: 70-84.

Belenky G, Wesensten NJ, Thorne DR, et al. (2003) Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *Journal Of Sleep Research* 12: 1-12.

Bilsborough JC, Greenway K, Opar D, et al. (2014) Comparison of anthropometry, upper body strength and lower body power characteristics in different levels of Australian Football players. *Journal Of Strength And Conditioning Research / National Strength & Conditioning Association*.

Bishop D. (2004) The effects of travel on team performance in the Australian national netball competition. *Journal of Science and Medicine in Sport* 7: 118-122.

Bollinger T, Bollinger A, Oster H, et al. (2010) Sleep, immunity, and circadian clocks: a mechanistic model. *Gerontology* 56: 574-580.

Borb AA and Achermann P. (1999) Sleep Homeostasis and Models of Sleep Regulation. *Journal of Biological Rhythms* 14: 559-570.

Borbély AA. (1982) A two process model of sleep regulation. *Hum neurobiol* 1: 195-204.

Borg G. (1970) Perceived exertion as an indicator of somatic stress. *Scand j rehabil med* 2: 92-98.

Bradley WJ, Cavanagh B, Douglas W, et al. (2015a) Energy intake and expenditure assessed 'in-season' in an elite European rugby union squad. *European Journal Of Sport Science* 15: 469-479.

Bradley WJ, Cavanagh BP, Douglas W, et al. (2015b) Quantification of Training Load, Energy Intake, and Physiological Adaptations During a Rugby Preseason: A Case Study From an Elite European Rugby Union Squad. *The Journal of Strength & Conditioning Research* 29: 534-544.

Brandt R, Bevilacqua GG and Andrade A. (2017) Perceived sleep quality, mood states, and their relationship with performance among Brazilian elite athletes during a competitive period. *Journal of Strength and Conditioning Research* 31: 1033-1039.

Brewer C, Dawson B, Heasman J, et al. (2010) Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport* 13: 618-623.

Buchheit M, Cholley Y and Lambert P. (2015) Psychometric and Physiological Responses to a Pre-season Competitive Camp in the Heat With a 6-hr Time Difference in Elite Soccer Players. *International Journal Of Sports Physiology And Performance*.

Buchheit M, Racinais S, Bilsborough J, et al. (2013a) Adding heat to the live-high train-low altitude model: a practical insight from professional football. *British Journal Of Sports Medicine* 47: i59-i69.

Buchheit M, Racinais S, Bilsborough JC, et al. (2013b) Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport* 16: 550-555.

Buguet A. (2007) Sleep under extreme environments: effects of heat and cold exposure, altitude, hyperbaric pressure and microgravity in space. *Journal Of The Neurological Sciences* 262: 145-152.

Caia J, Halson SL, Scott TJ, et al. (2017a) Intra-individual variability in the sleep of senior and junior rugby league athletes during the competitive season. *Chronobiol Int* 34: 1239-1247.

Caia J, Scott TJ, Halson SL, et al. (2017b) Do players and staff sleep more during the pre- or competitive season of elite rugby league? *European Journal Of Sport Science*: 1-9.

Caia J, Scott TJ, Halson SL, et al. (2018a) The influence of sleep hygiene education on sleep in professional rugby league athletes. *Sleep Health* 4: 364-368.

Caia J, Thornton HR, Kelly VG, et al. (2018b) Does self-perceived sleep reflect sleep estimated via activity monitors in professional rugby league athletes? *Journal Of Sports Sciences* 36: 1492-1496.

Carriço S, Skorski S, Duffield R, et al. (2018) Post-match sleeping behavior based on match scheduling over a season in elite football players. *Science and Medicine in Football* 2: 9-15.

Carskadon MA. (2011) Sleep in Adolescents: The Perfect Storm. *Pediatric Clinics of North America* 58: 637-647.

Carskadon MA and Dement WC. (1982) Nocturnal determinants of daytime sleepiness. *Sleep* 5 Suppl 2: S73-S81.

Carskadon MA and Dement WC. (2005) Normal human sleep: an overview. *Principles and practice of sleep medicine* 4: 13-23.

Cheng AJ and Rice CL. (2005) Fatigue and recovery of power and isometric torque following isotonic knee extensions. *J Appl Physiol (1985)* 99: 1446-1452.

Chontong S, Saetung S and Reutrakul S. (2016) Higher sleep variability is associated with poorer glycaemic control in patients with type 1 diabetes. *Journal Of Sleep Research* 25: 438-444.

Claudino JG, J Gabbet T, de Sá Souza H, et al. (2019) Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis. *BMJ Open Sport & Exercise Medicine* 5: e000475.

Cole RJ, Kripke DF, Gruen W, et al. (1992) Automatic sleep/wake identification from wrist activity. *Sleep* 15: 461-469.

Cook C, Beaven CM, Kilduff LP, et al. (2012) Acute caffeine ingestion's increase of voluntarily chosen resistance-training load after limited sleep. *International Journal Of Sport Nutrition And Exercise Metabolism* 22: 157-164.

Cormack SJ, Newton RU and McGuigan MR. (2008a) Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal Of Sports Physiology And Performance* 3: 359-374.

Cormack SJ, Newton RU, McGuigan MR, et al. (2008b) Neuromuscular and endocrine responses of elite players during an Australian rules football season. *International Journal Of Sports Physiology And Performance* 3: 439-453.

Cormack SJ, Newton RU, McGuigan MR, et al. (2008c) Reliability of measures obtained during single and repeated countermovement jumps. *International Journal Of Sports Physiology And Performance* 3: 131-144.

Coutts AJ, Quinn J, Hocking J, et al. (2010) Match running performance in elite Australian Rules Football. *Journal Of Science And Medicine In Sport / Sports Medicine Australia* 13: 543-548.

Crane JD, Ogborn DI, Cupido C, et al. (2012) Massage therapy attenuates inflammatory signaling after exercise-induced muscle damage. *Science translational medicine* 4: 119ra113-119ra113.

Croft L, Bartlett JD, MacLaren DPM, et al. (2009) High-intensity interval training attenuates the exercise-induced increase in plasma IL-6 in response to acute exercise. *Applied Physiology, Nutrition, And Metabolism = Physiologie Appliquée, Nutrition Et Métabolisme* 34: 1098-1107.

Cunniffe B, Hore AJ, Whitcombe DM, et al. (2010) Time course of changes in immuneoendocrine markers following an international rugby game. *European Journal Of Applied Physiology* 108: 113.

Curcio G, Ferrara M and De Gennaro L. (2006) Sleep loss, learning capacity and academic performance. *Sleep Medicine Reviews* 10: 323-337.

Daanen HA, Lamberts RP, Kallen VL, et al. (2012) A systematic review on heart-rate recovery to monitor changes in training status in athletes. *International Journal Of Sports Physiology And Performance* 7: 251-260.

Danielsson K, Markström A, Broman J-E, et al. (2016) Delayed sleep phase disorder in a Swedish cohort of adolescents and young adults: Prevalence and associated factors. *Chronobiology International* 33: 1331-1339.

Dattilo M, Antunes HKM, Medeiros A, et al. (2011) Sleep and muscle recovery: endocrinological and molecular basis for a new and promising hypothesis. *Medical Hypotheses* 77: 220-222.

de Souza L, Benedito-Silva AA, Pires MLN, et al. (2003) Further validation of actigraphy for sleep studies. *Sleep* 26: 81-85.

Delextrat A, Hippocrate A, Leddington-Wright S, et al. (2014) Including stretches to a massage routine improves recovery from official matches in basketball players. *The Journal of Strength & Conditioning Research* 28: 716-727.

Dement WC. (2005) Sleep extension: getting as much extra sleep as possible. *Clinics In Sports Medicine* 24: 251.

Devlin BL, Leveritt MD, Kingsley M, et al. (2017) Dietary Intake, Body Composition, and Nutrition Knowledge of Australian Football and Soccer Players: Implications for Sports Nutrition Professionals in Practice. *International Journal Of Sport Nutrition And Exercise Metabolism* 27: 130-138.

Dinges DF, Orne MT, Whitehouse WG, et al. (1987) Temporal placement of a nap for alertness: contributions of circadian phase and prior wakefulness. *Sleep* 10: 313-329.

Doeven SH, Brink MS, Kosse SJ, et al. (2018) Postmatch recovery of physical performance and biochemical markers in team ball sports: a systematic review. *BMJ Open Sport & Exercise Medicine* 4.

Dosseville F, Laborde S and Lericollais R. (2013) Validation of a chronotype questionnaire including an amplitude dimension. *Chronobiology International* 30: 639-648.

Driver HS, Rogers GG, Mitchell D, et al. (1994) Prolonged endurance exercise and sleep disruption. *Medicine And Science In Sports And Exercise* 26: 903-907.

Duffield R, Murphy A, Kellett A, et al. (2014) Recovery from repeated on-court tennis sessions: combining cold-water immersion, compression, and sleep recovery interventions. *International Journal Of Sports Physiology And Performance* 9: 273-282.

Dumortier J, Mariman A, Boone J, et al. (2018) Sleep, training load and performance in elite female gymnasts. *European Journal Of Sport Science* 18: 151-161.

Dunican IC, Higgins CC, Jones MJ, et al. (2018) Caffeine use in a Super Rugby game and its relationship to post-game sleep. *European Journal Of Sport Science*: 1-11.

Dupuy O, Douzi W, Theurot D, et al. (2018) An Evidence-Based Approach for Choosing Post-exercise Recovery Techniques to Reduce Markers of Muscle Damage, Soreness, Fatigue, and Inflammation: A Systematic Review With Meta-Analysis. *Frontiers In Physiology* 9.

Eagles A, McLellan C, Hing W, et al. (2016) Changes in sleep quantity and efficiency in professional rugby union players during home based training and match-play. *The Journal Of Sports Medicine And Physical Fitness* 56: 565-571.

Erlacher D, Ehrlenspiel F, Adegbesan OA, et al. (2011) Sleep habits in German athletes before important competitions or games. *Journal Of Sports Sciences* 29: 859-866.

Everson CA and Crowley WR. (2004) Reductions in circulating anabolic hormones induced by sustained sleep deprivation in rats. *American Journal Of Physiology. Endocrinology And Metabolism* 286: E1060-E1070.

Famodu OA, Montgomery-Downs H, Thomas JM, et al. (2017) Impact of a single week of sleep extension on performance, mood, and nutrition among female college track athletes. *Sleep* 40: A32-A32.

Fanchini M, Schena F, Castagna C, et al. (2015) External Responsiveness of the Yo-Yo IR Test Level 1 in High-level Male Soccer Players. *International Journal Of Sports Medicine* 36: 735-741.

Faraut B, Nakib S, Drogou C, et al. (2015) Napping reverses the salivary interleukin-6 and urinary norepinephrine changes induced by sleep restriction. *J Clin Endocrinol Metab* 100: E416-426.

Fitzgerald D, Beckmans C, Joyce D, et al. (2019) The influence of sleep and training load on illness in nationally competitive male Australian Football athletes: A cohort study over one season. *Journal of Science and Medicine in Sport* 22: 130-134.

Flanagan OJ. (2001) *Dreaming souls: Sleep, dreams, and the evolution of the conscious mind*: Oxford University Press on Demand.

Fondell E, Axelsson J, Franck K, et al. (2011) Short natural sleep is associated with higher T cell and lower NK cell activities. *Brain, Behavior, And Immunity* 25: 1367-1375.

Foster C, Florhaug JA, Franklin J, et al. (2001) A new approach to monitoring exercise training. *Journal Of Strength And Conditioning Research / National Strength & Conditioning Association* 15: 109-115.

Foundation NS. (2019) *Learn how many minutes to doze to feel happier and more alert.* Available at: https://www.sleep.org/articles/how-long-to-nap/.

Fowler P, Duffield R, Howle K, et al. (2015) Effects of northbound long-haul international air travel on sleep quantity and subjective jet lag and wellness in professional Australian soccer players. *International Journal Of Sports Physiology And Performance* 10: 648-654.

Fragala MS, Jajtner AR, Townsend JR, et al. (2015) Leukocyte IGF-1 Receptor Expression during Muscle Recovery. *Medicine And Science In Sports And Exercise* 47: 92-99.

