Assessment of sleep characteristics of elite team sport athletes

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Assessment of Sleep Characteristics of Elite Team Sport Athletes

By

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Thesis Declaration

This thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution.

No other person's work has been used without due acknowledgement in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committee (where required).

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This journey began with a conversation with my then high performance manager and now PhD supervisor Dr Stuart Cormack when we were both working at the Essendon Football Club. We were noticing that sleep was having an impact on both the players and the coaching staff, yet the program did not have anything in place to assess the sleep habits of players, or strategies for players who were presenting with poor sleep. That was enough for me to begin this journey to attempt to answer some of these questions to ultimately be able to optimise the sleep and performance of the athletes and coaches I was working with.

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List of Publications Related to This Thesis

1. **Lalor BJ**, Halson SL, Tran J, Kemp JG, Cormack SJ. No compromise of competition sleep compared with habitual sleep in elite Australian footballers. *International Journal of Sports Physiology and Performance*. 2018;13(1):29-36.

2. **Lalor BJ**, Halson SL, Tran J, Kemp JG, Cormack SJ. A complex relationship: sleep, external training load, and well Being in elite Australian footballers. *International Journal of Sports Physiology and Performance*. 2020;15(6):777-787.

3. **Lalor BJ**, Halson SL, Tran J, Kemp JG, Cormack SJ. Business class travel preserves sleep quality & quantity and minimises jet-lag during the Women's World T20 Cricket Tournament. *International Journal of Sports Physiology and Performance*. Forthcoming 2021.

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Abstract

Despite the known restorative effects of sleep and the important role it may play in minimising fatigue and optimising adaptation from training, it has been suggested that athletes exhibit poorer sleep characteristics when compared to the general population. Whilst there have been investigations of the sleep characteristics exhibited during competition, analysis of the objective sleep characteristics of team sport athletes prior to and during important competition is limited, particularly in elite female athletes. In addition to the competition itself, there are a number of factors that may influence an athlete's sleep. These include the training and competition schedule, phases of training and competition, internal and external training load, the athlete's sleep environment, and domestic and international travel. However, the impact of a combination of these factors on objective sleep has rarely been explored in elite team sport athletes. Therefore, the main aim of this thesis was to investigate the objective sleep characteristics of elite male and female team sport athletes during competition. Three studies were conducted in a high performance sport environments to assess: (1) the impact of match start time and days relative to a match on sleep; (2) the relationships between sleep, training load and well-being; and (3) the impact of the quality and quantity of sleep obtained during a long-haul flight on competition sleep and perceptual measures including well-being and jetlag.

Study 1 assessed the objective sleep characteristics, via wrist worn actigraphy, of 45 elite male Australian Football (AF) players during the pre-season (habitual) and across four home matches during the competitive season. For each match start time, the 22 participants who were selected to play were assigned an activity monitor to be worn the night before (-1), night of (0), one night after (+1), and two nights after (+2) each match. Differences observed in sleep onset latency (ES=0.11 ± 0.16), sleep rating (ES=0.08 ± 0.14) and sleep duration (ES=0.08 ± 0.01) between competition and habitual periods were *trivial*. Sleep efficiency (%) was *almost certainly* higher during competition than habitual, however this was not reflected in the subjective rating of sleep quality. In many cases, the differences between match start times were *trivial* or *unclear*. The evening match start time, compared to all other start times, resulted in the clearest differences (e.g., evening matches had a *likely* longer sleep latency and *almost certainly* lower sleep efficiency). The differences in sleep characteristics based on days relative to the match were primarily *trivial*, however there were *almost certain* decreases in sleep duration for the night of the match compared to +1 and +2 nights post-match. The findings of this study indicated that, in general, elite AF competition does not

appear to cause substantial disruption to sleep characteristics when compared to habitual sleep. Whilst the match start time had some impact on sleep variables, it appears that any match, regardless of match start time, may cause disruption to players' sleep characteristics. The clearest disruption to AF players' sleep occurred in the nights (+1 and +2) immediately following a match, which provides an ideal opportunity for intervention to optimise sleep and recovery. Importantly, the subjective ratings of sleep from shortened well-being questionnaires, used routinely in the high performance environment appear limited in their ability to accurately provide an indication of sleep quality.

It is recognised that numerous factors may influence the sleep characteristics of AF players, including player well-being and training and match day load. Nevertheless, the relationships between load, well-being and sleep prior to and following training and matches are not well understood.[1] Study 2 assessed the association between objective sleep characteristics, self-reported measures of well-being and external load of 38 elite male AF players over a 15-day pre-season training period. External load was assessed during main field sessions and self-ratings of well-being were collected daily. Canonical correlations were moderate between pre training sleep and training load (r range = 0.32–0.49), pre training sleep and well-being (r = 0.32), and well-being and post training sleep (r = 0.36). Moderate-to-strong canonical correlations were observed between dimensions representing training load and post training sleep (r range = 0.31 to 0.67). Player Load ™ (PL) and Player Load ™ 2D (PL2D) showed the greatest association to pre and post training objective sleep characteristics and well-being. External load metrics PL and PL2D showed the greatest association between both objective sleep characteristics and well-being measures in AF players. This association was observed both prior to and following main AF training sessions. Fragmented sleep was associated with players completing the following training session with a higher PL2D, and increased wake bouts were associated with lower mood and higher soreness ratings. Our findings highlight that the relationship between objective sleep characteristics, training load and well-being are not defined by one measure (e.g., sleep duration). Instead, a complex interaction of sleep variables may influence both external load and the well-being of AF players. These findings have implications for practitioners, particularly when choosing variables to monitor AF players' sleep to assist in the planning and evaluation of training.

The sleep characteristics for both Study 1 and 2 were assessed in players' habitual sleep environments, however it is often a requirement for an elite team sport athlete to travel both domestically and internationally for competition.[2-5] In order to investigate the impact of international travel on the sleep characteristics, well-being and performance of elite team sport athletes,[6] the participant group for Study 3 was extended to elite female cricket players, as players are required to travel both domestically and internationally for competition. There have been no assessments of the objective in-flight sleep characteristics when athletes have the ability to lie flat whilst travelling in business class, however the difficulties of obtaining good quantity and quantity of sleep during long-haul travel are well documented,[4,7] Study 3 assessed the impact of the quality and quantity of sleep during an international flight on subsequent objective sleep characteristics, training and match day load, self-reported well-being, and perceptions of jetlag in 11 elite female cricketers during an International Cricket Council T20 Women's World Cup. To our knowledge, Study 3 is the first objective assessment of the in-flight sleep of elite team sport athletes seated in business class during an international flight. The results of Study 3 indicate that maximising the opportunity for in-flight sleep quality and quantity by planning the team departure time and business class seat selection appear to benefit elite female cricket players' recovery and sleep exhibited during competition. The quality of sleep obtained in-flight had an impact on the self-reported measures of fatigue during the tournament. Players with a lower in-flight sleep efficiency reported higher levels of fatigue during the tournament. Study 2 highlighted that fragmented sleep prior to a main training session was associated with lower ratings of mood and increased ratings of soreness. This further supports that the quality and quantity of in-flight sleep may have had a positive impact on an athlete's overall well-being and readiness to train upon arrival at the international competition destination. The preservation of both the sleep quality and quantity during long-haul travel may also be an important strategy to manage jetlag.[3,8] Players that slept for longer during the flight presented with minimal perceptions of jetlag and this was maintained across the monitoring period. In contrast, players with lower in-flight sleep duration reported some perceptions of jetlag, which improved two days after arrival at the destination. It is acknowledged that the financial constraints of travelling business class may be a limitation for elite team sporting organisations, however the investment to achieve sleep quality and quantity similar to habitual values prior to an important international competition may outweigh the costs associated with the alternative approach of an arriving days earlier (e.g., accommodation) to facilitate recovery from travel.

In summary, the three studies in this thesis add to the knowledge of the objective sleep characteristics of elite male and female team sport athletes exhibited during competition. Our findings demonstrate that the sleep characteristics during competition are not compromised when compared to habitual. However, the habitual characteristics were not optimal, providing the greatest opportunity for intervention. The findings provide high performance practitioners and coaches with information to assist with the implementation of individualised and team strategies to optimise the sleep, well-being and performance of elite team sport athletes. Furthermore, preserving the sleep quality and quantity during international travel should be considered when planning travel and training upon arrival at the international competition destination.

Chapter 1: Introduction and Overview

Performance in elite sport is influenced by the interaction of fitness and fatigue.[9] For positive adaptation to occur, a balance between the training dose and recovery is required and, as a result, managing training dose and the individual response is critical.[10] Optimising the training dose is important for improving physical capacity and minising negative training states such as non-functional overreaching.[11] In order to achieve this, high performance programs typically quantify training and competition loads and the psychophysiological responses to those loads.[12]

Training and competition load can be measured using both external load and internal load metrics. External load refers to “what the athlete did” and may include duration, distance and speed which in team sports are commonly measured with microtechnology devices including Global Positioning Systems (GPS) and accelerometers.[12] Internal load refers to “how the athlete responded” and can be measured both subjectively (e.g., rating of perceived exertion (RPE)) and objectively (e.g., heart rate).[12] In addition, athletes regularly undergo assessments to monitor their status during training and competition.[12] Common examples of these include tests of neuromuscular function and hormonal profile.[13] However, one of the most common approaches is the requirement for athletes to subjectively rate their fatigue, muscle soreness, mood and sleep, amongst other variables, using various tools known as athlete reported outcome measures (AROMs).[14]

There are a number of psychometric inventories that have been validated to assess an athlete’s status.[15] These inventories may be used to assess; sleep quality (via the Pittsburgh Sleep Quality Index (PSQI)); symptoms of stress and life stress (via Daily Analyses of Life Demands for Athletes (DALDA)), both physical and mental stress (via Recovery Stress Questionnaire for Athletes (RESTQ-Sport)) and mood (via the Profile of Mood States (POMS)).[15] However, these inventories are not routinely administered in high performance environments due to their length and potential burden on the athlete.[15] As a result, high performance programs commonly use customised shortened well-being questionnaires which are administered daily to obtain global assessments of how athletes are tolerating training, competition and life outside of sport.[15] These customised questionnaires have demonstrated their ability to provide insight into an athlete’s status in areas such as muscle soreness, fatigue, mood, stress and sleep.[13] However, the sleep items on well-being questionnaires, which often include measures of sleep quality and quantity, have received limited attention.[16]

The subjective ratings of sleep are routinely collected in high performance programs. However, reports of athletes' inability to recall the sleep duration that they obtain each night questions the use of subjective assessments of sleep in team sport athletes.[17] It has been suggested that the self-rating of poor sleep quality may encompasses a variety of sleep issues and may include; frequent waking; a prolonged time to fall asleep or a reduced sleep quality or duration.[16] Conversely, good sleep quality may represent minimal wake time and waking feeling refreshed with minimal daytime sleepiness.[16] As a result, subjective ratings of sleep quality may represent several objective sleep characteristics.[16] It is unknown whether subjective ratings of sleep quality and quantity are reflected in measures of objective sleep quality measured via actigraphy in elite team sport athletes.

Despite the known restorative effects of sleep, it has been suggested that athletes' exhibit poorer sleep characteristics when compared to the general population.[18] As a result, there is an increased focus to objectively measure athletes' sleep quality and quantity, in an attempt to optimise performance and well-being. Polysomnography (PSG) is considered the gold standard for monitoring sleep. A PSG assessment monitors brain activity (via electroencephalogram (EEG)), eye movement, muscle activity and heart rhythm (via electrocardiogram (ECG)) during sleep, and generally requires the participant to spend a night in a sleep laboratory with a technician in attendance. For that reason, it is often not viable to complete long-term sleep monitoring studies in elite athletes, particularly prior to and during competition.[19] Activity monitors provide a practical alternative to PSG in the high performance environment and have been validated for sleep estimation in athletic populations.[20,21] To date, objective assessments of athletes' sleep characteristics using activity monitors have focused on the impact of training schedules,[22,23] training load,[24,25] air travel,[4,26,27] the night prior to competition,[28,29] and a particular focus on competition scheduled in the evening.[30] Whilst there have been investigations regarding the sleep characteristics exhibited during competition periods,[29,31,32] the analysis of the objective sleep characteristics of team sport athletes prior to and throughout important competition periods is limited, particularly in elite female athletes. There are a number of investigations that do not compare findings during competition to how athletes usually sleep in their home and training environment.[31] This may lead to assumptions regarding the impact that competition has on athletes' sleep without consideration of athletes' habitual sleep characteristics. In other cases, the analysis of competition objective sleep characteristics have been captured during pre-season competition[30] or during the competitive season without the inclusion of matches.[33] Although providing insight into the sleep characteristics exhibited during these phases, they may not reflect actual behaviour and sleep characteristics exhibited during a competition phase. Developing an understanding of how an elite athlete usually sleeps will allow practitioners to establish an appropriate baseline for comparison with the sleep characteristics exhibited during competition. This will provide both the practitioner and athlete with insight into the opportunities to optimise sleep during training at home and competition.

In addition to the competition itself, a number of factors may impact an athlete's sleep. These include the training and competition schedule,[30] phases of training and competition,[32] internal and external training load,[25,34,35] the athlete's sleep environment,[36] and domestic and international travel.[5,23-25] However, the impact of a combination of these factors on objective sleep has rarely been investigated in elite team sport athletes. For example, although internal and external load measures are routinely collected in high performance environments, the interactions between internal and external load and objective sleep characteristics of elite team sport athletes prior to and following training sessions have not been thoroughly investigated. To date, investigations have focused on the relationship between internal and external load and the sleep characteristics exhibited following a training session. For example, in rugby league, higher external training loads have been associated with small increases in objective sleep quality and quantity following a pre-season training session.[25] This relationship has also been explored in Australian Football (AF) where changes in session RPE (sRPE) showed a moderate negative correlation with the sleep duration of players during a pre-season training camp.[36] However, the sleep characteristics of players in this study may have been confounded by the shared living environment and altered daily schedule during the training camp. Importantly, the impact of the sleep characteristics prior to the training session on the internal and external load of team sport athletes has not been investigated and warrants further investigation.