Fullagar H, Skorski S, Duffield R, et al. (2016a) The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players. *Chronobiology International* 33: 490-505.

Fullagar HH, Duffield R, Skorski S, et al. (2015a) Sleep and recovery in team sport: current sleep-related issues facing professional team-sport athletes. *International Journal Of Sports Physiology And Performance* 10: 950-957.

Fullagar HK and Bartlett JD. (2015) Time to wake up: individualising the approach to sleep promotion interventions. *British Journal Of Sports Medicine* 50: 143-144.

Fullagar HK, Duffield R, Skorski S, et al. (2015b) Sleep, Travel and Recovery Responses of National Footballers During and Following Long-Haul International Air Travel. *International Journal Of Sports Physiology And Performance*.

Fullagar HK, Skorski S, Duffield R, et al. (2015c) Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Medicine (Auckland, N.Z.)* 45: 161-186.

Fullagar HK, Skorski S, Duffield R, et al. (2016b) Impaired sleep and recovery after night matches in elite football players. *Journal Of Sports Sciences*: 1-7.

Gabbett TJ. (2018) Debunking the myths about training load, injury and performance: empirical evidence, hot topics and recommendations for practitioners. *British Journal Of Sports Medicine*.

Gordijn M and Beersma D. (2007) Circadian control of the sleep–wake cycle. *Physiology and Behaviour* 90: 190-195. doi:110.1016/j.physbeh.2006.1009.1010.

Gronfier C, Luthringer R, Follenius M, et al. (1996) A quantitative evaluation of the relationships between growth hormone secretion and delta wave electroencephalographic activity during normal sleep and after enrichment in delta waves. *Sleep* 19: 817-824.

Guilhem G, Hug F, Couturier A, et al. (2013) Effects of air-pulsed cryotherapy on neuromuscular recovery subsequent to exercise-induced muscle damage. *The American journal of sports medicine* 41: 1942-1951.

Hagenauer MH and Lee TM. (2012) The neuroendocrine control of the circadian system: Adolescent chronotype. *Frontiers in Neuroendocrinology* 33: 211-229.

Halson SL. (2008) Nutrition, sleep and recovery. *European Journal Of Sport Science* 8: 119-126.

Halson SL. (2014) Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine (Auckland, N.Z.)* 44 Suppl 1: S13-S23.

Hausswirth C, Louis J, Aubry A, et al. (2014) Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Medicine And Science In Sports And Exercise* 46: 1036-1045.

Hill D, Cureton K, Collins M, et al. (1988) Diurnal Variations in Responses to Exercise of "Morning Types" and "Evening Types". *Journal of Sports Medicine and Physical Fitness* 28: 213-219.

Holt RIG and Sönksen PH. (2008) Growth hormone, IGF-I and insulin and their abuse in sport. *British Journal Of Pharmacology* 154: 542-556.

Hooper SL and Mackinnon LT. (1995) Monitoring overtraining in athletes. *Sports Medicine* 20: 321-327.

Hopker JG, Coleman DA, Wiles JD, et al. (2009) Familiarisation and reliability of sprint test indices during laboratory and field assessment. *Journal Of Sports Science & Medicine* 8: 528-532.

Hopkins W. (2007) *A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value*. Available at: sportsci.org/2007/wghinf.htm.

Hopkins W, Marshall S, Batterham A, et al. (2009) Progressive statistics for studies in sports medicine and exercise science. *Medicine And Science In Sports And Exercise* 41: 3.

Hopkins WG. (2000) Measures of reliability in sports medicine and science. *Sports Medicine* 30: 1-15.

Horne J, Anderson C and Platten C. (2008) Sleep extension versus nap or coffee, within the context of 'sleep debt'. *Journal Of Sleep Research* 17: 432-436.

Horne JA and Ostberg O. (1976) A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal Of Chronobiology* 4: 97-110.

Hynynen E, Uusitalo A, Konttinen N, et al. (2006) Heart rate variability during night sleep and after awakening in overtrained athletes. *Medicine & Science in Sports & Exercise* 38: 313-317.

Imeri L and Opp MR. (2009) How (and why) the immune system makes us sleep. *Nature Reviews Neuroscience* 10: 199.

Ispirlidis I, Fatouros IG, Jamurtas AZ, et al. (2008) Time-course of changes in inflammatory and performance responses following a soccer game. *Clinical Journal of Sport Medicine* 18: 423-431.

Issurin VB. (2010) New horizons for the methodology and physiology of training periodization. *Sports Medicine* 40: 189-206.

Jean-Louis G, Zizi F, Von Gizycki H, et al. (1998) Actigraphic assessment of sleep in insomnia: application of the Actigraph Data Analysis Software (ADAS). *Physiology & Behavior* 65: 659-663.

Johnston RD, Gibson NV, Twist C, et al. (2013) Physiological responses to an intensified period of rugby league competition. *Journal Of Strength And Conditioning Research / National Strength & Conditioning Association* 27: 643-654.

Juhari F, Ritchie DM, O'Connor F, et al. (2017) The Quantification of Within Week Session Intensity, Duration and Intensity Distribution Across a Season in Australian Football Using the Session RPE Method. *International Journal Of Sports Physiology And Performance* 13: 940-946.

Juliff LE, Halson SL and Peiffer JJ. (2014) Understanding sleep disturbance in athletes prior to important competitions. *Journal of Science and Medicine in Sport* 18: 13-18.

Jürimäe J, Mäestu J, Purge P, et al. (2004) Changes in stress and recovery after heavy training in rowers. *Journal Of Science And Medicine In Sport / Sports Medicine Australia* 7: 335-339.

Jürimäe J, Mäestu J, Purge P, et al. (2002) Relations among heavy training stress, mood state, and performance for male junior rowers. *Perceptual And Motor Skills* 95: 520-526.

Kamdar BB, Kaplan KA, Kezirian EJ, et al. (2004) The impact of extended sleep on daytime alertness, vigilance, and mood. *Sleep Medicine* 5: 441-448.

Karni A, Tanne D, Rubenstein BS, et al. (1994) Dependence on REM sleep of overnight improvement of a perceptual skill. *Science (New York, N.Y.)* 265: 679-682.

Kempton T and Coutts AJ. (2015) Factors affecting exercise intensity in professional rugby league match-play. *Journal Of Science And Medicine In Sport / Sports Medicine Australia*.

Kempton T, Sullivan C, Bilsborough JC, et al. (2014) Match-to-match variation in physical activity and technical skill measures in professional Australian Football. *Journal Of Science And Medicine In Sport / Sports Medicine Australia*.

Killer SC, Svendsen IS, Jeukendrup AE, et al. (2015) Evidence of disturbed sleep and mood state in well-trained athletes during short-term intensified training with and without a high carbohydrate nutritional intervention. *Journal Of Sports Sciences*: 1-9.

Knowles OE, Drinkwater EJ, Urwin CS, et al. (2018) Inadequate sleep and muscle strength: Implications for resistance training. *Journal of Science and Medicine in Sport* 21: 959-968.

Knutson KL, Spiegel K, Penev P, et al. (2007) The metabolic consequences of sleep deprivation. *Sleep Medicine Reviews* 11: 163-178.

Kölling S, Endler S, Ferrauti A, et al. (2015) Comparing Subjective With Objective Sleep Parameters Via Multisensory Actigraphy in German Physical Education Students. *Behavioral Sleep Medicine*: 1-17.

Kölling S, Steinacker JM, Endler S, et al. (2016) The longer the better: Sleep–wake patterns during preparation of the World Rowing Junior Championships. *Chronobiology International* 33: 1-12.

Kosmadopoulos A, Sargent C, Darwent D, et al. (2014) Alternatives to polysomnography (PSG): a validation of wrist actigraphy and a partial-PSG system. *Behavior Research Methods* 46: 1032-1041.

Kraemer WJ, Flanagan SD, Comstock BA, et al. (2010) Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *The Journal of Strength & Conditioning Research* 24: 804-814.

Krustrup P, Mohr M, Amstrup T, et al. (2003) The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine And Science In Sports And Exercise* 35: 697.

Kunorozva L, Roden LC and Rae DE. (2014) Perception of effort in morning-type cyclists is lower when exercising in the morning. *Journal Of Sports Sciences* 32: 917-925.

Kunorozva L, Stephenson KJ, Rae DE, et al. (2012) Chronotype and PERIOD3 Variable Number Tandem Repeat Polymorphism in Individual Sports Athletes. *Chronobiology International* 29: 1004-1010.

Lalor BJ, Halson SL, Tran J, et al. (2017) Competition Sleep Is Not Compromised Compared To Habitual In Elite Australian Footballers. *International Journal Of Sports Physiology And Performance*: 1-23.

Lastella M, Lovell GP and Sargent C. (2014a) Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *European Journal Of Sport Science* 14 Suppl 1: S123-S130.

Lastella M, Roach G, Hurem D, et al. (2010) Does chronotype affect elite athletes' capacity to cope with the training demands of triathlon? In: Society AC (ed) *Living in a 24/7 World: The impact of circadian disruption on sleep, work and health.* Adelaide, Australia, 25-28.

Lastella M, Roach GD, Halson SL, et al. (2014b) The effects of transmeridian travel and altitude on sleep: preparation for football competition. *Journal Of Sports Science & Medicine* 13: 718-720.

Lastella M, Roach GD, Halson SL, et al. (2014c) The impact of a simulated grand tour on sleep, mood, and well-being of competitive cyclists. *The Journal Of Sports Medicine And Physical Fitness* 55: 1555-1564.

Lastella M, Roach GD, Halson SL, et al. (2014d) Sleep/wake behaviour of endurance cyclists before and during competition. *Journal Of Sports Sciences*: 1-7.

Lastella M, Roach GD, Halson SL, et al. (2015) Sleep/wake behaviour of endurance cyclists before and during competition. *Journal Of Sports Sciences* 33: 293-299.

Lastella M, Roach GD, Halson SL, et al. (2014e) Sleep/wake behaviours of elite athletes from individual and team sports. *European Journal Of Sport Science* 15: 94-100.

Lastella M, Roach GD, Halson SL, et al. (2016) The Chronotype of Elite Athletes. *Journal of Human Kinetics* 54: 219-225.

Lastella M, Vincent GE, Duffield R, et al. (2018) Can Sleep Be Used as an Indicator of Overreaching and Overtraining in Athletes? *Frontiers In Physiology* 9.

Lee-Chiong TL. (2006) *Sleep. A comprehensive handbook*: Hoboken, N.J. : Wiley-Liss ; Chichester : John Wiley [distributor].

Leeder J, Glaister M, Pizzoferro K, et al. (2012) Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *Journal Of Sports Sciences* 30: 541-545.

Lehmann M, Gastmann U, Petersen KG, et al. (1992) Training-overtraining: performance, and hormone levels, after a defined increase in training volume versus intensity in experienced middle- and long-distance runners. *British Journal Of Sports Medicine* 26: 233-242.

Leproult R, Deliens G, Gilson M, et al. (2014) Beneficial Impact of Sleep Extension on Fasting Insulin Sensitivity in Adults with Habitual Sleep Restriction. *Sleep* 38: 707-715.

Libert JP, Di Nisi J, Fukuda H, et al. (1988) Effect of continuous heat exposure on sleep stages in humans. *Sleep* 11: 195-209.

Machado AF, Ferreira PH, Micheletti JK, et al. (2016) Can water temperature and immersion time influence the effect of cold water immersion on muscle soreness? A systematic review and meta-analysis. *Sports Medicine* 46: 503-514.

Mah CD, Mah KE, Kezirian EJ, et al. (2011) The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 34: 943-950.

Mann TN, Platt CE, Lamberts RP, et al. (2015) Faster Heart Rate Recovery With Increased Rpe: Paradoxical Responses After an 87-Km Ultramarathon. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins)* 29: 3343-3352.

Markovic G, Dizdar D, Jukic I, et al. (2004) Reliability and factorial validity of squat and countermovement jump tests. *Journal Of Strength And Conditioning Research / National Strength & Conditioning Association* 18: 551-555.

Marqués-Jiménez D, Calleja-González J, Arratibel-Imaz I, et al. (2018) Influence of different types of compression garments on exercise-induced muscle damage markers after a soccer match. *Research in Sports Medicine* 26: 27-42.

Martin B and Haney R. (1982) Self-selected exercise intensity is unchanged by sleep loss. *European Journal Of Applied Physiology And Occupational Physiology* 49: 79-86.

Martin BJ. (1981) Effect of sleep deprivation on tolerance of prolonged exercise. *European Journal Of Applied Physiology And Occupational Physiology* 47: 345-354.

Martin BJ. (1986) Sleep deprivation and exercise. *Exercise And Sport Sciences Reviews* 14: 213-229.

Martin BJ. (1988) Sleep loss and subsequent exercise performance. *Acta Physiologica Scandinavica. Supplementum* 574: 28-32.

Martin BJ, Bender PR and Chen H. (1986) Stress hormonal response to exercise after sleep loss. *European Journal Of Applied Physiology And Occupational Physiology* 55: 210-214.

Martin BJ and Chen HI. (1984) Sleep loss and the sympathoadrenal response to exercise. *Medicine And Science In Sports And Exercise* 16: 56-59.

Martin BJ and Gaddis GM. (1981) Exercise after sleep deprivation. *Medicine And Science In Sports And Exercise* 13: 220-223.

McLean BD, Coutts AJ, Kelly V, et al. (2010) Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal Of Sports Physiology And Performance* 5: 367-383.

McLean BD, Petrucelli C and Coyle EF. (2012) Maximal Power Output and Perceptual Fatigue Responses During a Division I Female Collegiate Soccer Season. *The Journal of Strength & Conditioning Research* 26: 3189-3196.

McNair D, Lorr M and Droppleman L. (1971) *Manual profile of mood states.*, San Diego, CA: Educational & Industrial Testing Service.

Meeusen R, Duclos M, Foster C, et al. (2013) Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine And Science In Sports And Exercise* 45: 186-205.

Meier-Ewert HK, Ridker PM, Rifai N, et al. (2004) Effect of sleep loss on C-reactive protein, an inflammatory marker of cardiovascular risk. *Journal Of The American College Of Cardiology* 43: 678-683.

Meyer T, Wegmann M, Poppendieck W, et al. (2014) Regenerative interventions in professional football. *Sport-Orthopädie - Sport-Traumatologie - Sports Orthopaedics and Traumatology* 30: 112-118.

Milewski MD, Skaggs DL, Bishop GA, et al. (2014) Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *Journal Of Pediatric Orthopedics* 34: 129-133.

Miller B, O'Connor H, Orr R, et al. (2014) Combined caffeine and carbohydrate ingestion: effects on nocturnal sleep and exercise performance in athletes. *European Journal Of Applied Physiology* 114: 2529-2537.

Mohr M, Draganidis D, Chatzinikolaou A, et al. (2016) Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. *European Journal Of Applied Physiology* 116: 179-193.

Morgenthaler T, Alessi C, Friedman L, et al. (2007) Practice parameters for the use of actigraphy in the assessment of sleep and sleep disorders: an update for 2007. *Sleep* 30: 519-529.

Mougin F, Simon-Rigaud ML, Davenne D, et al. (1991) Effects of sleep disturbances on subsequent physical performance. *European Journal Of Applied Physiology And Occupational Physiology* 63: 77-82.

Mullaney DJ, Kripke DF and Messin S. (1980) Wrist-actigraphic estimation of sleep time. *Sleep* 3: 83-92.

Mullington JM, Haack M, Toth M, et al. (2009) Cardiovascular, inflammatory, and metabolic consequences of sleep deprivation. *Progress In Cardiovascular Diseases* 51: 294-302.

Myllymäki T, Rusko H, Syväoja H, et al. (2012) Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. *European Journal Of Applied Physiology* 112: 801-809.

Nédélec M, Halson S, Delecroix B, et al. (2015) Sleep Hygiene and Recovery Strategies in Elite Soccer Players. *Sports Medicine* 45: 1547-1559.

Nédélec M, McCall A, Carling C, et al. (2013) Recovery in soccer: Part II - Recovery strategies. *Sports Medicine* 43: 9-22.

Nedeltcheva AV, Kilkus JM, Imperial J, et al. (2010) Insufficient sleep undermines dietary efforts to reduce adiposity. *Annals Of Internal Medicine* 153: 435-441.

Neubauer O, Sabapathy S, Ashton KJ, et al. (2014) Time course-dependent changes in the transcriptome of human skeletal muscle during recovery from endurance exercise: from inflammation to adaptive remodeling. *Journal Of Applied Physiology (Bethesda, Md.: 1985)* 116: 274-287.

Nieman DC. (1997) Immune response to heavy exertion. *Journal Of Applied Physiology (Bethesda, Md.: 1985)* 82: 1385-1394.

O'Donnell S and Driller MW. (2017) Sleep-hygiene education improves sleep indices in elite female athletes.

O'Donnell S, Beaven CM and Driller M. (2018) The Influence of Match-Day Napping in Elite Female Netball Athletes. *International Journal Of Sports Physiology And Performance* 13: 1143-1148.

Oakley N. (1997) Validation with polysomnography of the Sleepwatch sleep/wake scoring algorithm used by the Actiwatch activity monitoring system. *Bend: Mini Mitter, Cambridge Neurotechnology*.

Obal F, Jr. and Krueger JM. (2004) GHRH and sleep. *Sleep Medicine Reviews* 8: 367-377.

Oda S and Shirakawa K. (2014) Sleep onset is disrupted following pre-sleep exercise that causes large physiological excitement at bedtime. *European Journal Of Applied Physiology* 114: 1789-1799.

Ogai R, Yamane M, Matsumoto T, et al. (2008) Effects of petrissage massage on fatigue and exercise performance following intensive cycle pedaling. *British Journal Of Sports Medicine*.

Okamoto-Mizuno K, Tsuzuki K, Mizuno K, et al. (2005) Effects of partial humid heat exposure during different segments of sleep on human sleep stages and body temperature. *Physiology & Behavior* 83: 759-765.

Oliver SJ, Costa RJS, Laing SJ, et al. (2009) One night of sleep deprivation decreases treadmill endurance performance. *European Journal Of Applied Physiology* 107: 155-161.

Patel SR. (2009) Reduced sleep as an obesity risk factor. *Obesity Reviews: An Official Journal Of The International Association For The Study Of Obesity* 10 Suppl 2: 61-68.

Pitchford N, Robertson S, Sargent C, et al. (2017) A Change in Training Environment Alters Sleep Quality But Not Quantity in Elite Australian Rules Football Players. *International Journal Of Sports Physiology And Performance* 12: 75-80.

Plews DJ, Laursen PB, Stanley J, et al. (2013) Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. *Sports Medicine* 43: 773-781.

Rae DE, Chin T, Dikgomo K, et al. (2017) One night of partial sleep deprivation impairs recovery from a single exercise training session. *European Journal Of Applied Physiology*: 1-14.

Rampinini E, Alberti G, Fiorenza M, et al. (2014) Accuracy of GPS Devices for Measuring High-intensity Running in Field-based Team Sports. *International Journal Of Sports Medicine*.

Reilly T and Gilbourne D. (2003) Science and football: a review of applied research in the football codes. *Journal Of Sports Sciences* 21: 693-705.

Reilly T and Piercy M. (1994) The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics* 37: 107-115.

Reilly T, Waterhouse J and Edwards B. (2005) Jet lag and air travel: implications for performance. *Clinics In Sports Medicine* 24: 367.

Richmond L, Dawson B, Hillman DR, et al. (2004) The effect of interstate travel on sleep patterns of elite Australian Rules footballers. *Journal of Science and Medicine in Sport* 7: 186-196.

Ritchie D, Hopkins WG, Buchheit M, et al. (2016) Quantification of training and competition load across a season in an elite Australian football club. *International Journal Of Sports Physiology And Performance* 11: 474-479.

Roach GD, Schmidt WF, Aughey RJ, et al. (2013) The sleep of elite athletes at sea level and high altitude: a comparison of sea-level natives and high-altitude natives (ISA3600). *British Journal Of Sports Medicine* 47 Suppl 1: i114-i120.

Roberts SS, Teo W-P, Aisbett B, et al. (2019) Extended Sleep Maintains Endurance Performance better than Normal or Restricted Sleep. *Medicine And Science In Sports And Exercise*.

Roenneberg T, Wirz-Justice A and Merrow M. (2003) Life between clocks: daily temporal patterns of human chronotypes. *Journal of Biological Rhythms* 18: 80-90.

Rowell AE, Aughey RJ, Hopkins WG, et al. (2016) Identification of Sensitive Measures of Recovery Following External Load From Football Match Play. *International Journal Of Sports Physiology And Performance*: 1-25.

Rowsell GJ, Coutts AJ, Reaburn P, et al. (2011) Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal Of Sports Sciences* 29: 1-6.

Sadeh A. (2011) The role and validity of actigraphy in sleep medicine: an update. *Sleep Medicine Reviews* 15: 259-267.

Sainani KL. (2018) The Problem with" Magnitude-based Inference". *Medicine And Science In Sports And Exercise* 50: 2166-2176.

Samuels C. (2008) Sleep, recovery, and performance: the new frontier in high-performance athletics. *Neurologic Clinics* 26: 169.

Santos RVT, Tufik S and De Mello MT. (2007) Exercise, sleep and cytokines: is there a relation? *Sleep Medicine Reviews* 11: 231-239.

Sargent C, Halson S and Roach GD. (2014a) Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *European Journal Of Sport Science* 14 Suppl 1: S310-S315.

Sargent C, Lastella M, Halson SL, et al. (2014b) The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiology International* 31: 1160-1180.

Sargent C, Lastella M, Halson SL, et al. (2015) The validity of activity monitors for measuring sleep in elite athletes. *Journal of Science and Medicine in Sport* 19: 848-853.

Sargent C and Roach GD. (2016) Sleep duration is reduced in elite athletes following night-time competition. *Chronobiology International* 33: 667-670.

Sargent C, Schmidt WF, Aughey RJ, et al. (2013) The impact of altitude on the sleep of young elite soccer players (ISA3600). *British Journal Of Sports Medicine* 47 Suppl 1: i86-i92.

Saw A, Main L and Gastin P. (2015) Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *British Journal Of Sports Medicine* 49.

Schibler U and Sassone-Corsi P. (2002) A web of circadian pacemakers. *Cell* 111: 919-922.

Schwartz J and Simon RD. (2015) Sleep extension improves serving accuracy: A study with college varsity tennis players. *Physiology & Behavior* 151: 541-544.

Scott TJ, Black CR, Quinn J, et al. (2013) Validity and reliability of the session-RPE method for quantifying training in Australian football: a comparison of the CR10 and CR100 scales. *Journal of Strength and Conditioning Research* 27: 270-276.

Sexton-Radek K and Hartley A. (2013) College residential sleep environment. *Psychological Reports* 113: 903-907.

Shearer DA, Jones RM, Kilduff LP, et al. (2015) Effects of competition on the sleep patterns of elite rugby union players. *European Journal Of Sport Science* 15: 1-6.

Silva MRG and Paiva T. (2016) Poor precompetitive sleep habits, nutrients' deficiencies, inappropriate body composition and athletic performance in elite gymnasts. *European Journal Of Sport Science* 16: 726-735.

Skein M, Duffield R, Edge J, et al. (2011) Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. *Medicine And Science In Sports And Exercise* 43: 1301-1311.

Skein M, Duffield R, Minett GM, et al. (2013) The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery. *International Journal Of Sports Physiology And Performance* 8: 556-564.

Smith DJ. (2003) A framework for understanding the training process leading to elite performance. *Sports Medicine* 33: 1103-1126.

Souissi N, Chtourou H, Aloui A, et al. (2013) Effects of time-of-day and partial sleep deprivation on short-term maximal performances of judo competitors. *The Journal of Strength & Conditioning Research* 27: 2473-2480.

Souissi N, Sesboüé B, Gauthier A, et al. (2003) Effects of one night's sleep deprivation on anaerobic performance the following day. *European Journal Of Applied Physiology* 89: 359-366.

Souissi N, Souissi M, Souissi H, et al. (2008) Effect of Time of Day and Partial Sleep Deprivation on Short-Term, High-Power Output. *Chronobiology International* 25: 1062-1076.