For some athletes, international travel forms a large part of their yearly schedule, both for training and competition. The changes in time zone, sleep environment, sleep-wake routines and markers of circadian rhythm (e.g., core body temperature and melatonin) associated with international travel also have the potential to impact the sleep, well-being and performance of athletes.[4] The mismatch between players' body clocks and local time associated with international travel may result in symptoms of jetlag, which may impact sleep characteristics and self-reported well-being measures, including fatigue and mood.[8] The challenge of obtaining good quality and quantity of sleep during plane travel is well documented.[4,8] Professional football players reported 5.5 h of truncated sleep during an 18 h international flight, well below the sleep duration recommendations for the general population.[4] A shorter mean sleep duration (2.5 h) reported during a 24 h of simulated long-haul travel was associated with a reduced intermittent-sprint performance following simulated travel.[7]

The implications of a reduced in-flight sleep quality and quantity on subsequent sleep characteristics, symptoms of jetlag and well-being in elite athletes during a competition phase are not well understood and remain to be confirmed with further research.[3]

Therefore, the first aim of this research was to assess the sleep characteristics of elite team sport athletes during the competitive season in response to different match times and to compare in-season sleep characteristics to habitual sleep characteristics. The second aim was to assess the relationships between subjective ratings of well-being, measures of external load and objective sleep characteristics prior to and following the main training sessions completed by elite team sport athletes. The final aim was to determine the impact of the quality and quantity of sleep obtained during an international flight on subsequent objective sleep characteristics, self-reported well-being, and perceptions of jetlag during a competition.

Specifically, this thesis aimed to answer the following research questions;

1. What are the sleep characteristics of elite male Australian Football (AF) players during the competitive season in response to different match times and how do these compare to habitual sleep characteristics?

2. What are the relationships between external loads, subjective ratings of athlete well-being and sleep characteristics in elite AF players during a pre-season training period?

3. What is the impact of an international flight on objective sleep characteristics, perceptions of jetlag, and self-reported well-being following an international flight and over the course of an international T20 tournament in elite female cricket players.

Chapter 2: Literature Review

Sleep

Sleep serves a number of functions including; the restoration of energy, memory consolidation and learning, recovery from daily tasks, in addition to protection from potential danger (resting at night).[11] The importance of sleep can be reflected through the impact that inadequate sleep can have on how well the human body functions.[11] For example, the absence of sleep can have harmful consequences including a negative influence on cognitive processes, feeding behaviour, the regulation of glucose, in addition to the hypothalamic pituitary adrenal (HPA) axis.[37,38] Sleep is strongly linked with improving daily functioning, memory, learning capacity and academic performance.[11] The requirement for sleep is defined as "the optimum amount of sleep required to remain alert and fully awake and to function adequately throughout the day".[39] The recommended sleep duration for the general population is approximately 7.5–8h.[39] Adequate sleep efficiency, suitable timing of sleep and the absense of sleep disorders are also essential for healthy sleep.[40] Genetic, behavioural and environmental factors may also determine an individuals sleep requirements.[41] It has been suggested that the daily sleep requirement of elite athletes to recover from the rigors of physical training and competition may be increased in comparison to the general population.[40]

There are two distinct phases of sleep, non-rapid eye movement (NREM) and rapid eye movement (REM) sleep.[42] These two sleep phases rotate in a 'sleep cycle', with each cycle lasting between 90 to 110 mins.[39] Healthy adults will experience 4–6 sleep cycles during a normal sleep oppourtunity.[39] Non Rapid Eye Movement sleep is divided into four stages (Stages 1, 2, 3 and 4).[42] The sleep stages 3 and 4 are together defined as slow-wave sleep (SWS). [42] The phases and stages of sleep are outlined in Figure 1.

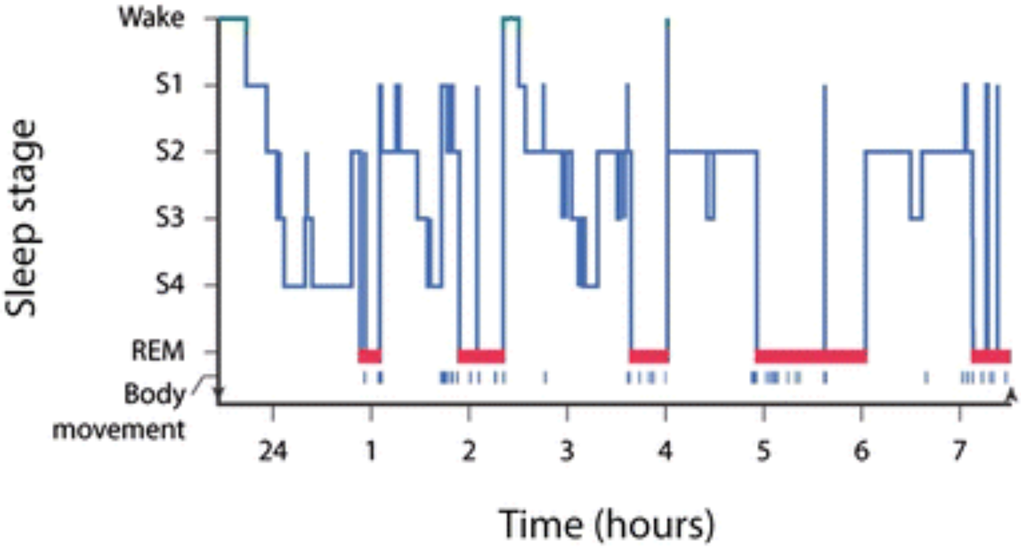

Figure 1: The Progression of Sleep Stages Across a Single Night in a Normal Young Adult is Illustrated in this Sleep Histogram. (Halson S.L. Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine*. 2014;44(1):13-23)

It has been suggested that SWS has an important role in the recovery function of sleep.[14,13] Compared to periods of wakefulness, SWS is coupled with a decrease in brain glucose utilisation, blood pressure, heart rate and sympathetic nervous system activity.[14,13] Throughout the SWS stage, the stress hormone cortisol is inhibited whilst growth hormone is released, which stimulates protein synthesis necessary for tissue repair and growth.[14,37] It is these restorative processes that occur during SWS that may be important for elite athletes to recover from the daily rigors of training and competition.

The REM phase of sleep has been described as "an activated brain in a paralyzed body".[43] Rapid Eye Movement sleep, is charactertised by periods of rapid eye movement, EEG activation and a loss of muscle strength.[43] During this stage of sleep, the brain displays similar brain wave patterns to those observed during wakefulness.[43] However, spinal motor neurons are inhibited, suppressing muscle activation during the REM sleep phase.[43] The REM phase of sleep has a critical role in the consolidation of memories and protein synthesis.[43]

Sleep is one of the most apparent behaviours that is under circadian regulation.[44] Circadian rhythms are biological activities that occur over a ~24h period in human metabolism.[44] The physiological and psychological variables that change rhythmically over a ~24h period include core body temperature, cortisol, blood pressure, heart rate, hunger, cognitive performance, strength, flexibility, alertness and fatigue.[45] These variables are controlled by environmental signals or 'zietgebers' via a central circadian pacemaker which is loacted in the hypothalamus.[45] For humans, the most powerful zeitgeber is light and as a result the sleep-wake cycle may influence the circadian system via exposure to periods of light and dark.[44,45] Light exposure has a major influence on the circadian system and numerous functions rise and fall over an ~24 hour period.[12] For this reason, an increased level of alertness and performance occur during the daytime.[16]

Sleep propensity, or the drive to sleep, is inversely related to core body temperature (CBT), peaking before usual bedtime and decreases in the latter half of the evening.[44] The stress hormone cortisol and blood pressure decrease in the evening and rise in the morning.[44] In contrast, the hormone melatonin increases in the evening prior to usual bedtime and peaks in the middle of the night, with levels decreasing in the morning.[44] Other stimuli including social contact, consuming food, and physical activity, may also assist in the regulation of the sleep/wake cycle.[45] Humans can voluntarily adjust their sleep/wake behaviour, which may impact ability to remain alert during the day and capacity to sleep at night.[44] For an elite athlete, abrupt changes in sleep/wake behaviour may occur as a result of the scheduling of training and competition, or due to time zone changes associated with transmeridian travel.[46]

Sleep Measurement in Elite Athletes

Despite the known restorative effects of sleep, it has been reported that athletes exhibit poorer sleep characteristics when compared to the general population.[18] As a result, there is a focus on measuring athletes sleep quality and quantity during training and competition, in an attempt to optimise performance and well-being.[47] Polysomnography is the gold standard for monitoring sleep and is used to identify sleep disorders.[19] Polysomnography provides detailed information regarding sleep architecture, sleep duration and sleep quality.[20] Polysomnography typically incorporates the measurement of brain activity (via electroencephalography EEG), eye movement (via electrooculogram ECG), muscle activity (via electromyograms EMG) and heart rhythm (via electrocardiogram ECG) during sleep.[19] Overnight PSG requires the participant to spend a night in a sleep laboratory and a technician to be in attendance. This measurement process is costly and time consuming and therefore it is often not viable to complete during long term monitoring in elite athletic populations, particularly prior to and during important competitions.[19]

The measurement of sleep in elite athletes is often performed using both objective and subjective techniques with activity monitoring the most common objective measure of sleep that is used in a high performance environment.[48] In addition to objective measurements, sleep is often assessed using subjective measures including validated sleep questionaires, shortened well-being questionaires and the use of sleep diaries.[49] Both objective and subjective methods to measure sleep have benefits and limitations within the elite athlete polulation and will be outined below.

Activity monitors provide a practical alternative to PSG in the high performance environment and have been validated for sleep estimation in athletic populations.[20,21] Activity monitors are a useful way to identify sleep and wake behaviour of elite athletes in the habitual training environment,[23,24,50] during periods of travel,[2,5,27] training and competition.[28,31,51] Activity monitors are portable, non-invasive and can be operated remotely without the need of a technician, allowing large numbers of athletes (e.g., a team) to be monitored at the same time.

Activity monitors house accelerometer that can estimate sleep characteristics, including sleep duration and sleep efficiency via the detection of movement during sleep.[20] Sleep wake estimates are then calculated using validated algorithms.[20] Threshold (low, medium and high) based algorithms estimate periods of sleep and wake determined when the activity count fall above or below the activity threshold during the sleep monitoring period.[20] Epochs (30 or 60s) with activity scores that are above the threshold setting used during the sleep monitoring period are scored as "wake".[20] Considering that activity monitors are based on the principle that movement is increased when people are awake, it is acknowledged that activity monitors may overestimate sleep when people lie still in bed, but are not asleep.[21] However, when activity monitors are used in combination with a sleep diary to assist in the detection of periods of sleep, the bias of an activity monitor to measure sleep has been deemed to be minimal.[20]

There have been a number of investigations to determine the validity of the thesholds used to estimate sleep when using activity monitors.[21,48] The validity of activity monitors compared to PSG in healthy adults demonstrated that the ability of an activity monitor to detect sleep was high (91-96%), however it was found that the capacity to detect wake was low (38-54%).[20] The authors reported that when using the medium sleep-wake threshold in healthy adults, the sleep duration was underestimated by approximatley 50 minutes and wake duration is overestimated by approximatley 40 minutes. This highlights the importance of the selection of the sleep/wake threshold, in addition to the interpretation and feedback to the individual (coach and athlete) when using activity monitors to assess sleep.

Compared to the general population, athletes display different movement patterns during sleep, and this is particularly apparent during heavy training phases.[52] It is possible that sleep may be underestimated in athletes if they display high movement levels during sleep.[21] For this reason, the population specific validity of the use of activity monitors has also been investigated in elite team sport athletes.[48] For example, it has been suggested that the ability of an acitvity monitor (Actical® Philips Respironics, Inc., Bend, Oregon, USA) to detect wake in elite athletes is lower than their ability to detect sleep.[48] The specificity in a sample of elite athletes (67%-82%) were higher than values reported in healthy adults (38-54%).[21,48] In comparison to the gold standard PSG, the medium threshold selected when using the Actiware software had the smallest mean bias for the following sleep characteristics; wake after sleep onset (WASO), sleep duration and sleep efficiency.[48] The authors suggest that practitioners using Actical activity monitors to asses the sleep of elite team-sport athletes should select the medium threshold, which has been show to be moderately sensitive to sleep.[48] These findings reinforce that when using activity monitors, selecting an appropriate sleep/wake threshold is imperative when measuring sleep in the athlete population.[21]

Subjective Assessment of Sleep in Elite Sport

There have been numerous assessments of the sleep characteristics of elite athletes prior to and during competition that have been completed by subjective assessments alone.[53] [54] The qualitative methods used to assess the sleep characteristics in elite sport have included the Competitive Sports, Sleep and Dreams questionnaire, The Pittsburgh Sleep Quality Index (PSQI), The Epworth Sleepiness Scale (ESS) and more recently The Athlete Sleep Behaviour Questionnaire (ASBQ).[49,50,54-56]

The PSQI provides practitioners with a valid and reliable measure of sleep quality.[57] The PSQI may provide practitioners with the ability to identify "good" and "poor" sleepers and in addition may assist with the identification of sleep disturbances that may impact sleep quality.[57] The PSQI is a simple tool, consisting of 19 self-rated questions that are used to assess sleep quality over a month period.[57] The 19 self-rated questions (weighted on a 0-3 scale) are grouped into the following seven score categories including; 1) sleep duration, 2) subjective sleep quality 3) sleep onset latency, 4) sleep disturbances 5) sleep efficiency 6) sleeping medication use and 7) daytime dysfunction.[57] The seven category scores are summed to produce a PSQI score, which may range from 0-21.[57] A higher PSQI score indicates lower sleep quality.[57] Although the PSQI is not routinely administered in elite sport, it has been used to identify 'good' or 'poor' sleepers in this population.[54]

The Epworth Sleepiness Scale (ESS), is an 8 item questionaire that provides a measurement of the subject's level of daytime sleepiness. The ESS can be self-administered and produces scores from 0 to 24, with scores >10 suggesting increased levels of daytime sleepiness. The

ESS correlates with objective measures of daytime sleepiness measured by the multiple sleep latency test (MSLT), and has the ability to distinguish individuals with and without sleep disorders and those who are and are not sleep deprived.[58] This measurement tool has been used to assess alterations in mood and daytime sleepiness during a period of sleep extension in collegiate basketball players.[17] It has been hypothesised that the combination of an athletes chronotype and training schedule may influence an athletes ability to perform, therefore the ESS has also been used in conjunction with Morningness-Eveningness questionnaire (MEQ) to determine the chronotype of elite athletes from a number of sports.[56] The MEQ can be used to classify athletes' based on their preference to performing activities in either the morning or the evening.[56] The MEQ comprises of 19 questions which produce a score ranging from 16 to 96.[56] The lower scores suggest the athletes' preference to complete an activity in the evening and higher scores indicating preference for the morning.[56] The Horne and Ostberg classification system is used to determine the participants chronotype score (evening type (16-41), intermediate type (42-58) and morning type (59-86)).[56] Chronotype scores may be used to assist in the timing of training sessions in high performance environments.[56]

Athlete specific inventories have been developed to assist in the assessment of the sleep/wake behaviors of elite athletes.[49] The ASBQ is a practical tool for high performance practitioners to assess the sleep behaviours of elite athletes which has been validated against established sleep questionnaires including the ESS and PSQI.[49] The ASBQ may be useful for monitoring changes in athletes sleep/wake behaviour over the course of a season or for assessing strategies implemented to in high performance programs to optimise sleep.[59] The ASBQ is an 18-item questionnaire that assesses the sleeping behaviour of athletes and includes areas that may impact an athletes sleep/wake behaviour including; muscle soreness, dehydration and changes in sleep and wake times.[49] The ASBQ asks participants to report how frequently they participate in certain behaviours and the score of each response (1= never, 2 = rarely, 3 = sometimes, 4 = frequently, 5 = always) are combined to provide an ASBQ score.[49] A higher ASBQ score is reflective or poor sleep behaviour.[49]

To provide a more targeted insight into the sleep characteristics of athletes during competition, The Competitive Sports, Sleep, and Dreams questionnaire inventory has been developed.[55] This qualitative assessment tool has primarily been developed to establish the incidence of sleep problems prior to important competition.[54,55] The Competitive Sports, Sleep, and Dreams questionnaire obtains information on the sleep habits of athletes prior to competition or matches.[54,55] Athletes are required to report the number of occasions they slept worse, better or as usual prior to competitions over the past 12 months.[54,55] If an athlete reports experiencing poor sleep prior to competition they are required to answer a series of closed response questions identifying; problems experienced falling asleep, the reasons for sleep disturbances, the perceived effect of disrupted sleep and the strategies used, if any to assist with the sleeping difficulties prior to competition.[54,55] When asked about their sleep prior to competition 65.8% of athletes indicated that they experienced disturbed sleep prior to a sporting event at least once in their career and 62.3% of athletes had experienced this in the past 12 months.[55] An inability to fall asleep was identified as the major factor effecting sleep.[55] This study and the use of this qualitative assessment tool provided an insight into the self-reported difficulties athletes experience sleeping prior to a competition. However, this sleep assessment tool has not undergone the same validation as the ASBQ and may not provide a true indication of the sleep difficulties experienced prior to and during competition. More recently, The Competitive Sports, Sleep, and Dreams questionaire has been used in conjuction with the PSQI to assess the competition sleep habits of a large sample of Australian athletes.[54] Similar to previous findings employing the questionaire, 64% of athletes reported sleep difficulties before to competition at least once time in the previous 12 month period.[54] The main sleep disruption reported prior to competition was a prolonged time to fall asleep due to anxiety regarding competition.[54] Interestingly, a large number (59.1%) of team sport athletes did not have any strategies in place to assist with the poor sleep experienced during competition when compared with individual athletes.[54] This investigation highlighted the need for education and strategies to optimise sleep in the elite athlete population group.[54] The assessment of sleep difficulties in this study were restricted only to periods of competition,, suggesting that further investigation into the habitual sleep habits of elite athletes is warranted.

The above-mentioned qualitative methods to assess the sleep characteristics of elite athletes may provide insight to sleep habits or identify poor sleepers in large groups of elite athletes. However these questionnaires are rarely routinely administered in elite sport due to their length and potential burden on the athlete.[15] As a result, due to the ease of adminstration with large groups (e.g., team sport athletes), practitioners often implement customised shortened questionnaires which include subjective ratings of both sleep quality and quantity as part of routine monitoring practices in high performance environments.[60] It has been suggested that memory biases, mood and personality may affect self-reported assessments of sleep therefore the sleep items in shortened well-being questionnaires may not give an accurate evaluation of an athletes sleep quality.[61] In additon, it has also been highlighted that subjects perceive a longer time to fall asleep, recall less wake episodes and either over or underestimate total sleep time.[62] Other research has observed that athletes perceive a good night's sleep, which was in contrast to objective measures of sleep quality.[55,2] These reports of an athletes inability to accurately report their sleep/wake behaviour, questions the usefullness of subjective assessments of sleep quality in team sport athletes.[17] The mismatch of subjective and objective sleep duration has been observed in collegiate basketball players, where players self report of total sleep duration was significantly higher than sleep duration measured by actigraphy.[17] In contrast, a strong agreement between the self-reported and activity monitor derived sleep duration has been observed in a group of elite rugby league players.[16] These contrary findings emphasise the need to investigate the accuracy of the sleep items in shortened well-being questionnaires to assess sleep in other team sport populations. It has been suggested that the self-rating of poor sleep quality may encompasses a range of sleep related issues including, an extended sleep onset latency, frequent awakenings or an inadequate sleep duration.[16] Conversely, good sleep quality may represent limited awakenings, waking feeling refreshed with minimal daytime sleepiness.[16] As a result, subjective ratings of sleep quality can reflect several objective sleep characteristics, including sleep efficiency.[16] It is therefore unknown if the sleep items in shortened well-being questionnaires are reflected in measures of objective sleep measured via actigraphy including sleep efficiency, sleep onset latency and WASO in elite team sport athletes.

Sleep Characteristics of Elite Athletes

It has been suggested that obtaining sufficient quality and quantity of sleep is the most important recovery tool for elite athletes.[63] The physical recovery provided by the restorative role of SWS is considered critical to recovery effectively from the rigors of training and competion.[64] However, the emphasis on sleep as a key recovery modality may be overlooked or not prioritised when scheduling training in high performance environments.[22] In order to prevent neurobehavioral deficits in daytime performance, at least 8h of sleep each night is recommended, and increasing habitual sleep duration from 7 to 8h per night has been shown to result in faster reaction time and improvements in daytime alertness and mood.[65,66]

Despite the known restorative effects of sleep and the important role sleep may play in minimising fatigue and optimising adaptation from training, previous investigations have demonstrated that elite athletes exhibit poorer sleep characteristics when compared to the general population.[17,18,23,50,51,67] In particular, disturbed sleep has been reported to be high among elite athletes. [4,27,30,32,54,55,68,69] In particular, the sleep quality of elite athletes appears to be at risk prior to competition and matches, following international travel to training and competition and also during periods of intense training.[4,27,30,32,54,55,68,69] Two underlying mechanisms have been identified that contribute to the sport related insomnia symptoms in the athletic population, these include; cognitive arousal prior to sleep and sleep restriction.[68] It has been proposed that elite sport itself may degrade the sleep quality of elite athletes and as a result, the objective assessments of elite athletes sleep have focused on factors that may negatively impact sleep, with particular emphasis on the sleep prior to and during competition.[68,30,53,70,71] As outlined previously, a number of investigations do not compare the findings prior to and during competition to an athlete's sleep in their habitual and training environments.[31,30] This may lead to assumptions regarding the impact competition has on athletes sleep, without consideration of athletes habitual sleep characteristics. In other cases, the analysis of competition objectively measured sleep characteristics have been captured during pre-season competition[30] or during the competitive season without the inclusion of matches.[33] Although providing insight into the sleep characteristics exhibited during these phases, they may not reflect actual behaviour and sleep characteristics exhibited during a competition phase.

Habitual Sleep Characteristics

The quality of the literature that has investigated the habitual sleep of elite athletes is low, with limited controlled comparisons of athlete and non-athlete sleep.[68] Using activity monitors, Leeder et. al., reported normative sleep data for elite athletes by collecting 'out of competition' data in the athletes home sleep environment.[18] The sleep data was collected from a number of Olympic sport athletes (individual and team sports) and was compared to an age and sex matched non-athletic control group.[18] The main finding was that the athlete group appeared to have a similar sleep duration when compared to the control group.[18] There were, however, significant differences between the athletes and controls for all other sleep variables which may indicate that the quality of sleep of athletes was compromised when compared to the controls.[18] In particular, the athlete group had a longer sleep onset latency, a lower sleep efficiency, spent more time in bed not sleeping and experienced a higher awakenings.[18] When compared to controls, the athlete group had considerably larger individual variation for each sleep variable (e.g., sleep latency 18.2$\pm$16.5 min, moving min 87.6$\pm$32.6 min and time awake 1:17$\pm$0:31 min).[18] The 'out of competition' sleep characteristics reported by Leeder et. al, are similar to findings from a systematic review which identified a high overall incidence of sleep disturbances in elite athletes, including; longer sleep latencies, greater awakenings and reports of day time fatigue.[68] Despite being collected out of competition, the normative sleep data reported that the mean sleep duration of 6.55$\pm$0.43 (h:min) fell below the National Sleep Foundation sleep duration recommendation of between 7-9h of sleep for healthy adults.[72,73]

The comparison between 'out of competition' athletes and non-athletic controls provided some insight into the habitual sleep characteristics of elite athletes, however the assessment duration of four nights may have not been long enough to obtain reliable habitual measures.[74] More recently, the habitual sleep/wake behaviour of elite athletes has been assessed over seven consecutive nights during an out of season phase and comparing the sleep/wake behaviours of individual athletes with those of team sport athletes.[75] Sleep data was collected from Australian athletes across nine sports including basketball, cycling, football, mountain biking, race walking, Australian football, rugby union, swimming and triathlon.[75] The average sleep duration of 6.8h is similar to previous findings,[18] indicating that both Australian elite team sport and individual athletes were obtaining below the general population recommendations for sleep duration.[18,75] In particular, it was observed that individual athletes obtained on average less sleep (6.5h compared to 7.0h) and had a lower sleep efficiency when compared to athletes from team sports.[75] It has been speculated that the shorter sleep duration of individual sport athletes may be attributed to training starting early in the morning.[47] Training sessions that start early have been reported to severely restrict the sleep duration of elite swimmers.[23] Early morning training schedules may limit the efficacy of training, given the impact that chronic sleep restriction can have on both mental and physical performance.[23] It has been demonstrated that perception of effort increases under sleep deprivation which may influence an athletes time to fatigue during training.[11] Similarly, when sleep duration is less than 6h per night, there are disturbances in glucose metabolism and appetitie regulation, cognitive function and immune function, all of which can impact an athletes ability to perform.[23]

With this in mind, future investigations should aim to further increase the understanding of the sleep of both individual and team sport elite athletes. Firstly, it is recommended that establishing an appropriate baseline through the collection of habitual sleep data over a sufficient time period (5 or more nights) in order to provide an insight to how an athlete usually sleeps.[74] Establishing an appropriate baseline will allow the comparison to the sleep characteristics exhibited over a number of scenarios that elite athletes experience during both training and competition including; domestic and international travel,[2,5,27,45] a change in sleep environment,[36] evening competition[30,70,71], the training load and the athletes schedule.[22,23,34,76-79] This will provide both the practitioner and athlete with an insight into the opportunities to optimise sleep during periods of training at home and competition.

Competition Sleep Characteristics

The sleep characteristics exhibited during competiton is of importance to both athletes, coaches and performance support staff.[54] Previous work assessing sleep during competition include; the night/s prior to competition, the night of competiton and the night/s immediatley following competition.[47] The assessment of one of these categories in isolation e.g., the night of competition may not be an accurate reflection of the sleep characteristics of elite athletes. In addition, a recent systematic review revealed that the majority of studies assessing sleep during competition have recruited male team sport sport athletes, therefore these findings may not be reflective of athletic populations, including elite female team sport athletes.[47] This emphasises the need to assess the sleep of elite team athletes over a number of competition scenarios, including a variety of competition start times; the nights prior to and following competition; during and following an international flight to an international competition destination and to include elite female athletes in future investigations.

The Night Prior to Competition

Previous investigations have indicated that athletes percieve their sleep quality is impaired the night prior to competition.[54,55] The main sleep difficulty reported was trouble initiating sleep due to nervouseness and thoughts about the competition.[54] Recent work assessing subjective ratings of sleep support the findings of impaired subjective sleep quality prior to competition.[80] In this investigation, athletes rated their sleep quality significantly worse on the morning of competition compared to four nights prior to competition.[80] There was, however, no significant change observed for ratings of "feeling refreshed", suggesting the athletes perceived a recovery effect of their sleep.[80] In addition, the athletes did not report difficulties initiating sleep and did not report waking up more frequently the night prior to competition when compared to other nights.[80] Despite the peception of poor sleep quality not being mirrored in the percieved non-restorative effects of sleep, or in the sleep difficulties reported, the authors concluded that the poor sleep experienced prior to competition is an issue for elite athletes and therefore needs be considered by high performance support staff.[80] Furthermore, the authors indicated that it is not clear if the impaired perceptions of sleep quality impact training or competition performance and that more research in the field is required.[80] However, a recent systematic review and meta analysis did not find consistent evidence of the prevalence of pre-competition sleep disturbances, further highlighting the potential limitation of subjective assessments of sleep.[47] The mismatch between objective and subjective assessments of sleep during competition suggest that the sleep of elite athletes should not be assessed by subjective measures alone.

Contrary to previous reports of impaired sleep prior to important competition, elite Australian football players slept for longer, relative to baseline, prior to matches played both home and away.[26] Similar findings have been reported in elite female basketball players, where the sleep duration the night prior to competiton was longer when compared to a habitual baseline.[81] The authors hypothesised that elite team sport athletes may have developed effective strategies to assist with pre-competition anxiety, therfore the players ability to fall asleep was not impacted.[81] Interestingly, the sleep duration prior to a netball competition was longer than the night after (+1) competition.[82] A similar increase in pre-competition sleep duration and efficiency in comparison to nights following (+2) competition has also been observed in elite male volleyball players.[83] However, it is unknown how the sleep duration the night prior to competition in both of these investigations compare to how the players *usually* sleep.[82,83]

The Night Following Competition

It has been suggested that it is diffcult for athletes to achieve the sleep duration and sleep efficiency recommendations on the night of competiton.[47] This may be due to cognitive arousal prior to sleep and sleep restriction as a result to a delay in bedtime following competition.[47] A delay in bedtime following competiton may be attributed to a number of factors including post-match recovery and media commitments, travel immediatley following competiton, muscle pain, elevated core body temperature, increased circulating cortisol, sympatetic hyperactivity, the use of caffiene during competition and the use of alcohol following competition.[84] Athletes may also experience a lengthened sleep onset latency following competiton, further delaying sleep and shortening sleep duration.[51]

Competition Scheduled in the Evening

There has been a particular focus on the assessment of sleep following competition scheduled in the evening.[30,70,71,83] A significant decrease in sleep duration and later bedtime has been reported in elite male football players, with the authors attributing the sleep reduction to a later bedtime as a result of the timing of the match.[53] Sargent et. al assessed the impact of match start time on the sleep/wake behaviour of elite Australian football players.[30] The authors concluded that match start time impacted the sleep/wake behaviour in the sleep opportunity following the match.[30] It was reported that sleep onset was later, the total time in bed was shorter and the sleep duration following the evening match was less than following the match scheduled in during the day.[30] However, these findings may have been confounded by the change in the sleep environment following the night match.