Spiegel K, Leproult R and Van Cauter E. (1999) Impact of sleep debt on metabolic and endocrine function. *Lancet* 354: 1435-1439.

Stiller JW and Postolache TT. (2005) Sleep-wake and other biological rhythms: functional neuroanatomy. *Clinics In Sports Medicine* 24: 205.

Suppiah HT, Low CY and Chia M. (2015) Effects of sports training on sleep characteristics of Asian adolescent athletes. *Biological Rhythm Research* 46: 523-536.

Taylor SR, Rogers GG and Driver HS. (1997) Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Medicine And Science In Sports And Exercise* 29: 688-693.

Teng E, Lastella M, Roach G, et al. (2011) The effect of training load on sleep quality and sleep perception in elite male cyclists. *Little Clock, Big Clock: Molecular to Physiological Clocks, eds G. Kennedy and C. Sargent.(Melbourne: Australasian Chronobiology Society, Victoria University)*: 5-10.

Terry PC and Lane AM. (2000) Normative values for the profile of mood states for use with athletic samples. *Journal of Applied Sport Psychology* 12: 93-109.

Thorlund JB, Michalsik LB, Madsen K, et al. (2008) Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. *Scandinavian Journal Of Medicine & Science In Sports* 18: 462-472.

Thornton HR, Delaney JA, Duthie GM, et al. (2017a) Effects of Pre-Season Training on the Sleep Characteristics of Professional Rugby League Players. *International Journal Of Sports Physiology And Performance*: 1-23.

Thornton HR, Duthie GM, Pitchford NW, et al. (2016) Effects of a Two-week High Intensity Training Camp on Sleep Activity of Professional Rugby League Athletes. *International Journal Of Sports Physiology And Performance*: 1-19.

Thornton HR, Duthie GM, Pitchford NW, et al. (2017b) Effects of a 2-Week High-Intensity Training Camp on Sleep Activity of Professional Rugby League Athletes. *International Journal Of Sports Physiology And Performance* 12: 928-933.

Thorpe RT, Strudwick AJ, Buchheit M, et al. (2015) Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players. *International Journal of Sports Physiology & Performance* 10: 958-964.

Torres R, Ribeiro F, Duarte JA, et al. (2012) Evidence of the physiotherapeutic interventions used currently after exercise-induced muscle damage: systematic review and meta-analysis. *Physical Therapy in Sport* 13: 101-114.

Van Cauter E and Copinschi G. (2000) Interrelationships between growth hormone and sleep. *Growth Hormone & IGF Research: Official Journal Of The Growth Hormone Research Society And The International IGF Research Society* 10 Suppl B: S57-S62.

Van Den Berg JF, Van Rooij FJ, Vos H, et al. (2008) Disagreement between subjective and actigraphic measures of sleep duration in a population-based study of elderly persons. *Journal Of Sleep Research* 17: 295-302.

Venter RE. (2014) Perceptions of team athletes on the importance of recovery modalities. *European Journal Of Sport Science* 14 Suppl 1: S69-S76.

Vgontzas AN, Zoumakis E, Bixler EO, et al. (2004) Adverse effects of modest sleep restriction on sleepiness, performance, and inflammatory cytokines. *The Journal Of Clinical Endocrinology And Metabolism* 89: 2119-2126.

Vieira A, Bottaro M, Ferreira-Junior JB, et al. (2015) Does whole-body cryotherapy improve vertical jump recovery following a high-intensity exercise bout? *Open access journal of sports medicine* 6: 49.

Vitale J, Bonato M, Galasso L, et al. (2017) Sleep quality and high intensity interval training at two different times of day: A crossover study on the influence of the chronotype in male collegiate soccer players AU - Vitale, Jacopo A. *Chronobiology International* 34: 260-268.

Walker MP. (2008) Cognitive consequences of sleep and sleep loss. *Sleep Medicine* 9 Suppl 1: S29-S34.

Wall SP, Mattacola CG, Swanik CB, et al. (2003) Sleep efficiency and overreaching in swimmers. *Journal of Sport Rehabilitation* 12: 1-12.

Walters PH. (2002) Sleep, the athlete, and performance. *Strength & Conditioning Journal* 24: 17-24.

Waterhouse J, Atkinson G, Edwards B, et al. (2007) The role of a short post-lunch nap in improving cognitive, motor, and sprint performance in participants with partial sleep deprivation. *Journal Of Sports Sciences* 25: 1557-1566.

Watson AM. (2017) Sleep and Athletic Performance. *Current Sports Medicine Reports* 16: 413-418.

Weiss AR, Johnson NL, Berger NA, et al. (2010) Validity of activity-based devices to estimate sleep. *Journal of clinical sleep medicine: JCSM: official publication of the American Academy of Sleep Medicine* 6: 336.

Werner H, Molinari L, Guyer C, et al. (2008) Agreement rates between actigraphy, diary, and questionnaire for children's sleep patterns. *Archives of pediatrics & adolescent medicine* 162: 350-358.

West BT, Welch KB and Galecki AT. (2014) *Linear mixed models: a practical guide using statistical software*: CRC Press.

Wolfson AR and Carskadon MA. (2003) Understanding adolescent's sleep patterns and school performance: a critical appraisal. *Sleep Medicine Reviews* 7: 491-506.

Youngstedt SD. (2005) Effects of exercise on sleep. *Clinics In Sports Medicine* 24: 355.

Youngstedt SD and O'Connor PJ. (1999) The influence of air travel on athletic performance. *Sports Medicine (Auckland, N.Z.)* 28: 197-207.

Zainuddin Z, Sacco P, Newton M, et al. (2006) Light concentric exercise has a temporarily analgesic effect on delayed-onset muscle soreness, but no effect on recovery from eccentric exercise. *Applied Physiology, Nutrition, and Metabolism* 31: 126-134.

Zech A, Witte K and Pfeifer K. (2008) Reliability and performance-dependent variations of muscle function variables during isometric knee extension. *Journal of Electromyography and Kinesiology* 18: 262-269.

Zhong X, Hilton HJ, Gates GJ, et al. (2005) Increased sympathetic and decreased parasympathetic cardiovascular modulation in normal humans with acute sleep deprivation. *J Appl Physiol (1985)* 98: 2024-2032.

APPENDICES

Appendix 1 – Pre-Participation Questionnaire

ADULT PRE-EXERCISE SCREENING TOOL

This screening tool does not provide advice on a particular matter, nor does it substitute for advice from an appropriately qualified medical professional. No warranty of safety should result from its use. The screening system in no way guarantees against injury or death. No responsibility or liability whatsoever can be accepted by Exercise and Sports Science Australia, Fitness Australia or Sports Medicine Australia for any loss, damage or injury that may arise from any person acting on any statement or information contained in this tool.

Name:____

Date of Birth:____________________ Male ☐ Female ☐ Date: ____________________

STAGE 1 (COMPULSORY)

AIM: to identify those individuals with a known disease, or signs or symptoms of disease, who may be at a higher risk of an adverse event during physical activity/exercise. This stage is self administered and self evaluated.

Please circle response

1.	Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke?	Yes	No
2.	Do you ever experience unexplained pains in your chest at rest or during physical activity/exercise?	Yes	No
3.	Do you ever feel faint or have spells of dizziness during physical activity/exercise that causes you to lose balance?	Yes	No
4.	Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months?	Yes	No
5.	If you have diabetes (type I or type II) have you had trouble controlling your blood glucose in the last 3 months?	Yes	No
6.	Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise?	Yes	No
7.	Do you have any other medical condition(s) that may make it dangerous for you to participate in physical activity/exercise?	Yes	No

IF YOU ANSWERED 'YES' to any of the 7 questions, please seek guidance from your GP or appropriate allied health professional prior to undertaking physical activity/exercise

IF YOU ANSWERED 'NO' to all of the 7 questions, and you have no other concerns about your health, you may proceed to undertake light-moderate intensity physical activity/exercise

I believe that to the best of my knowledge, all of the information I have supplied within this tool is correct.

Signature ______________________________ Date ____________________

EXERCISE INTENSITY GUIDELINES

INTENSITY CATEGORY	HEART RATE MEASURES	PERCEIVED EXERTION MEASURES	DESCRIPTIVE MEASURES
SEDENTARY	< 40% HRmax	Very, very light RPE# < 1	• Activities that usually involve sitting or lying and that have little additional movement and a low energy requirement
LIGHT	40 to <55% HRmax	Very light to light RPE# 1-2	• An aerobic activity that does not cause a noticeable change in breathing rate • An intensity that can be sustained for at least 60 minutes
MODERATE	55 to <70% HRmax	Moderate to somewhat hard RPE# 3-4	• An aerobic activity that is able to be conducted whilst maintaining a conversation uninterrupted • An intensity that may last between 30 and 60 minutes
VIGOROUS	70 to <90% HRmax	Hard RPE# 5-6	• An aerobic activity in which a conversation generally cannot be maintained uninterrupted • An intensity that may last up to about 30 minutes
HIGH	≥ 90% HRmax	Very hard RPE# ≥ 7	• An intensity that generally cannot be sustained for longer than about 10 minutes

= Borg's Rating of Perceived Exertion (RPE) scale, category scale 0-10

ADULT PRE-EXERCISE SCREENING TOOL

STAGE 2 (OPTIONAL)

Name:____

Date of Birth:____________________ Date: ____________________

AIM: To identify those individuals with risk factors or other conditions to assist with appropriate exercise prescription. This stage is to be administered by a qualified exercise professional.

Question		RISK FACTORS
1. Age Gender	≥ 45yrs Males or ≥ 55yrs Females +1 risk factor	
2. Family history of heart disease (eg: stroke, heart attack) Relative / Age / Relative / Age ☐ Father ___ ☐ Mother ___ ☐ Brother ___ ☐ Sister ___ ☐ Son ___ ☐ Daughter ___	If male < 55yrs = +1 risk factor If female < 65yrs = +1 risk factor Maximum of 1 risk factor for this question	
3. Do you smoke cigarettes on a daily or weekly basis or have you quit smoking in the last 6 months? Yes No If currently smoking, how many per day or week?	If yes, (smoke regularly or given up within the past 6 months) = +1 risk factor	
4. Describe your current physical activity/exercise levels: Sedentary ☐ Light ☐ Moderate ☐ Vigorous ☐ Frequency (sessions per week): Light ___ Moderate ___ Vigorous ___ Duration (minutes per week): Light ___ Moderate ___ Vigorous ___	If physical activity level < 150 min/ week = +1 risk factor If physical activity level ≥ 150 min/ week = -1 risk factor (vigorous physical activity/ exercise weighted x 2)	
5. Please state your height (cm) weight (kg)	BMI = ________ BMI ≥ 30 kg/m² = +1 risk factor	
6. Have you been told that you have high blood pressure? Yes No	If yes, = +1 risk factor	
7. Have you been told that you have high cholesterol? Yes No	If yes, = +1 risk factor	
8. Have you been told that you have high blood sugar? Yes No	If yes, = +1 risk factor	

Note: Refer over page for risk stratification.

STAGE 2 Total Risk Factors =

9. Have you spent time in hospital (including day admission) for any medical condition/illness/injury during the last 12 months? Yes No	If yes, provide details
10. Are you currently taking a prescribed medication(s) for any medical conditions(s)? Yes No	If yes, what is the medical condition(s)?
11. Are you pregnant or have you given birth within the last 12 months? Yes No	If yes, provide details. I am ____ months pregnant or postnatal (circle).
12. Do you have any muscle, bone or joint pain or soreness that is made worse by particular types of activity? Yes No	If yes, provide details

STAGE 3 (OPTIONAL)

AIM: To obtain pre-exercise baseline measurements of other recognised cardiovascular and metabolic risk factors. This stage is to be administered by a qualified exercise professional. (Measures 1, 2 & 3 – minimum qualification, Certificate III in Fitness; Measures 4 and 5 minimum level, Exercise Physiologist*).

	RESULTS		RISK FACTORS
1. BMI (kg/m^2)		BMI ≥ 30 kg/m^2 = +1 risk factor	
2. Waist girth (cm)		Waist > 94 cm for men and > 80 cm for women = +1 risk factor	
3. Resting BP (mmHg)		SBP ≥140 mmHg or DBP ≥90 mmHg = +1 risk factor	
4. Fasting lipid profile*		Total cholesterol ≥ 5.20 mmol/L = +1 risk factor	
Total cholesterol		HDL cholesterol >1.55 mmol/L = -1 risk factor	
HDL		HDL cholesterol < 1.00 mmol/L = +1 risk factor	
Triglycerides		Triglycerides ≥ 1.70 mmol/L = +1 risk factor	
LDL		LDL cholesterol ≥ 3.40 mmol/L = +1 risk factor	
5 Fasting blood glucose*		Fasting glucose ≥ 5.50 mmol = +1 risk factor	
		STAGE 3 Total Risk Factors =	

RISK STRATIFICATION

Total stage 2
or
Total stage 3
Plus stage 2 (Q1 - Q4)

≥ 2 RISK FACTORS – MODERATE RISK CLIENTS

Individuals at moderate risk may participate in aerobic physical activity/exercise at a light or moderate intensity (Refer to the exercise intensity table on page 2)

< 2 RISK FACTORS – LOW RISK CLIENTS

Individuals at low risk may participate in aerobic physical activity/exercise up to a vigorous or high intensity (Refer to the exercise intensity table on page 2)

Note: If stage 3 is completed, identified risk factors from stage 2 (Q1-4) and stage 3 should be combined to indicate risk. If there are extreme or multiple risk factors, the exercise professional should use professional judgement to decide whether further medical advice is required.

Appendix 2 – Sleep Diary

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Participant

Sleep Diary

Name:

Date:

Monitor ID:

If you have any questions whatsoever, please do not hesitate to contact me either by phone or email:

Nathan Pitchford
Mobile: 0488 992 431
Email: nathan.pitchford@live.vu.edu.au

Personal Details

D.O.B: ___/___/___ Age: ________ yr

Height: _______ cm Weight: ________ kg

Sleep History

How many hours of sleep do you need to feel rested?

______ hours

How satisfied are you with the amount of sleep you get?

Very dissatisfied 1 2 3 4 5 6 7 8 9 10 *Very Satisfied*

Overall, how would you rate the quality of your sleep?

☐ very poor ☐ poor ☐ fair ☐ good ☐ very good ☐ excellent

Epworth Sleepiness Scale

How likely are you to doze off or fall asleep in the following situations?
0 = Would never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

Sitting and reading	____________
Watching TV	____________
Sitting, inactive in a public place (e.g. cinema or meeting)	____________
As a passenger in a car for an hour without a break	____________
Lying down to rest in the afternoon when possible	____________
Sitting and talking to someone	____________
Sitting quietly after lunch not having had alcohol	____________
In a car when you stop at traffic for a few minutes	____________

Participant Instructions

Thank you for participating in this study. The lessons we learn about your sleep patterns during this study could help to devise strategies to **maximise your recovery and performance.** To enable us to monitor your sleep, you will need to:

(i) wear an activity monitor

(ii) keep a sleep diary

The watch must be worn each day and night for the duration of the monitoring period.

What is an Activity Monitor?

An Activity Monitor is a small device worn like a wristwatch that continuously records body movement. It is a device that can be used to provide information about the amount and quality of your sleep.

- It is best if you wear your Activity Monitor **at all times.**
- The Activity Monitor is water resistant **but not waterproof** – The Activity Monitor can be worn in the rain, but **not in the shower or pool.**
- It is important that you always wear the Activity Monitor on your **non dominant hand.**
- Please take care of your Activity Monitor – **replacement value = $1800.**

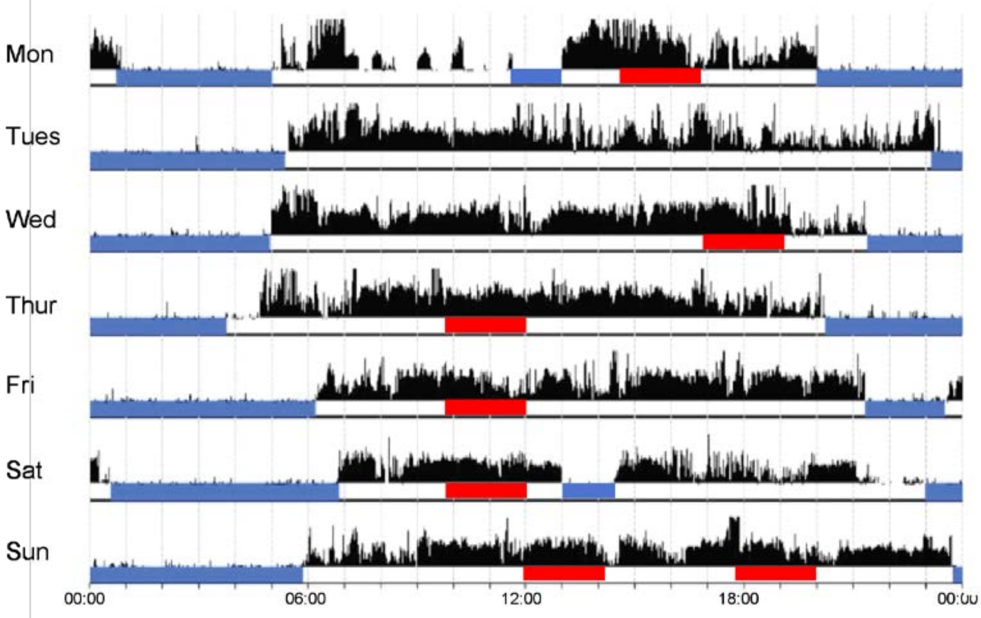
Keeping a Sleep Diary

In this booklet, you will find your sleep diary. The purpose of the diary is to record the times when you are attempting to sleep. This information will be used in conjunction with data from the activity monitor to determine when you fell asleep and woke up.

Instructions

1. Complete a single line of the diary for every sleep period. Use extra lines for naps if needed.
2. Date – the date that you go to bed.
3. Time of Last Caffeine Intake - Record the time of your last caffeine intake (coffee, red bull, coke, etc)
4. Pre-Sleep Arousal Level – Record your arousal level **prior to** sleep.
5. Bed Time – the time that you start attempting to sleep. Don't include time spent reading, watching TV.
6. Get Up Time – the time that you stop attempting to sleep. Don't include time spent reading, watching TV, etc.
7. Sleep Quality – the quality of your sleep compared to a 'normal' sleep period.
8. Please complete the diary straight after every sleep period to aid accuracy. This will have a big influence on the quality of the data that we collect.

What will your data look like?



This figure shows an example of the type of data that you will collect:

- The figure represents 7 days of data.
- Each line represents a day of data, from midnight to midnight.
- The **red** horizontal bars represent training times we will get from your coaches.
- The **blue** horizontal bars represent bed times we will get from your diary.
- The **black** vertical bars represent the level of activity we will get from your activity monitor.
- By combining the information from your sleep diary and activity monitor, we will use special software to determine (i) what time you went to sleep, (ii) what time you woke up, (iii) how much sleep you got, and (iv) how good or bad your sleep was.
- At the end of the sleep audit, you will get a report about your sleep/wake patterns that will include a figure like the one above.

Sleep Diary

Date	Sleep Location	Caffeine Intake Amount & Time	Did you use electronic devices (TV etc) before bed? Yes/No & Duration	Pre-Sleep Arousal Circle	Pre-Sleep Anxiety How anxious are you about tomorrow's events? Circle	Bed Time hh:mm	Get-up Time hh:mm	Sleep Quality Circle	Last night what disturbed your sleep? List (heat, noise, thoughts, restless, anxiety, etc.)
16/11	Hotel	2 cups (4pm & 8pm)	Yes – 20 min	very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all	22:30	06:30	very good | good | average | poor | very poor	Couldn't sleep due to noise from the road.
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	

Instructions

1. Complete a single line of the diary for every sleep period or training session. Use extra lines for naps and additional training sessions if needed.
2. Time of Last Caffeine Intake - Record the time of your last caffeine intake (coffee, red bull, coke, etc)
3. Pre-Sleep Arousal Level – Record your arousal level prior to sleep.
4. Pre-Sleep Anxiety Level – Record how anxious you feel prior to sleep.
5. Bed Time – the time that you start attempting to sleep. Don't include time spent reading, watching TV.
6. Get Up Time – the time that you stop attempting to sleep. Don't include time spent reading, watching TV, etc.
7. Sleep Quality – the quality of your sleep compared to a 'normal' sleep period.
8. Sleep Disruptions – record if anything kept you awake or caused you to awaken throughout the night.
9. Please complete the diary straight after every sleep period to aid accuracy. This will have a big influence on the quality of the data that we collect.

Sleep Diary

Date	**Sleep Location**	**Caffeine Intake** Amount & Time	**Did you use electronic devices (TV etc) before bed?** Yes/No & Duration	**Pre-Sleep Arousal** Circle	**Pre-Sleep Anxiety** How anxious are you about tomorrow's events? Circle	**Bed Time** hh:mm	**Get-up Time** hh:mm	**Sleep Quality** Circle	**Last night what disturbed your sleep?** List (heat, noise, thoughts, restless, anxiety, etc.)
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	
				very high | high | moderate | low | none	extremely | quite a bit | moderately | a little | not at all			very good | good | average | poor | very poor	

Instructions

1. Complete a single line of the diary for every sleep period or training session. Use extra lines for naps and additional training sessions if needed.
2. Time of Last Caffeine Intake - Record the time of your last caffeine intake (coffee, red bull, coke, etc)
3. Pre-Sleep Arousal Level – Record your arousal level prior to sleep.
4. Pre-Sleep Anxiety Level – Record how anxious you feel prior to sleep.
5. Bed Time – the time that you start attempting to sleep. Don't include time spent reading, watching TV.
6. Get Up Time – the time that you stop attempting to sleep. Don't include time spent reading, watching TV, etc.
7. Sleep Quality – the quality of your sleep compared to a 'normal' sleep period.
8. Sleep Disruptions – record if anything kept you awake or caused you to awaken throughout the night.
9. Please complete the diary straight after every sleep period to aid accuracy. This will have a big influence on the quality of the data that we collect.

Appendix 3 – Morningness-Eveningness Questionnaire

VICTORIA UNIVERSITY
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Morning-Evening Questionnaire

Name: ______________________________

Date: ___/___/___

If you have any questions whatsoever, please do not hesitate to contact me either by phone or email:

Nathan Pitchford

Mobile: 0488 992 431

Email: nathan.pitchford@live.vu.edu.au

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

MORNINGNESS-EVENINGNESS QUESTIONNAIRE

Self-Assessment Version

For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.

A. *Approximately* what time would you get up if you were entirely free to plan your day?

[5] 5:00 AM – 6:30 AM
[4] 6:30 AM – 7:45 AM
[3] 7:45 AM – 9:45 AM
[2] 9:45 AM – 11:00 AM
[1] 11:00 AM – 12 NOON

B. *Approximately* what time would you go to bed if you were entirely free to plan your evening?

[5] 8:00 PM – 9:00 PM
[4] 9:00 PM – 10:15 PM
[3] 10:15 PM – 12:30 AM
[2] 12:30 AM – 1:45 AM
[1] 1:45 AM – 3:00 AM

C. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

[4] Not at all
[3] Slightly
[2] Somewhat
[1] Very much

D. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?

[1] Very difficult
[2] Somewhat difficult
[3] Fairly easy
[4] Very easy

E. How alert do you feel during the first half hour after you wake up in the morning?

[1] Not at all alert
[2] Slightly alert
[3] Fairly alert
[4] Very alert

F. How hungry do you feel during the first half hour after you wake up?

[1] Not at all hungry
[2] Slightly hungry
[3] Fairly hungry
[4] Very hungry

G. During the first half hour after you wake up in the morning, how do you feel?

[1] Very tired
[2] Fairly tired
[3] Fairly refreshed
[4] Very refreshed

H. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

[4] Seldom or never later
[3] Less than 1 hour later
[2] 1-2 hours later
[1] More than 2 hours later

I. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 AM. Bearing in mind nothing but your own internal “clock,” how do you think you would perform?