There are number of possible contributing factors to poor sleep following an evening match. The mechanisms responsible for disturbed sleep in elite netball players following evening matches has been investigated[71] and found that players experienced a lower sleep qualty, lower sleep duration, and a reduced perception of sleep quality following a night game when compared to a recovery day.[71] In addition adrenaline and noradrenaline concentrations were reported to be increased prior to and following night matches in comparison with a time matched rest day.[71] The authors also reported a strong negative correlation (r = -0.611, p = < 0.01) between sleep efficiency and the players hyperarousal trait score.[71] Therefore, there is a potential for players with a higher hyperarousal scale rating to be susceptible to disturbed sleep during competition or during periods of stress.[71] Although this investigation provided insight into the possible mechanisms for poor sleep following night matches in team sport athletes, the comparisons made were to a rest day, not matches scheduled at different times of the day, which limits the ability to assess the effect of competition on sleep.[71] In addition, only one match was included in the assessment. A longitudinal investigation including more than one match and a number of match start times may provide further insight into the effect of competition start time on players sleep. The sleep characteristics of elite athletes across a number of different competition timetabling scenarios has yet to be investigated.

In addition to the competition itself, there are a number of factors that may influence athlete's sleep. These include the training and competition schedule,[30] phases of training and competition,[32] internal and external training load,[25,34,35] the athletes sleep environment[36] and domestic and international travel.[5,23-25] However, the impact of a combination of these factors on objective sleep has rarely been investigated in elite team sport athletes.

Training and Competition Schedule

The schedule of an elite athlete, including early morning training sessions and competition scheduled in the evening, may contribute to inconsistent sleep/wake cycles.[75] Shift work patterns, typified by extremely early or late start times, often leading to individuals incurring a sleep debt, have been shown to negatively impact both sleep and recovery.[66] Accumulating a sleep debt may influence an athletes mood, reaction time, level of daytime sleepiness, cognitive functioning and the ability to complete memory tasks.[8] It is possible that the training and competition schedule of an elite athlete which includes a variety of early morning and late evening training and competition start times, may have a similar impact on athletes sleep and recovery.

An athletes training schedule or the sport they engage in may influence their habitual sleep duration by impacting an athletes sleep/wake behavior.[22] For example, the difference in sleep characteristics of team versus individual athletes has been attributed to the training demands and potential early morning scheduling of training in individual sports, which may impact the quality and quantity of sleep an athlete obtains.[23,75] A number of investigations have reported that the sleep/wake behaviour of an athlete may be dependant on the training and competition schedule.[22,23,85] Sargent et. al assessed the sleep/wake behaviours of 70 elite athletes from a number of sports across two weeks of training.[22] The majority of training sessions commenced between 0500h and 0900h.[22] The investigation revealed that there were marked differences between the sleep/wake behaviour prior to training days when compared to rest days.[22] The time in bed was significantly shorter and the bed time and wake time were significantly earlier on nights prior to training. In addition, the sleep duration obtained on the night prior to training was significantly less than on nights prior to recovery days.[22] There have been similar sleep/wake behaviours observed in elite rugby league players on nights prior to training days when compared to nights prior to a non-training day.[51] Players spent longer in bed and had an increased sleep duration and sleep efficiency, when compared to a night prior to training.[51] Consideration of an athletes habitual sleep characteristics is imperative in order to implement strategies, including an adjustment of training times to optimise the sleep and performance of elite athletes.

The amount of sleep obtained in shiftworkers has been examined and has indicated that for each hour the work start time is prior to 0900h, sleep duration is shortened by approximatley 30 minutes.[22] An assessessment of the impact that training start times on sleep duration found that the sleep duration of elite athletes also occurred in a similar sytematic fashion.[22] For every hour that training time as advanced from 0800h to 0500h sleep was reduced by 6min (0700h), 48min (0600h) and 102min (0500h).[22] The total hours slept has been shown to be reduced in elite swimmers that commenced training at 0600h.[20] In this group, a reduced sleep duration was observed on training days in comparison to non-training days, the authors attributing this as result of both the training schedule and training times of this elite group.[20] The sleep duration during the sleep oppourtunity prior to early morning training days was 5.4h, falling below the general population target of 7-8h/day.[20] The sleep efficiency prior to training and rest days was 71% and 77% respectively.[22] In addition to a the impact of training start time on sleep duration, it has also been reported that there was a significant effect for self-reported measures of fatigue and total sleep time.[22] Athletes with a shorter sleep time had higher levels of pre training fatigue, which may have impacted the effectiveness of training.[22]

To date, the relationship between pre training sleep, self-reported measures of well-being and training load has largely been unexplored.

In a comparison of the sleep/wake behaviours in elite rugby league players during the pre-season and competitive season, the scheduled training time (0700h) during pre-season led to an earlier wake for players to adequately prepare and arrive for training.[51] In contrast, during the competition phase, training started at 0900h allowing a later wake time for players.[51] However in order to compensate getting up earlier, players went to bed earlier during the preseason phase, a compensatory behaviour sleep behaviour previously observed in athletes participating in trianing sessions with an early morning start time.[51] As a result, there was no change in the sleep quality or quantity and the total time in bed when comparing the sleep/wake behaviours during the pre-season phase and competition phase of the season.[51] However, there are a number of limitations of this research. Firstly, the monitoring period during both the competitve and pre-season were relatively short (7 days) and may not be reflective of usual sleep/wake behaviour during the competitive season. Secondly, the sample size of players was small (n=7), therefore the findings may not be representative of the sleep characteristics of all players in the squad across the competitive season.[51] Similar to previous findings in elite swimers, the sleep duration of elite rugby league players has been shwn to be impacted by teams training schedule.[51] On nights before a training session during both the competition and pre-season phase, players spent less time in bed and as a result, sleep duration was reduced when compared to night before a day off.[51] Players may have had the intention of going to bed earlier to obtain a good nights sleep, however due to the variation in sleep propensity across a 24h day this may have been difficult.[22] Sleep propensity is highest from 0000h to 0700h, with a second peak in the afternoon.[22] A period of low sleep propensity in observed in the early evening where there may be difficulties initiating sleep.[22] This period has been termed the "forbidden zone" and may inhibit an athletes ability to initate sleep in the early evening when attempting to compensate for an early wake time.[22]

Sleep Environment

An athletes sleep environment may also be disrupted due to a change in training and competition location.[36] Athletes may be required to share living arragements and/or bedrooms with teammates.[24] In additon, the athletes sleep may be impacted by the noise and the overall comfort of the selected accomodation.[10] A change in sleep environment from players habitual sleep environment to a shared living arrangement during a pre-season camp has shown to impact the sleep quality of elite Australian football players during pre-season training.[36] The negative effect of a change in sleep environment was observed without factors that may impact sleep including a circadian phase shift due to time zone changes as a result of international or domestic travel; an altered training schedule or an increase in total training load.[36] Despite players spending a longer time in bed, players were unable to achieve their habitual sleep duration.[36] This may be attributed to the shared living arrangements (e.g., noise from teammate, more time in bed reading or watching television) during the monitoring period.

Consequences of Disturbed Sleep

Due to the various factors highlighted in the previous section, athletes may be predisposed to periods of sleep restriction during training and competition.[4,22,23,36,54,71] Sleep deprivation commonly describes extreme sleep loss (> 24h) where no sleep is obtained for prolonged periods, however this sustained wakefullness is less likely in the athletic population.[86] It is possible that athletes may be more at risk to partial sleep deprivation or sleep restriction, which may occur when sleep time is later or wake earlier than normal.[86] In addition, sleep fragmentation (where an athlete frequently wakes during the night) may be considered an important issue for elite athletes that warrants further exploration, particularly in the athletes habitual sleep and training environment.

Pain

Optimal sleep quality and quantity is considered to be important to maintain homeostasis of the pain-regulatory process.[87] When compared to healthy adults, individuals that suffer from insomnia have been shown to experience pain, including pressure pain more frequently and intensely.[88] An increase in body discomfort was reported in participants that had sleep limited to four hours per night over a 12-day period.[87] Generalised body pain, back and stomach pain over the 12-day sleep restriction period were observed in participants who were pain free at the beginning of the investigation.[87] These findings support the suggestion that sleep restriction may contribute to the pain experience and may be an important consideration for injured athletes or for elite athletes that experience sleep difficulties during both training and competition.[88]

Athletes may experience pain as a result of collisions, muscle damage associated with the training and competition or as a result of injuries.[89] It has been observed that elite swimmers had increased movement during a period of higher training load.[52] This increase in movement during sleep may have been caused by muscle soreness and fatigue following the increased load.[52] To date, there is limited information on the interactions between pain and sleep characteristics in elite athletes, in particular the association between soreness and fragmented sleep in the athletic population.

Cognitive Function

Maximising sleep quality and quantity may have a positive impact on performance, particularly when sustained attention, reaction time and cognitive tasks are required.[42] Extended wake periods or poor sleep has been shown to affect neurobehavioural performance, with studies demonstrating the effects of sleep deprivation on higher cognitive functioning.[42] In particular, when using a psychomotor vigilance task, a relationship has been established between the amount of sleep deprivation and the decrease in cognitive function.[90] It has also been established that even relatively moderate sleep restriction, if sustained over multiple nights can impact waking neurobehavioral functioning in healthy young adults.[91]

When sleep duration is less than 7h in healthy adults, it has been demonstrated that cognitive performance is poorer in tests for recation time and decision making, alertness and also memory.[86] Reaction time has been reported to be slower following an hour of sleep restriction over two consequtive nights.[92] Decision making is also impacted following periods of sleep restriction.[86] In elite sport, reaction time and anticipatory skill, which are important in decision making, are critical aspects of an athletes perceptual abilities and are considered to be advantagous to optimal performance.[93] For an elite athlete, an increase in reaction time following a small decrease is sleep duration may have a negative impact on performance which emphasises the importance of obtaining adequate sleep prior to training and competition.[86]

The disruption to sleep and possible sleep deprivation associated with shiftwork is well documented.[91,94-98] Shift work patterns are typified by rotating shifts times, night shifts, extended work hours or on-call periods and often require workers to obtain sleep during daylight hours.[66] Research conducted in aviation, mining and the military has demonstrated that sleepiness or fatigue associated with shiftwork can affect driving, decision making, short term memory and the ability to perform mathematical calculations.[90,91,94,96,98] A reduced sleep duration, sleep quality and consequtive night shifts have been associated with accidents involving shift-workers.[99,66] The irregular nature of an elite athletes training and competition schedule, consecutive matches during competition periods or the disruption in circadian rhythms due to frequent international travel may have a similar impact to shift work on an athletes habitual sleep and subsequent performance, recovery and well-being.[22]

Sleep deprivation studies aim to assess the effects of sleep loss where participants are kept awake continously for 24-72h, presenting a potential reason for the limited investigations undertaken in the elite athlete population.[100] Elite athletes may be predisposed to a varying amount of sleep deprivation during both training and competition.[101] The amount of sleep disruption experienced may be minor (2–4h) or extensive (sustained wakefulness >24h), and often dependant on the requirements of the sport (e.g., travel, match frequency and start time).[101] An investigation assessing the impact of 30h sleep deprivation on consecutive day intermittent sprint performance reported that sleep deprivation was associated with reduced glycogen levels, altered pacing and a reduced intermittent-sprint performance and an increase in perceptual strain.[101] Following a competitive rugby match, the same authors assessed the impact of overnight sleep deprivation on recovery compared to a 'normal' night of sleep (8h) to a sleep deprived night sleep (no sleep).[102] Overnight sleep deprivation negatively affected the recovery (measured via counter movement jump height and cognitive function tests) following a rugby league match.[102]

Immune Function

A compromised immune function may impact an elite athletes ability to train and compete.[103] Sleep and the circadian system has a strong influence on the immune system and function[104] and similar to other forms of stress, a disruption in sleep influences immunity via the stimulation of the hypothalamic-pituitary-adrenal axis and the sympathic nervous system.[105] An increase in the daytime levels of inflammatory markers (Tumor Necrosis Factor, Interleukin 1 and Interleukin 6) has been associated with sleep deprivation.[106] It has also been observed that increased leukocyte and neutrophil counts and C reactive protein[107] increase following prolonged sleep restriction.[106] A night of disrupted sleep, appears to "prime the immune system", resulting in the stimulation of cytotoxic T cells, lymphocytes, and natural killer cells to move from the blood stream to possible areas of infection following activity.[105] A single night of restricted sleep (in bed sleeping from 0200h to 0400h) has been shown to increase the neutrophil count the morning following disrupted sleep.[108] In this investigation, the neutrophil count returned to baseline following 10h of recovery sleep.[108] A similar observation was made when sleep restricted subjects were permitted to nap before the night time recovery sleep period, suggesting that supplementing disrupted night-time sleep with a nap may counter the inflammatory response.[108] Athletes that experience disrupted sleep (following an evening match or long-haul travel) may be at risk of a compromised immune system, which has the potential to lead to missed training days or inabilty to compete.[103] Strategies to counteract disrupted sleep should be considered in high performance programs.

A higher incidence of illness is associated with a reduced sleep duration in Australian Football (AF) players over the preseason and competitive season.[109] During the 46 week assessment period, a reduced sleep quality, both acutely and chronically, resulted in greater likelihood of illness in elite AF players.[109] In addition, athletes were likley to report a significantly lower sleep duration within 7 days prior to reporting an illness.[109] Interestingly, there were no significant associations between training load and the incidence of illness.[109] In contrast, the self-reported sleep measures of elite netball players indicated that 'very poor' sleep quality, in addition to reporting a sleep duration of <5h or >10h had an association with an increased illness risk.[110] The mixed findings of the relationship between sleep and illness in the elite athlete population may be partly due to the use of shortened well-being questionnaires to measure sleep.[61] Therefore, future research should aim to use valid techniques to measure the sleep of elite athletes to further ascertain the association between the sleep quality and sleep duration and illness in elite athletes.[109]

Subjective sleep measures have also been included in an assessment of the upper respiratory symptoms and subjective jetlag in professional rugby league players following a westward long-haul flight from Australia to the United Kingdom.[5] The findings suggested that westward long-haul travel exacerbates subjective jetlag and upper respiratory symptoms.[5] The authors proposed that due to the potential stress on the immune system as a result of intensive training, athletes may have an increased risk of upper respiratory illness following international travel, when compared to the general population.[5] A similar observation in the increased incidence of illness in endurance athletes following a long-haul flight with a decreased in-flight sleep duration.[46] To compensate for lost sleep, the athletes nap durations were "*likely*" increased on the first day of arrival and the sleep duration was "*likely*" increased the first night after arrival.[46] The athletes self-reported fatigue increased following the first night of sleep and it was reported that 25% of athletes experienced illness symptoms 3-5 days after arrival.[46] However, no changes in mucosal markers of immunity (sIgA) or stress (cortisol) were observed.[46] There is limited information regarding the incidence of illness following a long-haul flight. Specifically, there are few investigations on the impact of the sleep obtained in-flight on both the sleep characteristics and incidence of illness upon arrival. To appropriately assess the impact of a long-haul flight, objective in-flight sleep characteristics should be considered.

Injury

The body of work assessing the relationship between the sleep/wake behaviour of elite athletes and injury risk is limited.[110-112] However, poor sleep across several days/weeks may predispose athletes to injury.[112] To date, the majority of work investigating the association between sleep and injury risk has been undertaken in adolescent athletes.[113-116] A systematic review examining the association between sleep and sports injuries in adolescent athletes revealed that current evidence cannot ascertain the impact of an acute period of sleep deprivation may have on injury rates.[113] It was however reported that adolescent athletes with a habitual sleep duration below 8h per night, or reported sleep fragmentation, are more likely to experience musculoskeletal injuries.[113] It should be acknowledged that a number of these investigations assessed sleep though subjective measures, which may not provide an accurate assessment of the athletes sleep duration or sleep quality during the assessment period.[116,117] More recently, the relationship between self-reported measures of training load, well-being, injury and illness in elite female athletes has been assessed.[110] In this elite population, injury and illness had both an increased and decreased association with self-reported measures of well-being including soreness, sleep quality, and duration.[110] Specifically, the highest risk in the 7 day period prior to the injury occurrence was a reduction in sleep duration the night prior to the injury.[110]

In contrast, the relationship between objective and subjective sleep metrics and injury in collegiate football players highighted that sleep quality and sleep quality were not associated with injury risk.[114] It is however acknowledged that there are a number of contributing factors to the risk of injury in elite athletes, including training load and level of fatigue.[112] Previous work has investigated the impact of stress, competition anxiety, mood states and social support in American football players and rugby players.[118] It was reported that there was a significant relationship between high competitive state anxiety and tension and injury rates.[118] With this in mind, combined research assessing sleep, internal and external training loads and well-being of elite athletes may provide further insight into the relationship between these measures and the risk of injury in a high performance setting.[112]

The association between injury incidence and objective sleep of elite Australian football (AF) players has been assessed during the AF competitive season.[112] Each week, players sleep was assessed via actigrapy for five consequtive nights; three nights prior to the match, the night of the match and the night following the match during the competitive season, until an injury occurred that caused a player to miss a match.[112] There was no sigificant effect of sleep on injury occurence.[112] The authors hypothesis that lower sleep duration and efficiency would incease the incidence of injury was not supported. More recently, reduced objective sleep quality was associated with the number of injuries, injury severity, and longer absence time in elite soccer players.[111] The authors suggest that a low sleep efficiency, high sleep latency, and sleep fragmentation in team sport athletes should be an area of consideration for high performance personnel, due to the possible association with injuries in soccer players.[111] With this in mind, future research assessing sleep, internal and external training loads and well-being of elite athletes may provide further insight into the relationship between these measures and the risk of injury in a high performance setting.[112]

Other

As outlined in a previous section, training sessions scheduled early in the morning can impact the sleep duration of elite athletes.[22,23] Considering that chronic sleep restriction of <6h per night can impair both physiological and psychological performance, training sessions scheudled early in the morning may limit the value of the training session.[23] In addition, when sleep is restricted to less than six hours per night, there are substantial disturbances in cognitive and immune function, appetite control and glucose metabolism, all of which can impact an athletes ability to perform.[100,119-121]

It has been suggested that the impact of sleep restriction on performance may be sport specific.[86] For example, a reduction in the skill execution in tennis, darts and handball goalkeeping has been observed following sleep restriction.[86] However, swimming performance (measured by lap time) in trained swimmers did not differ in sleep restriction when compared to normal sleep time.[86] The sleep characteristics of collegiate basketball athletes assessed over multiple weeks, revealed reduced cognitive function, altered mood, daytime sleepiness, and poorer reaction time due to accumulating a sleep debt.[17] In some sleep deprivation studies, mood alteration is a consistent finding although performance has not always been affected.[122] For an elite athlete, mood alteration has the potential to affect motivation to train and willingness to give maximal effort in both training and competition.[11] In addition, perception of effort has been shown to increase following sleep deprivation, which may influence an athlete's time to fatigue during training and competition.[11] Despite the demonstrated performance implications of sleep deprivation, the impact of sleep restriction in elite athletes across a competitive season is largely unknown.

Travel and Sleep

Domestic and international travel forms a large part of many professional and Olympic athletes training and competition schedule.[2,4,5,27,123-125] Changes in time zones, habitual sleep environment, sleep/wake routines and the circadian rhythms changes associated with travel have the potential to impact an athletes sleep and training and competition performance.[2,4,5,27,123-125] To date, the investigations assessing the impact of international travel on performance in elite athletes have reported a reduced physical performance,[126] changes in physiological variables[127] and alterations to self-reported measures of well-being,[27,69] in particular mood and fatigue following transmeridan travel.[7] As discussed in the Sleep section (Chapter 2, pp 23-24), most physiological functions exhibit a circadian rhythm and performance following travel may depend upon the degree of disruption to the circadian rhythm, in addition to the time of training or competition relative to the circadian system.[7] Sleep disruption prior to, during and following travel may be responsible for the physiological and perceptual responses that impact performance, and it is possible that sleep disruption is the primary mechanism of the negative impacts on performance, health and self-reported well-being in athletes following transmeridian travel.[7]

The travel schedule of an elite athlete, specifically the flight duration, transit time and the selected travel class may influence the oppourtunity to obtain optimal sleep during travel.[47,69] The challenge of an athlete obtaining good quality and quantity of sleep in-flight has been well documented.[4,7,8,46] Contributing factors to the challenges of achieving optimal sleep in-flight include; an uncomfortable upright position of an economy class seat, mild exposure to hypoxia, light, noise, the timing of meals and a disruption in usual routine experienced in-flight.[46,69] The majority of in-flight sleep assessments of elite athletes have been during economy class travel or simulated economy class conditions, which may in fact amplify the difficulties reported obtaining sleep in-flight due to the cramped and uncomfortable conditions associated with economy class, in addition to an inability to lie flat to sleep during the flight.[4,5,7,27,46] For example, both sleep quality and quantity increased when the back angle of the seat was increased (e.g., ability to recline or lie flat).[95] The possible mechanisms for the difficulty sleeping in an upright position (i.e. seated in economy class) may include; difficulty maintaining head position and a heightened level of physiological arousal associated with a decrease in parasympathetic activity and an increase in sympathetic activity when attempting to sleep in an upright position.[95] Although the challenges of sleeping in an upright position in economy class have been highlighted,[7,27] the quality and quantity of the in-flight sleep when seated in other classes that have the ability to lie flat (e.g., some business class flights) have not been thoroughly investigated in the athletic population and should be considered in future research.[128]

Athletes may experience 'travel fatigue' following both international and domestic travel or as a result of high frequency travel across a competitive season.[129,130] The symptoms of travel fatigue may include persistent fatigue, headaches, changes in mood and loss of motivation.[131] These negative perceptual changes may be reflected in athletes self-reported measures of well-being during and following travel.[132,123,131] The total travel time, including the flight duration, time in transit, ground travel in addition to other stressors, including travel delays may contribute to travel fatigue.[132] The flight departure time may impact an athletes sleep/wake behaviour prior to international travel.[69] For example, a reduced sleep duration and sleep efficiency has been reported in elite athletes with both an early and late travel departure time.[69] These factors highlight the potential sleep disruption prior to departure, particularly if the planned flight departure time or flight duration encroaches on an athletes habitual sleep/wake behaviour.[47,69] Therefore it is possible that athletes may enter travel with an accumulated sleep debt, which may be further exacerbated during travel.

In addition to travel fatigue, travel that involves the crossing of several time zones may result in a variety of symptoms occurring in the days following travel, referred to as 'jetlag'.[8,131] Jetlag occurs as a result of the mismatch between a circadian system which is synchronized to the departure time zone and is also influenced by the sleep and wake time at the travel destination.[123] Sleep loss is one of the main reported symptoms of jetlag and as discussed in an earlier section (Chapter 2, Consequences of Disrupted Sleep pp 37-43), a disruption in sleep may impact an athlete's cognitive performance and induce negative perceptual changes including daytime fatigue and changes in mood.[69] Other symptoms of jetlag include irritability, loss of motivation to train, impaired mental and physical functioning, and irregular digestive function.[123,131] The severity of jetlag symptoms depend on the number of time zones crossed, in addition to the direction of travel.[8] For example, difficulties initiating sleep at the destination are observed following eastward flights, due to the circadian system running behind the local time.[123] In this case, the circadian system has to advance in order to adjust to the new time zone.[123] In contrast, following westward travel, the circadian system will be running ahead of the local time.[123] In this instance, the circadian system will need to shift back to adjust to the new time zone.[123] This is often associated with early awakenings following westward travel.[123,131] Ideally, athletes travel should be planned to arrive with adequate days prior to a competition to allow adequate time to adjust to the new time zone.[8]

The time period required for adjustment will be dependant on the number of time zones crossed, however it has been suggested that planning one day for each time zone crossed is reported to allow adequate time for adjustment irrespective of direction of travel.[8]

Similar to travel fatigue, the severity of jetlag symptoms may also have an impact on an athlete's self-reported measures of well-being.[69] Athletes may experience fatigue, tiredness and reduced motivation not only due to the sleep loss associated with jetlag, but also due to impact of the adjustment of the body clock following travel.[131] To date, there have been mixed findings on the impact of international travel on perceived well-being of elite athletes.[4,7,69] For example, no significant differences were observed in the well-being of professional footballers following westward travel, despite reports of truncated sleep durations in-flight.[4] In contrast, depression and greater perceived fatigue and anger were reported following a reduction in both sleep quality and quantity during simulated international travel.[7] As proposed earlier, preserving sleep quality and quantity during long-haul travel may be an important strategy of jetlag management and well-being.[3,8] Future research should aim to further explore the relationship between the quantity and quality of sleep obtained during the travel period on the perceived symptoms of jetlag and well-being upon arrival at the competition destination.[3,8] It has been suggested that preserving sleep quality and quantity during periods of travel may be an important strategy of jetlag management.[133] However there have been limited investigations of the quality or quantity of sleep athletes obtain during international travel in order to assess the association between the sleep obtained during travel and the perceptions of jetlag upon arrival. Therefore, future research should aim to assess the impact of the quality and quantity of sleep obtained during the travel period on subsequent symptoms of jetlag and well-being at the travel destination.

The quantity and quality of sleep obtained during the travel period and the flight arrival time may impact the athletes sleep/wake behaviours upon arrival.[4] For example, professional football players reported 5.5h of truncated in-flight sleep during 18h of long-haul travel, well below the general population sleep duration recommendations and also below the players self-reported habitual sleep duration.[4] As a result, a 'rebound' effect was observed upon arrival at the competition destination, with an increased sleep duration on the first night at the competition destination.[4] A limitation of investigations of athletes sleep following international business class travel is that they have not included an objective assessment of in-flight sleep, which in addition to the athletes sleep/wake behaviours following the flight, may impact the athlete's well-being and performance upon arrival.[69] The self-reported sleep and wellness of professional rugby league players following a business class flight suggests for up to 8 days following a westward flight, that the perceptions of jetlag and self-reported upper respiratory symptoms may be increased.[69] However an objective assessment of sleep obtained in-flight or following the flight was not included in this investigation, which due to the limitations of subjective measures of sleep in a previous section, may not provide a true indication of the impact of the flight has on players well-being and sleep upon arrival.[69] Therefore future research should aim to use objective techniques to measure in-flight sleep to futher explore the impact on international travel on subseqent sleep, well-being and performance.[4]

In addition to influencing the athletes' sleep/ wake behaviour upon arrival, the sleep obtained during the travel period may impact the symptoms of both jetlag and travel fatigue. Due to the perceptual changes that are associated with the symptoms of travel fatigue and jetlag, [132,123,131,69] the impact of athletes' perceptual measures on training load should also be a considered following international travel. The association between self-reported measures of well-being and training load in elite team sport athletes has been discussed in the Training Load and Well-being section (Chapter 2 Monitoring Training Load and the Training Response, pp 51- 52), however these relationships have been largely unexplored together with in-flight sleep following international travel.[4,69,134] One of the few studies that has assessed the impact of international travel on training load, sleep quantity, subjective jetlag ratings and subjective ratings of well-being (fatigue, sleep quality, muscle soreness, stress levels and mood) revealed that training time and load, combined with mean 'wellness' score (determined by summing the 5 scores from the well-being questionnaire) were lower in the week following the travel period.[69] This was likely due to differences in the training schedule in competition destination following travel, compared to the home training week.[69] This investigation revealed that sleep was reduced the night prior to travel due to the early departure time and also following competition which was attributed to the late match finish time.[69] The subjective ratings of jetlag were greater and well-being was reduced throughout the travel week, however it is possible that these ratings may have been confounded by the sleep disruptions associated with pre-flight and competition rather than the impact of the long-haul flight itself.[69] Future research should aim to investigate the relationship between objective in–flight sleep, training load, perceptions of jetlag and self-reported measures of well-being following international travel. Understanding and improving sleep duration and quality during international travel may improve player's well-being and capacity to train and compete upon arrival at the competition destination.

Travel forms an essential part of an athletes training and competition schedule, therefore the impact of the travel schedule on athletes habitual sleep/wake behaviours should be considered when the planning both the travel and the training schedule upon arrival. Given the reported disruptions to sleep prior to and during travel, the interaction between in-flight sleep, perceptions of jetlag, well-being and training load following the travel should be further investigated. Developing an in depth understanding of the interaction between these factors may assist high performance practitioners to effectively plan the travel of elite athletes to minimise the symptoms of travel fatgie and jetlag and to optimise both performance and well-being.

Strategies to Optimise Sleep in Elite Athletes

Due to the possible sleep disruptions elite athletes may experience during training and competition[22,23,30,54,67] and the known role that sleep plays in the recovery process, there are a number of interventions that may be employed to optimise sleep quality and quantity.[65,84,135-137] From normative habitual sleep data of elite athletes, it appears that not only increasing sleep duration, but also implementing strategies to improve the fragmented sleep that elite athletes experience may be an area of focus for high performance programs.[35,52] Common strategies used in the athletic population include sleep extension, napping, and education and implementation of sleep hygiene strategies.[137-140]

Sleep Extension

The performance benefits of sleep are apparent through the extension of sleep duration.[17,65,132,135,136,141] Sleep extension over a one week period improved the serving accuracy of tennis players.[136] The sprint times, skill execution (shooting accuracy), and self-reported mood of collegiate basketball players also improved following a 5-7 week sleep extension period where players were encouraged to obtained as much extra sleep as possible.[17] However, due to the absense of a control arm in this investigation, the performance improvements observed in collegiate basketball players may have been attributed to a training response, rather than the sleep extension intervention.[137] Recent work has assessed the effects of both the extension and restriction of habitual sleep duration on endurance cycling performance.[137] The counter balanced crossover design assessed three conditions: 1) sleep restriction, 2) normal sleep, and 3) sleep extension on time trial performance.[137] The study revealed that sleep extension led to an improved endurance performance when compared to habitual sleep and restricted sleep.[137] In a national netball tournament, the top two finishing teams had a higher sleep duration when compared to lower placed teams, indicating the amount of sleep obtained during a competition may also impact tournament standings.[29] Interestingly, the top two finishing teams also had a higher sleep duration than habitual, which is contrary to previous reports of disrupted sleep characteristics during competition.[29] Extending sleep may be a strategy employed by high performance programs in the lead up to periods with anticipated disrupted sleep including long-haul travel, consecutive days of competition, early morning training and evening matches.[4,23,70] Future research should aim to develop a further understanding of the impact that a range of competition, travel and training scenarios have on elite athletes sleep, to guide the development of individual sleep extension guidelines.