[4] Would be in good form
[3] Would be in reasonable form
[2] Would find it difficult
[1] Would find it very difficult

J. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

[5] 8:00 PM – 9:00 PM
[4] 9:00 PM – 10:15 PM
[3] 10:15 PM – 12:45 AM
[2] 12:45 AM – 2:00 AM
[1] 2:00 AM – 3:00 AM

K. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock," which one of the four testing times would you choose?

[6] 8 AM –10 AM
[4] 11 AM – 1 PM
[2] 3 PM – 5 PM
[0] 7 PM – 9 PM

L. If you got into bed at 11 PM, how tired would you be?

[0] Not at all tired
[2] A little tired
[3] Fairly tired
[5] Very tired

M. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

[4] Will wake up at usual time, but will not fall back asleep
[3] Will wake up at usual time and will doze thereafter
[2] Will wake up at usual time, but will fall asleep again
[1] Will not wake up until later than usual

N. One night you have to remain awake between 4-6 AM in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

[1] Would not go to bed until the watch is over
[2] Would take a nap before and sleep after
[3] Would take a good sleep before and nap after
[4] Would sleep only before the watch

O. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which of the following times would you choose?

[4] 8 AM – 10 AM
[3] 11 AM – 1 PM
[2] 3 PM – 5 PM
[1] 7 PM – 9 PM

P. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 PM. Bearing in mind only your internal "clock," how well do you think you would perform?

[1] Would be in good form
[2] Would be in reasonable form
[3] Would find it difficult
[4] Would find it very difficult

Q. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At *approximately* what time would you choose to begin?

[5] 5 hours starting between 4 AM – 8 AM
[4] 5 hours starting between 8 AM – 9 AM
[3] 5 hours starting between 9 AM – 2 PM
[2] 5 hours starting between 2 PM – 5 PM
[1] 5 hours starting between 5 PM – 4 AM

R. At *approximately* what time of day do you usually feel your best?

[5] 5 AM – 8 AM
[4] 8 AM – 10 AM
[3] 10 AM – 5 PM
[2] 5 PM – 10 PM
[1] 10 PM – 5 AM

S. One hears about “morning types” and “evening types.” Which one of these types do you consider yourself to be?

[6] Definitely a morning type
[4] Rather more a morning type than an evening type
[2] Rather more an evening type than a morning type
[1] Definitely an evening type

_____Total points for all 19 questions

Appendix 4 – Profile of Mood States Questionnaire

Profile of Mood States

Questionnaire

Name:

Date: ___/___/___

If you have any questions whatsoever, please do not hesitate to contact me either by phone or email:

Nathan Pitchford
Mobile: 0488 992 431
Email: nathan.pitchford@live.vu.edu.au

Instructions

1. Answer all of these questions as accurately as possible.
2. Provide responses based on ***how you have been feeling in the past 7 days***, including today.

Descriptive Word	Not at all	A Little	Moderately	Quite a Bit	Extremely	Descriptive Word	Not at all	A Little	Moderately	Quite a Bit	Extremely
Friendly						Nervous					
Tense						Lonely					
Angry						Miserable					
Worn out						Muddled					
Unhappy						Cheerful					
Clear headed						Bitter					
Lively						Exhausted					
Confused						Anxious					
Sorry for things done						Ready to fight					
Shaky						Good natured					
Listless						Gloomy					
Peeved						Desperate					
Considerate						Sluggish					
Sad						Rebellious					
Active						Helpless					
On edge						Weary					
Grouchy						Bewildered					
Blue						Alert					
Energetic						Deceived					
Panicky						Furious					
Hopeless						Efficient					
Relaxed						Trusting					
Unworthy						Full of pep					
Spiteful						Bad Tempered					
Sympathetic						Worthless					
Uneasy						Forgetful					
Restless						Carefree					
Unable to concentrate						Terrified					
Fatigued						Guilty					
Helpful						Vigorous					
Annoyed						Uncertain about things					
Discouraged						Bushed					
Resentful											

Adapted from McNair DM, Lorr M, Droppleman LF. *Manual for the profile of mood states. Educational and Industrial Testing Service*; 1971.

Appendix 5 – Laboratory-Study Wellness Questionnaire

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MELBOURNE AUSTRALIA

Daily Wellness Questionnaire

Name:______________________ Date: ___/___/___

	5	4	3	2	1	TOTAL
Fatigue	Very Fresh	Fresh	Normal	More Tired Than Normal	Always Tired	
Sleep Quality	Very Restful	Good	Difficulty Falling Asleep	Restless Sleep	Insomnia	
General Muscle Soreness	Feeling Great	Feeling Good	Normal	Increase In Soreness/Tightness	Very Sore	
Stress Levels	Very Relaxed	Relaxed	Normal	Feeling Stressed	Highly Stressed	
Mood	Very Positive Mood	A Generally Good Mood	Less Interested in others/activities than normal	Snappiness at Team-mates, Family and Co-workers	Highly Annoyed/Irritable/ Down	

Adapted from: McLean BD, Coutts AJ, Kelly V, et al. (2010) Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. International Journal Of Sports Physiology And Performance 5: 367-383.

If you have any questions whatsoever, please do not hesitate to contact me either by phone or email:

Nathan Pitchford
Mobile: 0488 992 431
Email: nathan.pitchford@live.vu.edu.au

Appendix 6 – Pitchford NW, Robertson SJ, Sargent C, Cordy J, Bishop D & Bartlett JD (2017). "A Change in Training Environment Alters Sleep Quality but not Quantity in Elite Australian Rules Football Players." International Journal of Sports Physiology and Performance 12: 75-80.

Section: Original Investigation

Article Title: A Change in Training Environment Alters Sleep Quality But Not Quantity in Elite Australian Rules Football Players

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Journal: *International Journal of Sports Physiology and Performance*

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Original Investigation

A change in training environment alters sleep quality but not quantity in elite Australian Rules football players.

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Running Head:

Training and sleep in Australian Rules football

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Abstract

Purpose: To assess the effects of a change in training environment on the sleep characteristics of elite Australian Rules football players. **Methods**: In an observational crossover trial, 19 elite Australian Rules football players had time in bed (TIB), total sleep time (TST), sleep efficiency (SE) and wake after sleep onset (WASO) assessed using wrist-watch activity devices and subjective sleep diaries across 8-day Home and Camp periods. Repeated measures ANOVA determined mean differences in sleep, training load (s-RPE) and environment. Pearson’s product moment correlations, controlling for repeated observations on individuals, were used to assess the relationship between changes in sleep characteristics at Home and Camp. Cohen’s effect sizes (*d*) were calculated using individual means. **Results**: On Camp TIB (+34 min) and WASO (+26 min) increased compared to Home. However, TST was similar between Home and Camp, significantly reducing Camp SE (-5.82%). Individually, there were strong negative correlations for TIB and WASO (r = -0.75 and r = -0.72, respectively) and a moderate negative correlation for SE (r = -0.46) between Home and relative changes on Camp. Camp increased the relationship between individual s-RPE variation and TST variation compared to Home (Increased-load; r = -0.367 vs 0.051, Reduced-load; r = 0.319 vs -0.033, Camp vs Home respectively). **Conclusions**: Camp compromised sleep quality due to significantly increased TIB without increased TST. Individually, Australian Rules football players with higher Home SE experienced greater reductions in SE on Camp. Together, this emphasises the importance of individualised interventions for elite team-sport athletes when travelling and/or changing environments.

Key Words: Sleep, team sports, travel, athletes, actigraphy.

Introduction

Australian Rules football (AF) clubs commonly undertake pre-season training camps to improve team cohesion and morale, and to maximise training adaptations using specific training methods[1]. However, camps also often require athletes to travel and sleep in unfamiliar environments, which may negatively impact sleep[2,3]. Sleep is widely considered to be a major contributor to athletic recovery[4] and performance[5], with evidence indicating that sleep disruption negatively affects psychological and physiological performance measures[6,7]. Investigating the influence of changing the training environment on the sleep of elite AF players may aid in the design of training interventions that minimise the potentially negative influences of poor sleep and recovery to maximise training adaptations.

Training camps often combine changes in the training environment with additional environmental stressors, such as altitude or heat[8,9]. In isolation, altitude and heat exposure have been shown to negatively influence objective measures of sleep quantity and quality[10,11]. However, the impact of changing training environment alone, such as during a training camp, on sleep quantity and quality is unknown. Changes in sleep location may disrupt sleep[2], with ~28% of athletes from a German sample reporting unusual surroundings as disruptive to sleep on the night prior to competition[3]. AF players also regularly travel interstate for pre-season camps and during the in-season period, resulting in reduced sleep durations when away from home on the night pre-game[12].

Another important consideration is the effect of increased training load on sleep. For example, Killer et al.[13] reported disturbed sleep and mood state during a period of intensified training, while Kolling et al.[14] reported less restful sleep in the first half of a 4-week training camp in elite youth rowers. Indeed, poor or disrupted sleep may negatively influence training adaptations and the efficacy of training interventions, an unfavourable situation for elite team-sport athletes. Given this, further research is required to uncover the influence of changing training and sleep location on quality and quantity of sleep during periods of high-training load.

The aim of the current study was to assess the effects of a change in physical sleeping environment on objective and subjective measures of sleep quality and quantity in elite Australian Rules footballers during a training camp in the pre-season training phase.

Methods

Nineteen professional AF players from the same Australian Football League club (age; 22.1 ± 3.5 y, height; 185.4 ± 7.6 cm, mass; 83.3 ± 7.8 kg) participated in this study. Participants were free from musculoskeletal injury and illness prior to participating in the study, and no injuries occurred during the data collection periods. Full informed consent was provided by participants and the research was approved by the University Human Research Ethics Committee and followed guidelines from the Declaration of Helsinki.

Sleep was assessed using wrist-watch activity devices across an 8-day Home and 8-day Camp period. Actiwatch 2 (Actiwatch 2, Philips Respironics, PA, USA) and Actigraph wGTX3 (Actigraph wGTX3 monitor, Actigraph, FL, USA) devices were used interchangeably during the Home period and, as such, cross-device validity was assessed prior to measurement. Six participants from a separate sample wore both wrist-worn activity devices and completed subjective sleep diaries on each morning for 3 consecutive nights in the home environment. Concurrent validity of the devices was assessed using Pearson correlation coefficients and typical error of estimate (TEE)[15]. Sleep efficiency (SE, r = 0.92, TEE = 2.1%), time in bed (TIB, r = 0.97, TEE = 2.9%), total sleep time (TST, r = 0.91, TEE = 6.2%) and wake after sleep onset (WASO, r = 0.96, TEE = 21.1%) demonstrated strong validity between devices. As such, these four objective measures were deemed suitable to determine sleep quantity (TIB, TST) and sleep quality (SE, WASO) for the current study.

Sleep onset latency (SOL) was deemed not reliable (r = 0.41, TEE = 57%) and so was not used in the study.

During both the Home and Camp periods, participants completed 5 ± 1 training-days and 3 ± 1 recovery-days. Both the Home (December 2014, n = 8, Actiwatch 2; or January 2015, n = 11, Actigraph wGTX3) and Camp (January-February 2015, n = 19, Actigraph wGTX3) periods took place during the pre-season training phase and followed similar time-of-day training schedules. Home training occurred at the club’s training facility in Melbourne, Australia (Latitude 37°S, Longitude 144°E), with participants sleeping in their normal home-based sleeping environment (in their own beds); they were not grouped or paired with other participants. The Camp occurred at the Sunshine Coast, Australia (Latitude 27°S, Longitude 153°E), with participants sleeping in a 4-Star hotel with access to air conditioning and comfortable bedding. On Camp, participants chose who to room with and were subsequently placed in a shared living environment with another participant. Training time was similar between Home and Camp (commencing between 9.30-10.00 am), and participants did not experience competition, transmeridian travel or a change in altitude, leaving location as the difference between Home and Camp environments. Daytime training environmental conditions for Home (23.6 ± 4.4°C, 66.5 ± 3.2% RH) and Camp (29.0 ± 1.8°C, 67.8 ± 6.5% RH) were retrospectively obtained via Australia’s Bureau of Meteorology (www.bom.gov.au). Overnight room temperature at both locations ranged between 18-22 °C and was kept constant through the use of air conditioning at the discretion of participants.

Subjective sleep diaries to collect bed time, wake time and a subjective sleep quality rating were utilised daily. Based on recommendations by Hooper and Mackinnon[16], a custom-designed daily subjective wellness questionnaire, where athletes subjectively rated measures of fatigue, stress, muscle soreness, sleep quality and mood on a 1-10 scale (1 being worst possible, 10 being best possible), was completed each morning prior to daily training activities. Training sessions were designed and implemented by coaching staff, with training load assessed using the session-RPE (s-RPE) method (Borgs CR-10 scale) - a valid measure of training load in team sports[17]. Participants undertook prescribed post-training, team-based recovery sessions on planned recovery days, consisting of cold-water immersion, stretching, self-myofascial release and hydrotherapy.

Repeated-measures ANOVA were used to analyse differences in objective sleep measures (TIB, TST, SE (TST ÷ TIB x 100) and WASO), s-RPE training load, temperature, relative humidity and subjective wellness between Home and Camp. One-way ANOVA was used to screen sleep onset and wake times for differences in sleep behaviour. The summation of fatigue, muscle soreness, stress, mood and sleep quality scores from the subjective wellness questionnaire represented total wellness, which has previously been used to track the response to competition in team-sport athletes[18]. Statistical significance was set to p = 0.6 via Bonferroni correction. Pearson correlation coefficients, controlling for repeated observations on players, were used to assess the relationship between sleep characteristics and s-RPE training load, relative Camp sleep characteristics (expressed as absolute change from individual environment mean), and absolute change in s-RPE training load from the individual environment mean. Cohen's effect sizes (d) were calculated using player mean values between Home and Camp (<0.2 = very small effect, 0.2-0.5 = small effect, 0.5-0.8 = moderate effect, >0.8 = large effect).

Results

Descriptive statistics for sleep characteristics and training-related parameters between Home and Camp are compared in Table 1. One-way ANOVA showed that sleep onset (p <0.001) and wake times (p = 0.003) were significantly earlier on Camp compared to Home (Table 1). Repeated measures ANOVA revealed that TIB (p <0.001) and WASO (p <0.001) were significantly increased on Camp compared to Home. However, there was no significant change in TST (p = 0.846), resulting in a significant decrease in SE (p <0.001) on Camp. Repeated measures ANOVA also showed that mean daily s-RPE training load (p = 0.398) and total player wellness (p = 0.023) were not significantly different on Camp compared to Home. Although training temperature (p <0.001) during Camp was significantly hotter than Home, relative humidity (p = 0.277) did not differ (Table 1). Despite the observed changes in objective sleep measures, there was no difference between Home and Camp for subjective ratings of sleep quality (Table 1).

Effect size calculations between grouped player mean values revealed a moderate effect of change in physical sleep environment on sleep onset (*d* = -0.47), a small effect on wake times (*d* = -0.36), large effects on TIB (*d* = 1.21), SE (*d* = -0.93) and WASO (*d* = 0.87), and only a very small effect on TST (*d* = -0.07). Effect size calculations also revealed a very small effect of a change in training environment on s-RPE training load (*d* = 0.10), a small effect on total player wellness (*d* = -0.36), a large effect on daytime training temperatures (*d* = 1.63), and only a very small effect on daytime training humidity (*d* = 0.13).

When analysing individualised responses to a change in physical sleep environment, relative changes in TIB (*r* = -0.75, p <0.001) and WASO (*r* = -0.72, p <0.001) on Camp had a strong negative correlation with absolute Home values (Figure 1). When accounting for daily variations of within-player training load, changes in s-RPE training load had weak correlations with changes in TST in the Home environment for both increased (*r* = 0.051, p = 0.74) and decreased s-RPE training load (*r* = -0.033, p = 0.74). Comparatively, in the Camp environment, changes in s-RPE training load displayed a moderate negative correlation with changes in TST for increased load (*r* = -0.367, p = 0.010) and a moderate positive correlation for decreased load (*r* = 0.319, p = 0.003) (Figure 2).

Discussion

The aim of the current study was to determine the effect of changing physical sleep environment on objective sleep quality and quantity in elite AF players during the pre-season training period. This study found that during Camp players spent longer in bed, as a result of earlier sleep onset times that were not matched by equal alterations in wake times, and exhibited more WASO, resulting in lower SE compared to Home. Further, players who spent less TIB at Home increased TIB to a greater extent on Camp compared to those who spent longer in bed at Home. Whilst these results are independent of mean daily training load, when changes in the individual daily training load are accounted for, alterations in daily training load on Camp resulted in greater changes in TST compared to Home. Together, these results have relevance for practitioners in highlighting the need for individualised sleep strategies so as to overcome the negative effects of changes in sleep environment.

This is the first study to observe a negative effect of changing sleep environment on sleep quality during periods of similar training loads in team-sport athletes. We found that athletes with higher sleep quality at Home were worse sleepers at Camp, whereas those that slept poorer at Home slept similarly on Camp. Sleep quality in athletes can be affected by numerous factors, such as travel[19], competition[20] and training load[21]. Further, Lastella et al.[22] have shown that increased daily competition load in cyclists, significantly reduces TIB and TST, without changes in subjective or objective sleep quality. The current study showed that a change from Home to Camp, where participants stayed in a hotel and roomed with a teammate, negatively impacted sleep quality, despite no difference in mean training load. Whilst poor sleep can result from changes in training load[13,21], these changes have predominantly been assessed on a global scale, without consideration for an individual's daily variation in load and sleep. Indeed, when accounting for variations in daily training load, this study found that when there is a change in sleep location, total sleep time responds in a different manner. For example, on Camp, as the change in daily training load varied further from the mean training load for each individual, there was a reduction in TST (Figure 2). Although these results appear consistent with previous research[21,23], it unclear as to the reason for this and so further research is required to determine the longer term effect on training adaptation.

Studies investigating changes in physical sleeping environment have focussed on situations where participants travel across multiple time-zones, creating a circadian dysrhythmia and reduced sleep quality[24]. Although the current study involved travel, it was in a Northerly direction during the day, without crossing time-zones and without impacting on participants’ sleep opportunities. Furthermore, camp situations are often accompanied by altered daily schedules, as a result of commitments outside of training, which may impact on sleep behaviour. Although sleep onset and wake times were earlier on Camp in the present study, this did not appear to be a result of altered daily schedules as there was no change between Home and Camp. However, it should be noted that due to the change in latitude, there is a small change in daylight savings, with earlier sunrise and sunset on Camp. Hence, it should not be discounted that the earlier sunset influenced the choice of bedtime each night.

Previous work involving changes in physical sleeping environment have examined tournament-type competition[20] or regular/weekly competition[12] and compared sleep during periods of competition in a different physical environment to sleep during periods of training at home[22,25]. Lastella et al.[25] found that ~68% of athletes report poorer sleep quality on nights prior to competition and that this is often related to feelings of anxiety, fatigue, mood, tension and vigour. Although no competition occurred in the Camp environment, athletes in the current study spent significantly longer in bed, without the benefits of increased sleep time. Indeed, WASO was ~30 min higher on Camp, and, therefore, may explain the difference in TIB between Home and Camp (~34 min). However, due to the very high TEE (57%) between activity devices for sleep onset latency (SOL) measurements, this study is limited in its application of this measure. In this regard, this should be seen as limitation of the current results. Nevertheless, future work should aim to identify the behavioural changes that are associated with changes in sleep behaviour.

The consideration of non-training related factors relevant to the physical environment are also important. Ambient environmental temperature can negatively impact sleep, with exposure to heat before and during the sleep period reducing TST and increasing night-time awakenings[26]. The present study showed significantly higher day-time temperatures on Camp compared to Home, corresponding with increased WASO and reduced SE, but no change in TST. However, the temperature difference between Home and Camp in the present study was much less than in previous literature and did not reach temperatures commonly used in studies of heat exposure and sleep[10,26]. Further, night-time temperatures in this study were athlete-controlled (18-22°C) through the use of air conditioning, thus inkeeping with recent sleep hygiene recommendations for athletic populations[27]. Although it cannot be entirely ruled out that the elevated daytime temperature on Camp influenced sleep in the present study, this does not explain the increased TIB and the lack of overnight heat being reported as a reason for disrupted sleep from the subjective sleep diaries. In addition, it is difficult to say whether air conditioning had any impact on WASO. Thus future research should examine the impact of both air conditioning and ambient overnight temperature on sleep. It is important to note that it is a possibility that the change in sleep behaviour may be driven by a conscious process of respecting their team-mates space and noise, as all participants in the present study shared rooms with another participant during the Camp period only. The degree and variation in the consideration of fellow participants may also vary depending on the individual relationships and habits of room-sharing participants and therefore should be considered in the interpretation of findings. Despite the need for individualised approaches so as to promote optimal sleep opportunities, the individualised nature of responses to changes in the physical sleep environment requires greater investigation. Together, this may have implications in the provision of sleep interventions and sleep hygiene recommendations.

In the current study we observed that those with higher Home SE experienced a greater decline in SE during Camp. Hence, it is important that individually tailored sleep interventions are implemented so as to maximise TST. For instance, if participants in the current study maintained Home SE of 84.7% whilst on Camp, TST as a result of increased TIB would have been extended by 29 min. Indeed, sleep extension in basketball players improved sprint time, free throw accuracy, reaction time and ratings of physical and mental wellbeing[28]. Theoretically, maximising TST and therefore recovery during a period of high training stress may accentuate training adaptations and aid in reducing the risk of injury[29]. However, given the lack of evidence on sleep extension in athletes, future research should aim to uncover the smallest worthwhile increase in sleep so as to improve training and/or competition performance.

Conclusion

A change in physical sleep environment, without external influences such as circadian phase-shifting, altered training schedules or increased total training load reduces the quality of sleep and effects the attainment of increased duration of sleep, despite spending longer periods of time in bed. This may have further flow-on effects to recovery and the adaptive training response during periods where physiological adaptations are crucial to performance. Furthermore, the individual variation in response to a change in environment stresses the importance of assessing sleep on a case-by-case basis, especially if assessment leads to the provision of interventions designed at improving the sleep of athletes during time spent in unfamiliar physical sleeping environments.

Practical Implications

- Efforts should be made to enhance sleep duration when changing physical sleep environments in order to maintain sleep quality.
- Understanding that individuals respond differently to changes in the physical sleeping environment may aid and improve sleep quality and quantity of travelling athletes or athletes who are required to regularly sleep in differing physical environments.
- Fluctuations in individual daily training loads when on Camp may make athletes more susceptive to altered sleep responses, highlighting the need for individualised interventions.

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References

1. Buchheit M, Racinais S, Bilsborough JC et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *J Sci Med Sport* 2013;16(6):550-555.

2. Bishop D. The effects of travel on team performance in the Australian national netball competition. *J Sci Med Sport* 2004;7(1):118-122.

3. Erlacher D, Ehrlenspiel F, Adegbesan OA et al. Sleep habits in German athletes before important competitions or games. *J Sports Sci* 2011;29(8):859-866.

4. Lastella M, Roach GD, Halson SL et al. The impact of a simulated grand tour on sleep, mood, and well-being of competitive cyclists. *J Sports Med Fit* 2014;3-33.

5. Samuels C. Sleep, recovery, and performance: the new frontier in high-performance athletics. *Neurol Clin* 2008;26(1):169.

6. Belenky G, Wesensten NJ, Thorne DR et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res* 2003;12(1):1-12.

7. Mougin F, Simon-Rigaud ML, Davenne D et al. Effects of sleep disturbances on subsequent physical performance. *Eur J Appl Physiol Occup Physiol* 1991;63(2):77-82.

8. Buchheit, M. Racinais, S, Bilsborough, J et al. Adding heat to the live-high train-low altitude model: a practical insight from professional football. *Br J Sports Med* 2013;47(Suppl 1):i59-i69.

9. Sargent C, Schmidt WF, Aughey RJ et al. The impact of altitude on the sleep of young elite soccer players (ISA3600). *Br J Sports Med* 2013;47(Suppl 1):i86-i92.