Sleep Hygiene and Education

Sleep hygiene are a combination of behavioural and environmental practices that assist in optimising sleep.[142] Sleep hygiene strategies have been demonstrated to be effective for optimising sleep/wake behaviours in elite athletes.[70,140,142,143] Sleep hygiene education is often included as part of routine education in high performance programs and specific examples of sleep hygiene behaviours include avoiding the use of electronic devices prior to bed time, not watching TV or using screens (e.g., iPads, laptops etc) in bed and establishing a cool, dark and quiet sleep environment.[70] In the general population, individual sleep hygiene education has been demonstrated to significantly improve sleep quality, however the findings in elite sport are mixed.[70,144-146]

Sleep hygiene can be assessed by measuring behaviours and environmental factors that are thought to interfere with sleep.[142] Sleep hygiene can be assessed via The Sleep Hygiene Index, which is a 13 item questionnaire where participants are required to indicate how frequently (always, frequently, sometimes, rarely, never) they engage in particular behaviours e.g., go to bed angry, stressed, upset or nervous or use caffeine or alcohol prior to bed.[142] Each item score is added to provide an assessment of sleep hygiene, a higher score indicating poor sleep hygiene.[142] An acute sleep hygiene strategy was assessed in highly trained amateur football players following an evening match.[70] Players allocated to the sleep hygiene group had no delays post-match to enable them to increase the players opportunity to sleep.[70] In addition, players rooms were temperature and light controlled (17 degrees C), were a provided with optional ear plugs and eye masks, and technology was removed ~30 minutes prior to bed.[70] The sleep hygiene strategy increased the sleep duration of players when compared to non-sleep hygiene group, despite an increase in fragmented sleep.[70] However, the sleep hygiene intervention demonstrated no improvements in markers of muscle damage and inflammation or perceived recovery and stress.[70] In addition, players did not report and differences between the two conditions.[70] In contrast, an acute sleep hygiene education program delivered to elite female athletes, resulted in a significant improvement in sleep duration and wake time..[143]

Personalised sleep hygiene strategies had a positive impact on both the objective and subjective sleep/wake behaviours of elite male cricket players.[145] The sleep hygiene education delivered to players included; strategies to optimise the sleep environment (e.g., a cool, dark and quiet bedroom), establishing a regular sleep/wake routine, minimising the use of stimulants and electronic devices prior to bed and the inclusion of relaxation techniques prior to bed.[145] The targeted individual sleep hygiene education improved the sleep efficiency and the time to fall asleep and daytime sleepiness in elite cricketers assessed via subjective (ASBQ, ESS and PSQI) and objective (wrist actigraphy) measures.[145] Further research is required to establish whether acute sleep hygiene strategies improve sleep in a chronic setting i.e. over a competitive season.[143]

Napping

Napping is a strategy that can be used to supplement disrupted nocturnal sleep, as a recovery tool and has been proposed to increase performance in the afternoon.[138,147,148] Combining nocturnal sleep and a supplementary nap during the daytime has been reported to reduce the decline in cognitive functions of adolescents where sleep duration over a 24h period was less (i.e. 6.5h) than recommended.[148] These findings suggest that a 6.5h nocturnal sleep combined with a l.5h nap achieved similar cognitive performances and mood as the nocturnal sleep only schedule.[148] Combining nocturnal sleep and a daytime nap may be a possible strategy for athletes to obtain an adequate sleep duration when nocturnal sleep is compromised (e.g., following competition or travel).

As mentioned earlier, an afternoon nap following a disrupted night sleep may also counter the inflammatory response associated with sleep restriction.[108] In addition, performance declines in the afternoon and including a nap may be a countermeasure of the "post-lunch dip" and reduce daytime sleepiness.[149] There are however some potential negative effects of napping such as 'sleep inertia', often described as feeling 'foggy' upon waking, which may impact on an athletes alertness and ability to make decisions or impair their reaction time.[149]

To ascertain the ideal nap duration for improving performance following restricted nocturnal sleep, an investigation comparing the benefits of a no nap control, with a nap duration of 5, 10, 20, and 30 minutes.[150] It was determined that a 10min nap was the most effective nap duration following mild nocturnal sleep restriction as this duration resulted in an increase in both performance and alertness when compared to other nap durations.[150] However, nap durations ranging from 9-30 minutes have also demonstrated a positive impact on alertness and performance following restricted nocturnal sleep, although findings regarding the performance improvements have been mixed.[138,139,150] For example, a post-lunch 30 minute nap improved alertness and sprint performance following partial sleep restriction.[138] In contrast, a 20 minute nap prior to the "post-lunch dip" improved daytime sleepiness and subjective ratings of performance however no improvements in performance were observed.[149] It may be important to consider the objective of the nap (e.g., recovery or to compensate for partial sleep restriction) to determine both the timing (e.g., prior to or following a training session or competition) and nap duration.

Elite athletes may include naps into their daily routine to assist with recovery following morning training sessions.[147] The sleep characteristics during a nap taken after a morning endurance training session have been assessed using PSG.[147] In addition, the scheduling of the of the nap, including the time between the training session and the nap on the sleep quality of the recovery nap was investigated.[147] A 90min endurance training session was followed by a 90min daytime nap either 1 or 2h after the training session, commencing at either 1030h or 1130h.[147] The duration of SWS was significantly greater during the 1130h naptime compared with the 1030h naps.[147] However, there was no significant difference in the duration of SWS between a 1h or 2h time interval between training and the nap.[147] In addition, the time interval between endurance training and nap duration had no significant effect on the duration of SWS.[147]

Due to the potential performance benefits following a nap, they may be included as part of pre-match routine for elite athletes.[139] The influence of match day napping on the self-reported energy levels, neuromuscular performance and coach perception of performance have been assessed in elite netball players.[139] Players were required to have 2h of downtime 6h prior to the commencement of each match during each season.[139] During downtime, players were encouraged to stay in their hotel room and were able to individually decide how to use this time to prepare for the match.[139] If a nap was taken, players were required to estimate the duration of the nap.[139] Following this period, players completed their warm up routine which included a team walk, followed by a jump test and completed perceptual measures.[139] The findings of this study revealed that the perceived match performance and objective measure of performance (neuromuscular jump) were higher for players that napped for less than 20 minutes on the day of competition in comparison to athletes that did not nap at all.[139] These findings suggest that providing opportunities in the team schedule to enable elite athletes to sleep prior to competition may have a positive impact on performance.

Monitoring Training Load and the Training Response

Performance in elite sport is a balancing act influenced by the interaction of fitness and fatigue.[151] Training has been defined as the process of systematically performing exercises to improve an athletes physical abilities and to acquire specific sport skills.[12] The exercise bout induces a psychophysiological response, and it is this response that disrupts homeostasis and provides the stimulus for adaptation.[12] These adaptive responses are required to support changes in an athletes physical capacity, injury prevention, health and to optimise performance.[12] As part of the normal training process athletes may experience a state of functional overeaching and an acute reduction in performance.[152] When the training stress and recovery is not balanced, an athlete may suffer from non-functional overeaching which may be characterised by the development of unplanned or persistent fatigue.[11,152] When balance is achieved, the optimal adaptation occurs during a period of recovery.[12,153] The training process to obtain physiological adapatations is outlined in Figure 2.[12] It is suggested that the training program should aim to target the systems that determine performance, including training status, nutriton, the environment and psychological status.[12] Interestingly, despite the known role in the recovery process, sleep has not been considered in this framework.

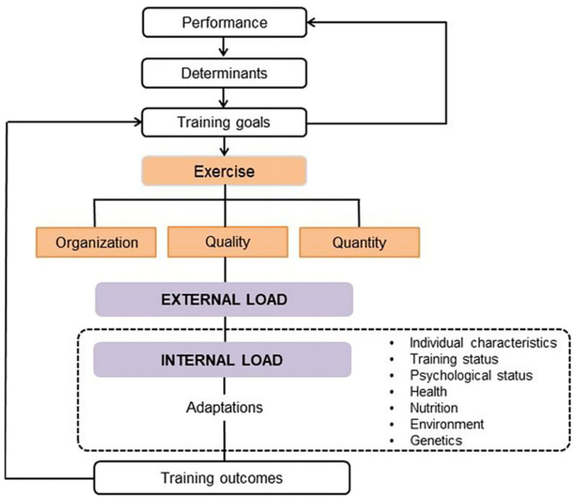

Figure 2: Theoretical Framework of the Training Process. (Impellizzeri F, Marcora S, and Coutts A. Internal and external training load: 15 Years On. *International Journal of Sport Physiology and Performance*. 2019;14:270-273)

Quantifying Training Load

In order to achieve an optimal balance between the training stress and recovery, high performance programs have an emphasis on quantifying training and competition load and the psychophysiological response to that load.[12] Training load can be quantified using both external and internal load metrics.[12] External load refers to "what the athlete did" and is determined by the planning of the training and competition and may include variables such as duration, speed and distance.[154] Internal load refers to "how the athlete responded" and can be measured both subjectively (e.g., rating of perceived exertion (RPE)) and objectively (e.g., heart rate).[12]

In team sports, external load can be measured in 'real time' with microtechnology devices such as Global Positioning Systems (GPS) and accelerometers.[12] Global Positoning System technology is routinely used team sport to examine training and competition load and performances, to assess positional workloads and to establish training intensities.[154] Initially, GPS was used to measure player movement including distance, speed and also the number of accelerations and decelerations.[154] More recently, the inclusion of an internal trixial accelerometer housed in GPS devices enable the sum of accelerations in all three axes (X,Y and Z planes) to enable the measurement of costly movements (eg: physical contact and grappling) not quantified by speed and distance.[154] Microtechnology devices have high reliability (CV = 1.9%) and are valid for quantifying external load in applied settings.[155] Player Load™ (PL)[155] is vector magnitude which combines the rate of acceleration from the three accelerometers, and useful for quantifying all activity including skill and contact based activities related to intermittent team sport.[155] Player Load™ 2D (PL2D) is derived from the anterioposterior and mediolateral accelerometers only[155] whilst Player Load ™ Slow (PL_{slow}) represents activity (e.g., grappling) performed at velocities < $2 m.s^{-1}$.[155] The ability to accurately monitor external load provides coaches and high performance staff with information to precisely plan, implement as well as review training and competition load.[153]

However, the exclusive use of external load measures does not provide a direct indication of the physiological stress imposed on individual athlete.[12] There are various factors, including the athletes health, training status and environmental conditions that may result in an individual athlete experiencing a different internal load when provided with the same external load.[12] Rate of Percieved Exertion (RPE) is a simple, non invasive and inexpensive measure and has been validated as a useful tool to estimate internal load.[156] The RPE scale is a reliable measure used to assess internal load due to strong correlations between RPE and physiological parameters in maximal and submaximal exercise.[157] Training intensity, assessed by the RPE scale and collected following the session, can be used in conjunction with session duration to quantify internal load in athletes.[9] The RPE is multiplied by session duration to calculate a training impulse score, referred to as the session-RPE (s-RPE).[158] As RPE represents psychophysiological effort it may be considered the gold standard for the quantification of internal load. [156]

As outlined in an earlier section, sleep disruption in athletes is associated with reduced cognitive function, altered mood, daytime sleepiness, and an increased reaction time.[17] An alteration in mood has the potential to affect an athletes motivation to train and willingness to give maximal effort.[11] In addition, perception of effort has been reported to increase following sleep deprivation.[11] Given that sleep deprivation can impair mental and physical performance, it is possible that disrupted or fragmented sleep prior to training may also impact individual athletes RPE.[23] Future research should consider the relationship between the sleep obtained prior to a training session and the individual athlete response to the training session through the measurement of session RPE.

Self-Reported Measures of Well-being

Whilst RPE represents the perceived effort during a session and can be combined with duration to provide a representation of internal load, the self-reported ratings of an athletes' response to training is also routinely collected.[159] A common approach used to monitor athletes in high performance programs is to use AROMS where athletes subjectively rate their fatigue, muscle soreness, mood and sleep, etc.[14,159] These inventories are used as status indicators of an athlete's readiness to train and may also aid communication between high performance staff and athletes and also between high performance staff and coaches.[14,160] Various psychometric inventories have been validated to assess an athlete's status during training and competition.[15] In particular, measures of perceived stress and recovery (e.g., (RESTQ-Sport), sleep quality (e.g., Pittsburgh Sleep Quality Index) mood disturbance (e.g., POMS) and life stress and the symptoms of stress (e.g., DALDA) have been investigated and can be used for athlete monitoring.[15] However due to their length and potential burden on the athlete, these inventories not routinely administered in an applied setting.[15]

Due to the ease of administration, customised well-being questionnaires are routinely implemented to assess how an individual athlete is tolerating training, competition and other external stressors.[15] However, the validity of single item well-being questionnaires is currently a matter of debate.[160,161] Originally devised to assist with the monitoring of overtraining, the origin of single item well-being questionnaires have been designed on the work of Hooper et al,[162] which included the following four items; fatigue, sleep quality, muscle soreness and stress.[161] However although routinely used, customised questionnaires are often designed 'in-house' and have not undergone a process of validation.[161]

Customised well-being questionnaires consist of a number of questions which athletes subjectively rate physical (e.g., fatigue and soreness) and psychological or lifestyle factors (e.g., mood, sleep, stress and well-being).[163,164] High performance programs typically administer well-being questionnaires in the morning, prior to the training session or competition using a Visual Analogue or Likert scale.[165] It is however possible that these questionnaires may be vulnerable to measurement error, including unknown biases in both meaning and interpretation.[161,160] Findings from a recent systematic review indicated that it is not known whether these measures respond to training load or influence an athletes recovery.[160] In addition, the sleep items on well-being questionnaires, which often include measures of sleep quality and quantity, have received limited attention.[16,17,16] The self-rating of poor sleep quality may encompasses a number of sleep disturbances issues including, an increased time to fall asleep, frequent awakenings and inadequate sleep duration.[16] Conversely, good sleep quality may represent minimal awakenings, waking feeling refreshed with minimal daytime sleepiness.[16] As a result, subjective ratings of sleep quality may represent several objective sleep characteristics..[16] It is therefore unknown if subjective ratings of sleep quality and quantity in routinely administered well-being questionnaires are reflected in measures of objective sleep quality measured via actigraphy including sleep efficiency, sleep onset latency and WASO in elite athletes.