10. Okamoto-Mizuno K, Tsuzuki K, Mizuno K et al. Effects of partial humid heat exposure during different segments of sleep on human sleep stages and body temperature. *Physiol Behav* 2005;83(5):759-765.

11. Roach GD, Schmidt WF, Aughey RJ et al. The sleep of elite athletes at sea level and high altitude: a comparison of sea-level natives and high-altitude natives (ISA3600). *Br J Sports Med* 2013;47(Suppl 1):i114-i120.

12. Richmond L, Dawson B, Hillman DR et al. The effect of interstate travel on sleep patterns of elite Australian Rules footballers. *J Sci Med Sport* 2004;7(2):186-196.

13. Killer SC, Svendsen IS, Jeukendrup AE et al. Evidence of disturbed sleep and mood state in well-trained athletes during short-term intensified training with and without a high carbohydrate nutritional intervention. *J Sports Sci* 2015;doi:10.1080/02640414.2015.1085589.

14. Kölling S, Steinacker JM, Endler S et al. The longer the better: Sleep–wake patterns during preparation of the World Rowing Junior Championships. *Chrono Inter* 2016;doi:10.3109/07420528.2015.1118384.

15. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 2000;30(1):1-15.

16. Hooper SL and Mackinnon LT. Monitoring overtraining in athletes. Recommendations. *Sports Med* 1995;20(5):321-327.

17. Scott TJ, Black CR, Quinn J et al. Validity and reliability of the session-RPE method for quantifying training in Australian football: a comparison of the CR10 and CR100 scales. *J Strength Cond Res* 2013;27(1):270-276.

18. McLean BD, Coutts AJ, Kelly V et al. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perf* 2010;5(3):367-383.

19. Reilly T, Waterhouse J and Edwards B. Jet lag and air travel: implications for performance. *Clin Sports Med* 2005;24(2):367.

20. Fullagar HH, Duffield R, Skorski S et al. Sleep, Travel and Recovery Responses of National Footballers During and Following Long-Haul International Air Travel. *Int J Sports Physiol Perf* 2015;doi:10.1123/ijspp.2015-0012.

21. Taylor SR, Rogers GG and Driver HS. Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Med Sci Sports Exerc* 1997;29(5):688-693.

22. Lastella M, Roach GD, Halson SL et al. Sleep/wake behaviour of endurance cyclists before and during competition. *J Sports Sci* 2015;33(3):293-299.

23. Hausswirth C, Louis J, Aubry A et al. Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Med Sci Sports Exerc* 2014;46(5):1036-1045.

24. Lastella M, Roach GD, Halson SL et al. The effects of transmeridian travel and altitude on sleep: preparation for football competition. *J Sports Sci Med* 2014;13(3):718-720.

25. Lastella M, Lovell GP and Sargent C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *Eur J Sport Sci* 2014;14(Suppl 1):S123-S130.

26. Libert JP, Di Nisi J, Fukuda H et al. Effect of continuous heat exposure on sleep stages in humans. *Sleep* 1988;11(2):195-209.

27. Nédélec M, Halson S, Delecroix B et al. Sleep Hygiene and Recovery Strategies in Elite Soccer Players. *Sports Med* 2015;45(11):1547-1559.

28. Mah CD, Mah KE, Kezirian EJ et al. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 2011;34(7):943-950.

29. Milewski MD, Skaggs DL, Bishop GA et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J Ped Ortho* 2014;34(2):129-133.

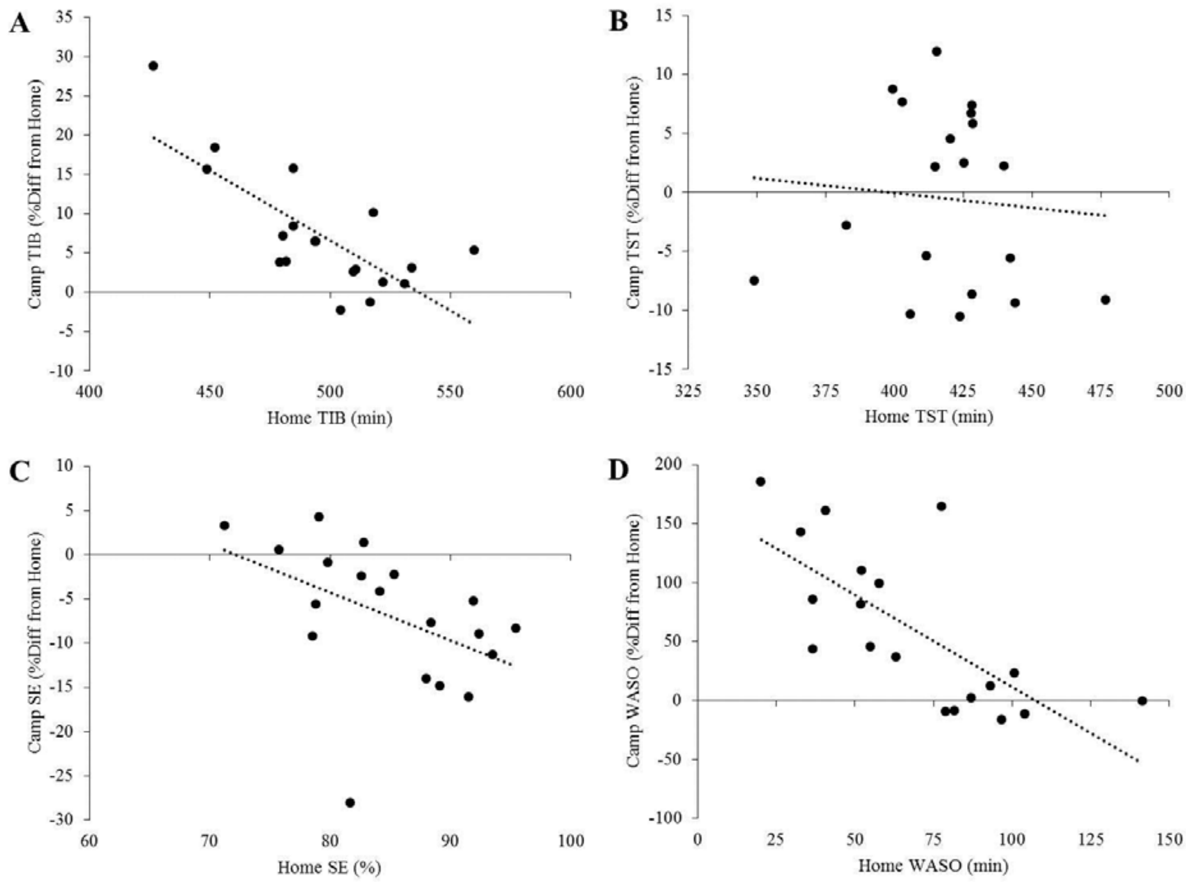

Figure 1. Sleep characteristics on Camp expressed as relative individual changes from mean Home (A) time in bed, (B) total sleep time, (C) sleep efficiency and (D) wake after sleep onset.

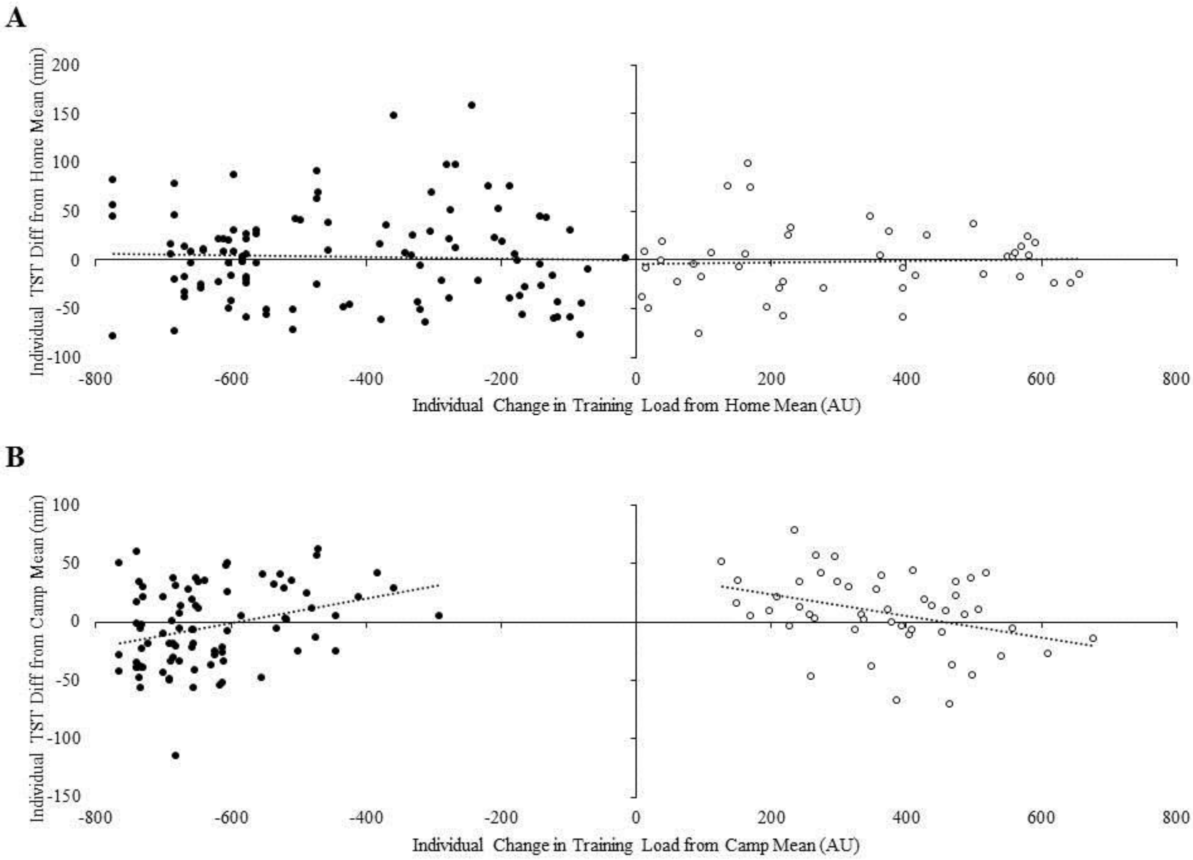

Figure 2. Variations in total sleep time from the environment mean in response to increased (Open circles) and decreased (Solid circles) daily training load from (A) the environment mean at Home and (B) on Camp.

Table 1. Difference in sleep and training characteristics between Home and Camp in elite Australian Football players. Data presented as mean ± SD.

	Home	**Camp**	**Effect Size (95%CI)**	**P-Value**
Sleep specific measures				
Bed time (hh:mm)	22:25 ± 02:02	21:40 ± 00:46	-0.47 (-0.71, -0.24)	<0.001*
Wake time (hh:mm)	06:51 ± 01:03	06:31 ± 00:44	-0.36 (-0.59, -0.13)	0.003*
Time in bed (min)	496.5 ± 31.5	530.6 ± 24.3	1.21 (0.50, 1.88)	< 0.001*
Total sleep time (min)	419.4 ± 25.6	417.0 ± 37.5	-0.07 (-0.71, 0.56)	0.846
Sleep efficiency (%)	84.7 ± 6.5	78.7 ± 6.5	-0.93 (-1.57, -0.24)	< 0.001*
Wake after sleep onset (min)	68.9 ± 29.9	96.5 ± 33.7	0.87 (0.19, 1.51)	< 0.001*
Subjective sleep quality (AU)	3.50 ± 0.43	3.46 ± 0.52	-0.08 (-0.72, 0.55)	0.946
Training specific measures				
s-RPE load (AU)	396 ± 394	440 ± 502	0.10 (-0.13, 0.32)	0.398
Temperature (°C)	23.6 ± 4.4	29.0 ± 1.8	1.63 (1.36, 1.88)	< 0.001*
Relative humidity (%)	66.5 ± 13.2	67.8 ± 6.5	0.13 (0.10, 0.35)	0.277
Total wellness (AU)	39.7 ± 2.9	38.8 ± 2.2	-0.36 (-0.65, -0.07)	0.023

AU = arbitrary units, CI = confidence intervals, hh:mm = time in hours and minutes, min = minutes, °C = degrees Celsius, % = percent, * = significant difference ($P < 0.006$).