Training Load and Well-being

Although well-being questionnaires have not necessarily undergone the validation process of other psychometric questionnaires, they have demonstrated some ecological validity.[60,166,165,167] For example, in Australian football, a lower pre training subjective composite wellness score may be associated with a decrease in external load during a training session.[60] In particular, a reduction in pre training wellness Z-scores corresponded to a reduction in PL™ and PL_{slow}.[60] There have been similar findings in American college football players, where subjective wellness Z scores and self-reported energy levels were associated with player load.[168] In particular, self-reported muscle soreness was associated with session-RPE training load, highlighting that perceived soreness may impact the players response to the training demands.[168] It is also possible that perceived soreness may also contribute to fragmented sleep post training.[25,35] However, there is limited information regarding the interactions between internal training load, muscle soreness, and objective sleep characteristics in elite sport.

Composite wellness scores, including total quality recovery (TQR) are often used in high performance programs as a measurement of an athlete's preparedness or readiness to train. [169] Rating of perceived exertion in small sided games in elite soccer players does not seem to be influenced by TQR and well-being measures collected prior to training, suggesting that these measures are not associated with altered internal load intensity during soccer-specific training.[166] There was an association between TQR and the composite score of the wellness measures (Hooper's Index), indicating that the two assessments may have the same objective of providing an indication of an athletes perceived recovery.[166] In contrast, a composite wellness score "Readiness to Train" (RTT), which is used as an measure of pre training and competition readiness has been shown to have no association with running performance.[169] In this instance, the composite wellness score was a poor indicator of pre training and competition readiness.[169] The sub-categories of the RTT that impacted the running performance of elite Gaelic football players included muscle soreness, sleep duration and sleep quality.[169] Given it is unknown if subjective ratings of sleep quality and quantity routinely administered in well-being questionnaires are reflected in measures of objective sleep, future research should aim to include objective measures of sleep to assess the influence of sleep quality on athlete recovery and well-being.

Monitoring external load may provide practitioners with information regarding recovery and well-being that might be expected in individuals following a training session.[170,32] The influence of external load from training and matches on subsequent perceived well-being measurements has been investigated in a number of team sports.[167,171] National Collegiate Athletic Association Division 1 football players who had a significantly ($p<0.05$) lower player load self-reported lower ratings of perceived fatigue and soreness following matches.[167] In contrast, a significantly ($p<0.05$) higher player load was observed in players who reported lower post game stress.[167] There was no impact of pre-match perceived wellness scores on the subsequent external match load in elite Australian football players.[171] Whilst external load is likely to have some influence on the recovery and well-being of athletes following training and competition, factors such as the sleep obtained in the subsequent sleep opportunity are also likely important.[172] Given the reported disruptions to sleep following competition, the interaction between external load and sleep following the session on perceived well-being should also be considered.

Training Load and Sleep

Extended periods of increased exercise intensity may disrupt the sleep quality and quantity of elite athletes.[34] As part of a normal training program, elite athletes will frequently experience periods of intensifed training, including during the lead up to and during competition and training camps.[24,77,173,174] The impact of an increase in training load, in particular during intense periods of training, can impact the sleep/wake behaviours of athletes.[52,76,77,85,173-177] For example, an increased training load in elite synchronised swimmers led to deteriorations in sleep quality and quantity, whilst elite cyclists experienced increased wake episodes and disruptions to self-reported mood, fatigue, stress and tension.[178] Similarily, an increase in training load was associated with reduced total sleep time and sleep efficiency during a simulated grand tour, a unique racing format in which cyclists were required to race 4 to 5h per day for three consecutive weeks.[176] The cyclists mood and general well-being measures declined during the simulated tour.[176] Despite objective measures of sleep efficiency being lower than baseline measures, self-reported sleep quality improved throughout the simulated tour.[176]

In contrast, a recent investigation reported that there was no association between sleep quality and sleep stage distributions (e.g., REM and non-REM) and the day-to-day variation in perceived training load.[34] Specifically, increased training loads were not associated with an increase in REM sleep, suggesting that there were no changes in sleep quantity or sleep stage distribution following daily changes in load.[34] In addition, perceived training loads were not associated with increased WASO or longer sleep onset latencies.[34] These findings suggest that sleep is not compromised by a high training load.[34] In addition it appears that an increase in training load is not associated with significant increases in the proportion of deep sleep.[34] Whilst an increased training load has been associated with reduced sleep quality and quantity and a decrease in subsequent well-being measures including mood, there are a number of factors in addition to training load that may impact the sleep and well-being of athletes following the session. These include the content of training (contact or non-contact), the start time of the training session, sleep obtained prior to the session and the individual response to the load. Therefore, these factors should be considered when assessing the relationship between training load and sleep. Future work should investigate the association between objective sleep (prior to and following the session) and external and internal load during both training and competition.

Prolonged periods of increased exercise is also often associated with training camps, which may impact the sleep/wake behaviours of elite athletes.[36,173] Training camps are often scheduled during the pre-season training phase, in the lead up to competition or may also be a part of the selection process for some sports.[24,173,174] For example, an intensified training load, specifically an increase in training duration, resulted in decreased sleep duration and sleep quality in elite rugby league players during a training camp.[173] However, the change in sleep characteristics observed may have been impacted by a change in sleep environment and training schedule.[173] In contrast, an assessment of the sleep/wake behaviours of elite adolescent female basketball players during a 14 day training camp revealed that the players sleep duration and sleep efficiency remained relatively consistent on nights following days with low, medium and high training loads suggesting that the training load during the camp did not impact the sleep characteristics during the training camp.[76] The interaction between internal and external load and the sleep characteristics of Australian Football players has also been explored in a camp setting.[36] Although the training load between home and camp training conditions did not differ significantly, changes in sRPE showed a moderate negative correlation with sleep duration during the training camp period.[36] Both studies demonstrated that during training camps, bed times and wake times were earlier and WASO and sleep efficiency were negatively affected.[173,174] However, the impact of training load on sleep during these periods may have been confounded by a change in sleep environment.[76,173] Without an understanding of how an athlete sleeps at home, it is not possible to make a comparison of the sleep characteristics exhibited during training camps. Therefore future research should aim to investigate the impact of training and competition load and the sleep/wake behaviours of athletes sleeping in their habitual sleep environment.

The specific content of the training session may also impact the sleep of athletes following the session.[25] Higher acceleration/deceleration training loads have been associated with small increases in sleep efficiency and duration in elite rugby league players during a pre-season training period.[25] Despite no objective or subjective measures of fatigue collected in this study, the authors hypothesized that training involving greater acceleration/decelerations may increase the players' perceptions of fatigue, increasing the players drive to go to sleep.[25] The collection of subjective measures of well-being, in addition to objective measures of sleep and training load, may provide further insight into the possible increased requirement for sleep following training with increased acceleration and deceleration loads.

Although the relationship between training load and sleep has been assessed, there is limited work that reports data in elite female athletes.[50,52,77] In addition, there have been conflicting findings regarding the relationship between training load, well-being and objective measures of sleep in elite female athletes.[50,52,77] For example, a decrease in sleep quality has been observed in professional ballet dancers over several weeks of intensive training in the lead up to a ballet premier performance.[50] This period of intensive training was also associated with mental stress, which may have had an impact on the sleep disruptions observed.[50] Conversely, the sleep duration of national female swimmers, measured via PSG, remained the same between peak and tapered training periods.[52] The time spent in SWS was significantly greater at the onset of higher training volumes and peak training periods when compared to periods of taper, which supports the restorative role of sleep in the athletic population.[52] However, the movement count during sleep was significantly greater during periods of higher training volumes, indicating possible fragmented sleep.[52] This is a similar to the observation of altered sleep efficiency in elite cyclists which was shown to gradually decline across a 9 day training camp and was attributed to an increase in wake bouts and increased movement when compared to the athletes habitual sleep.[178] An increased training load has been shown to have a small effect on muscle soreness, and match-play style training had a small additive effect on reported soreness levels in youth athletes.[35] There is however limited information regarding the interactions between external training load, muscle soreness, and sleep characteristics in elite sport, particularly in female athletes and this warrants further investigation.

Chapter 3: Methodology and Design

The methodology used for each study in this thesis are outlined below. Chapters 4,5 and 6 contain the methods from each study presented according to the author guidelines provided by the journal.

Study One - Competition Sleep Is Not Compromised Compared To Habitual In Elite Australian Footballers.

Participants

Forty-five elite male AF players from the same team were recruited to participate in this study. Participant characteristics were as follows (mean ± SD): height = 188.2 ± 7.3 cm; body mass = 87.0 ± 8.1 kg; age = 22.1 ± 3.3 years; AFL experience = 60 ± 59 games played.

Study Design

Sleep characteristics were assessed over a consecutive 10-day period during the pre-season (habitual) and across four home matches during the Australian Football League season. Habitual baseline sleep data was collected at the end of the pre-season training block. This period was chosen to be the most representative of habitual sleep characteristics, as players were accustomed to the training load and schedule. The same sleeping environment was maintained throughout the monitoring period. The preparation phase training consisted of three on-field training sessions, two strength sessions and a recovery session, all with consistent start times. In-season there were 2-3 field sessions, depending on the match day fixture. The start time of these sessions were also dependent on the match day fixture (start time ranging from 0800h-1000h).

Matches were played at the following times: Early PM (1:40 PM start), Mid-PM (2:10 PM start), Twilight (4:40 PM start), and Evening (7:10 PM start). All matches were played at home. Competition sleep characteristics were measured in the player's home environment. For each match start time, the 22 participants who were selected to play were assigned an activity monitor to be worn the night before (-1), night of (0), one night after (+1), and two nights (+2) after each match. The same team-based recovery (hydrotherapy and immediate nutrition protocols) were implemented after each game. A team recovery session was scheduled the morning after all matches at 0830h. Ethics approval was obtained from the university human research ethics committee, and the study protocols conformed to the recommendations of the Declaration of Helsinki.

Sleep Assessment

Participants undertook sleep monitoring using wrist-worn activity monitors (Actical, Philips Respironics, Inc., Bend, Oregon, USA), which are a valid alternative to polysomnography.[21] Players also recorded bed time (hh:mm) and wake time (hh:mm) in a sleep diary throughout the sleep monitoring period. Each activity monitor contained an omnidirectional piezoelectric accelerometer which sampled movement at 32 Hz. Activity monitors were worn continuously (except during games, contact training, and when in water) and recorded data in 1-min epochs. Sleep diary and activity monitor data was used to determine when participants were awake or asleep (Figure 4).

Time was scored as "sleep" when the following two conditions were met 1) the participant reported in the sleep diary that they were attempting sleep and 2) the activity count recorded on the activity monitor fell below the activity threshold set.[21] Epochs with activity scores that are above the threshold setting used were scored as "wake".[21] The scoring procedure was completed using the Philips Respironics' Actiwatch Algorithm with sensitivity set at "medium".[21] The following information was calculated for each night of sleep during the habitual and competition monitoring period: bed time (hh:mm), wake-up time (hh:mm), sleep onset latency (min), sleep duration (h), wake time (min), number of wake bouts, and sleep efficiency (%). The sleep diary was used by participants to record sleep location, bedtime (hh:mm), and wake-up time (hh:mm). Players completed a self-reported rating of sleep quality, measured on a 1–10 Likert point scale (1 = poor quality, 10 = high quality).

Figure 3: Actical Activity Monitor (Philips Respironics, Inc., Bend, Oregon, USA)

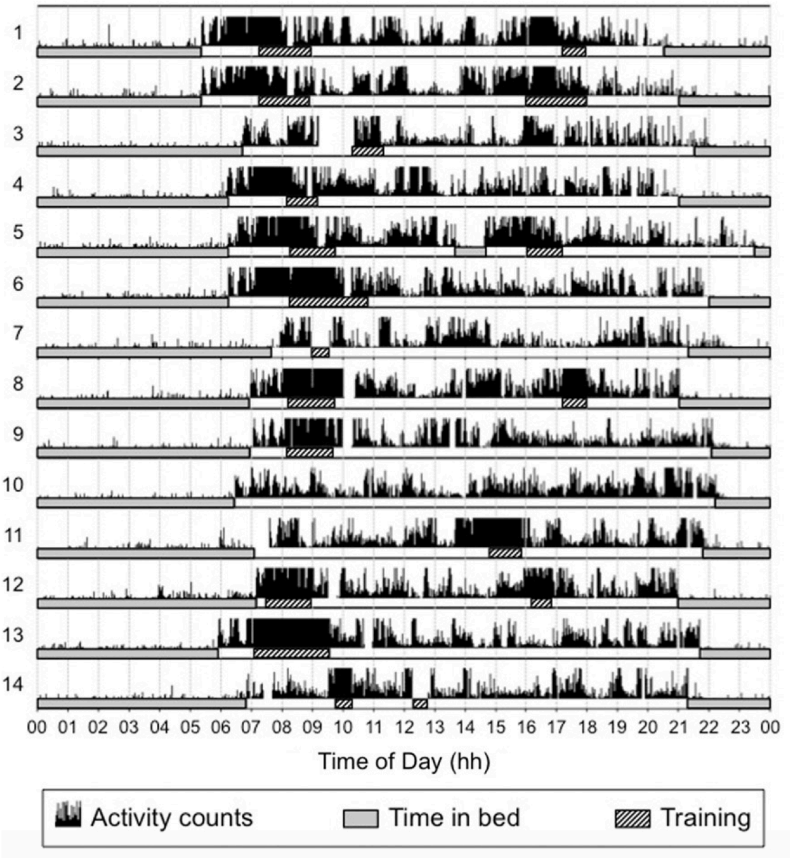

Figure 4: Example of an Athletes Training, Sleep and Activity Monitor Data for Each Night for a 14-day Monitoring Period. Black vertical bars respresent activity counts recorded in 1-min epochs; grey horizonal bars represent time in bed and hatched horizontal bars represent training sessions. (Sargent, C et. al. The impact of training schedules on the sleep and fatigue of elite athletes. Chronobio Int. 2014;31(10):1160-1168.

Statistical Analysis

Statistical analyses were conducted using JMP Pro (version 12, SAS Institute, USA). Exploratory data analysis confirmed that the data met parametric assumptions. A two-way ANOVA with Tukey's post hoc was used (factors: match start time × number of days to game) to examine whether sleep characteristics (e.g., sleep duration, sleep quality) varied between different match start times and different numbers of days relative to a match. A two-way nested ANOVA with Tukey's post hoc was conducted (factors: phase × match start time[phase]) to examine whether differences in sleep characteristics existed between phases (competition vs. habitual) and between each match start time, relative to the habitual phase (i.e., match start time nested within phase). In each case, the effect size ± 90% confidence interval (ES ± 90% CI) was calculated to quantify the magnitude of pairwise differences. Differences were considered practically important where there was > 75% likelihood of exceeding the smallest important ES value (0.2) and classified as: 75–94%, '*likely*'; 95–99%, '*very likely*'; and > 99%, '*almost certainly*'. Effects with less certainty were considered '*trivial*', and where the 90% CI simultaneously crossed substantially positive and negative values, the effect was deemed *'unclear'*.[179]

Study Two - A Complex Relationship: Sleep, External Training Load, and Well-Being in Elite Australian Footballers.

Subjects

Data was obtained from 38 elite male AF players from the same team (mean ± SD): height = 188.2 ± 7.3 cm; body mass = 87.0 ± 8.1 kg; age = 22.1 ± 3.3 years; AFL experience = 60 ± 59 games played. Ethics approval was obtained from the university human research ethics committee, conducted to conform to the recommendations of the Declaration of Helsinki.

Study Design

Participants undertook sleep monitoring over a consecutive 15-day period during the preparation phase of the season. A total of 14 training sessions occurred during the 15-day period. This included five main field, three conditioning, two cross training (boxing and cycling) and four strength training sessions. External training load was assessed for main field sessions only which all started at 9am and were followed by the same hydrotherapy and nutrition recovery protocols. Main field sessions consisted of a standardised warm up, 2 closed skill drills, 2 full ground skill drills, followed by 3 match simulation drills. Players training participation was not modified (e.g., drill participation) the monitoring period

Sleep Assessmenet

The sleep assessment methodology for this study is outlined in the Sleep Assessment section in Study One.

External Training Load

During the field-based training sessions, players wore the same microtechnology device (MinimaxX V4, Catapult Innovations, Melbourne Australia), sampling at 10 Hz. [155,180] Each device housed an internal triaxial accelerometer sampling at 100 Hz and are reported to be reliable (CV = 1.9%) and valid for quantifying external load in field settings.[155] The device sat firmly between the shoulder blades in a vest worn underneath the training jumper. The summation of the triaxial accelerations is determined as Player Load^{TM} (PL).[155] PL and Player Load ™ 2D (PL2D); an accumulation of data from the anterioposterior and mediolateral axes only and Player Load ™ Slow (PL_{slow}); a metric representing activity (e.g., grappling) performed at velocities < 2m.s^{-1}were also recorded. The Player Load ™ (PL) algorithm is a vector magnitude which combines the rate of acceleration from three planes of movement, and is suggested to incorporate all forms of activity including skill and contact based activities related to intermittent team contact sport.[155]

Catapult Sprint (version 5.1.0.3) software was used to download data.

External training load metrics were expressed in absolute form and relative to training duration.

Self-Reported Measures of Well-Being

Self-reported measures of soreness (calf, quad/knee, groin/hip and lower back), mood, sleep quality, sleep duration, leg heaviness, and energy levels were collected each morning prior to training. Well-being questions were completed (95% compliance) using a likert scale (ranging from 1 poor to 10 good) via an application (Smartabase, Fusion Sport) on players' phones.[181]

Statistical Analysis

Exploratory data analysis confirmed that most variables met parametric assumptions. Visual inspection of quantile-quantile plots showed that those variables that did not meet parametric assumptions presented with increasing residuals as the values of the variable increased. Square-root transformations can be effective for variables with such a data structure, so variables that violated parametric assumptions were transformed and then re-tested. The following variables did not meet parametric assumptions even after transformation, and thus were excluded from the primary analysis: bed time, PL_{slow}/min, HIR m, and HIR m/min. Descriptive statistics (median ± interquartile range) were calculated for all sleep, well-being, and external load variables.

Figure 5 outlines the interactions tested in the canonical correlation analysis. The variables used in each 'variable set' are presented in Table 1.

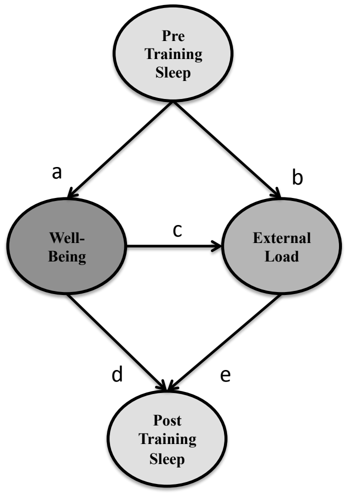

Figure 5: Associations Tested in the Canonical Correlation Analysis. Canonical correlations were used to examine the associations between: a) pre training sleep and subsequent pre training well-being, b) pre training sleep and subsequent external training load, c) pre training well-being and subsequent external training load, d) well-being and post training sleep and e) external training load and post training sleep.

Table 1: Variable Sets used in Canonical Correlation Analysis

External Training Load	**Objective Sleep Characteristics**	**Self-Reported Measures of Well-being**
Absolute loads	Sleep Onset Latency (min)	Mood (AU)
Total Distance (m)	Sleep Duration (hh:mm)	Calf Soreness (AU)
Player Load (AU)	Sleep Efficiency (%)	Leg Heaviness' (AU)
Player Load 2D (AU)	Wake Time (min)	Quad/Knee Soreness (AU)
Player Load Slow (AU)	Wake Bouts (number)	Groin/Hip Soreness (AU)
Maximum Speed (km/h)	Wake Bouts Av Duration (mm:ss)	Lower Back Soreness (AU)
HIR Distance (m)	Wake Up Time (hh:mm)	Sleep Duration (AU)
Loads relative to training duration		Energy Levels (AU)
Average Velocity (m/min)		Hamstring Soreness (AU)
Player Load (AU/min)		Sleep Quality (AU)
Player Load 2D (AU/min)		
HIR Distance (m/min)		

HIR: High Intensity Running > 24 km/h. Wake Bouts Av Duration: Wake Bouts Average Duration.

Canonical correlation analysis is a multivariate approach that quantifies the relationships between two sets of variables and is used to quantify relationships between multiple variables simultaneously.[182] This multivariate technique was selected because each of the primary measures in this study comprise multiple variables that, in combination, represent a person's sleep, external load, or well-being. To quantify relationships between two variable sets, the canonical correlation analysis procedure produces functions that are akin to multiple linear regressions.[182] Each function uses the variables from each variable set as inputs to two regressions (one for each variable set). Each regression produces one synthetic variable (i.e., one canonical dimension, or simply, dimension) for each variable set. The aim of these functions is to maximise the correlation strength between any pair of dimensions. Additionally, this analysis will produce as many dimensions as there are variables in the smaller variable set.[182] The dimensions are distinct from each other as they arise from different linear combinations of the same input variables, and must meet the condition of *double orthogonality*, where 'both synthetic variables in subsequent canonical functions must be uncorrelated with both synthetic variables in all preceding functions'.[182] Readers seeking more details about this procedure and its application are encouraged to review the primer on canonical correlation analysis written by Sherry & Henson.[182] Consider a canonical correlation analysis of the sleep and well-being variables. The first canonical function will produce Sleep Dimension 1 and Well-being Dimension 1. Sleep Dimension 1 is a linear combination of multiple sleep variables; the same concept applies for the Well-being Dimension 1. The weighting or contribution of each variable to its dimension is adjusted in the analysis to maximise the correlation strength between Sleep Dimension 1 and Well-being Dimension 1. The second canonical function will produce Sleep Dimension 2 and Well-being Dimension 2. In this function, the analysis again adjusts the weighting of each input variable to satisfy the condition of double orthogonality. Because of this condition, the strongest possible canonical correlation will always present between the Dimension 1 pairing, while subsequent canonical correlations express relationships given the residual variance in the variable sets that were unexplained by the preceding canonical function(s).

Key results produced by a canonical correlation analysis include: i) tests of dimensionality, ii) canonical loadings (also known as structure coefficients), and iii) cross-loadings. Tests of dimensionality produce the canonical dimensions, the canonical correlation coefficients between dimensions, and the statistical significance of each canonical correlation. The strength of relationships between dimensions (i.e., canonical correlations) is expressed using Pearson's correlation coefficient (r), interpreted in accordance with established thresholds[183] where: weak = $-0.3 > r \leq -0.1$ and $0.1 \geq r < 0.30$; moderate = $-0.5 > r \leq -0.3$ and $0.3 \geq r < 0.50$; and strong = $r \leq -0.5$ and $r \geq 0.5$. Canonical correlations that are statistically significant ($p < 0.05$) are presented in the results. Canonical loadings are also expressed as Pearson's *r*, where the coefficient represents the relationship between each variable in a variable set and the canonical dimension for the same variable set. The loading of each variable onto its canonical dimension is calculated in the presence of all other contributing variables to the same canonical dimension; as a result, canonical loadings are not affected by multicollinearity.[184] Cross-loadings represent the relationship between each variable in one variable set and the canonical dimension for the other variable set.[182]

All analyses were conducted using R (version 3.5.1)[185] and the following packages: 'dplyr' and 'reshape2' for data preparation[186] [187] 'MVN' for assumption testing {Korkmaz S, 2014} and 'CCA' for the canonical correlation analyses.[188]

Study Three - Business Class Travel Preserves Sleep Quality and Quantity and Minimised Jetlag During the Women's T20 Cricket World Cup.

Participants

Data was obtained from 11 elite female cricketers from the same team (mean ± SD): height = 168.4 ± 6.9 cm; body mass = 62.7 ± 4.7 kg; age = 24.1 ± 3.3 years. Ethics approval was obtained from the university human research ethics committee and the study conformed to the recommendations of the Declaration of Helsinki.

Study Overview

This study was conducted prior to departure and during the 2016 International Cricket Council (ICC) Women's T20 World Cup. The team were seated in business class and travelled west from Melbourne Australia (GMT + 10) to Chennai India (GMT +5.5), crossing 5.5 time zones. The outbound flight departed Melbourne at 0330h with a stopover in Dubai for 2 hours. The arrival time in Chennai was 2010h local time (0140h Melbourne). The total travel time was 19h 35min (Flight 1 Melbourne to Dubai: 13h 20min, Transit: 2h, Flight 2 Dubai to Chennai: 4h 15min). Refer to Figure 6 for the travel timeline. General sleep hygeine education was provided to players prior to departure for the tournament. This included recommendations on electronic device use prior to bed, optimal room environment and the importance of maintaining habitual sleep and wake routines. Players were encouraged to sleep when possible during travel. Upon arrival in India the players completed five training sessions (nets and field) followed by pool recovery, two strength sessions and one recovery session. A 'no team communication period' was scheduled from 1430 h to 1530h on selected days during the team schedule to allow players to disconnect from their phones or nap if they chose to. Players competed in one warm-up match and two T20 World Cup tournament matches during the monitoring period. Matches were played at 1530h (2) and 1930h (1). Refer to Figure 6 for the tournament period timeline. No sleep medication was used during the flights or the tournament. Objective sleep characteristics, subjective measures of well-being, perceived ratings of jetlag and training and competition internal load measures were collected throughout the monitoring period.

IF1	IF2		N1		N2		N3		N4		N5		N6		N7		N8		N9		N10		N11		N12	
Depart	Transit	Arrive																								
Melbourne Wed 03:30 (Chennai Wed 21:00) ^	**Arrive 12:55** (Melb Wed 19:55 Chennai Wed 14:15) **Depart 14.55** (Melb Wed 20:45 Chennai Wed 16:15)	**Chennai Thurs 20:10** (Melb Fri 1:40)		**9:00 Train** * ^ #		**9:30 Train** **15:00 Strength** * ^ # >		**8:30 Train** * ^ #		**15:30** * ^ #		**Rest** *^ >		**9:30 Depart** *		**14:30 Train** * #		**19:30** * # >		**11:00 Pool** * >		**9:00 Train** **17:30 Function** * #		**15:30** * #		**6:30 Depart** **14:00 Strengt h** * #

Figure 6: Study Design. IF1 and IF2 indicates the two in-flight sleep bouts over the two dates during the travel period from Melbourne, Australia to Chennai, India. Objective Sleep collection period. N1-N12 Indicates the night of the objective sleep monitoring during the tournament period. * Indicates self-reported measures of well-being were collected. ^ Indicates perceptions of jetlag were collected # Indicates training/or match load was collected. > Indicates team 'no communication zone'.

Represent match played and domestic flight respectively.

Objective Sleep Measures

The sleep assessment methodology is outlined in the Sleep Assessment section in Study One (Chapter 3 Methodology and Design, Sleep Assessment pp 62-63).

Habitual Sleep

Habitual sleep was measured in the players home sleep environment over a consecutive 5-day training period, 8 weeks post-tournament. This period was selected due to the travel and domestic competition commitments prior to departure. No travel or competition was scheduled during this period.

In-Flight Sleep

Players wore an activity monitor at all times during the international flights and transit. Players were seated in business class with seats that could recline to a flat bed. In addition to the procedures outlined above, players used the time stamp function on the activity monitor to assist identifying sleep periods.

Tournament Sleep

Day-time naps and night-time sleep periods were measured for twelve consecutive days. The team travelled once domestically (Chennai to Nagpur, no change in time zone), staying at two different five-star hotels. Players had their own room and could control conditions (e.g., light and temperature). There were no team curfews in place.

Assessment of Training and Competition Load

Training load was calculated as the product of session-RPE (s-RPE) and training session duration (min). This information was collected via the Cricket Australia Athlete Management System (AMS, Fair Play Pty Ltd) as part of routine monitoring.

Self-Reported Measures of Well-Being

Self-reported measures of soreness, fatigue, sleep, stress and total wellness score were collected daily. These questions were completed using a Likert scale (ranging from 1 = poor to 5 = excellent) via the AMS application on players' phones.[9]

Perceptions of Jetlag

Subjective ratings of jetlag (AM and PM) were assessed using a visual analogue scale (ranging from 1 very bad jetlag to 5 no jetlag) at 0900h and 1800h local time for six days after arrival.

Statistical Analysis

All analyses were conducted using R (version 4.0.2)[189] and the following packages: 'here' for managing script files;[190] 'readxl' for data importing[191] 'dplyr', 'stringr', 'janitor', 'tidyr', 'purrr' and 'tibble' for general data preparation tasks;[192-196] 'lubridate' and 'chron' for working with date and time data;[197,198] 'ggplot2' and 'patchwork' for data visualisation;[199,200] 'knitr' and 'kableExtra' for creating data tables;[201,202] 'nparLD' for conducting the non-parametric factorial analyses;[203] and 'psych' for conducting correlation analyses.[204]

Most variables violated parametric assumptions, so non-parametric techniques were used. Statistical significance was set at $p < 0.05$.

To determine the impact of in-flight sleep on tournament measures, a median split was used to create sub-samples based on 1) in-flight sleep quantity (two groups: higher vs. lower) and 2) in-flight sleep quality (two groups: higher vs. lower). Two non-parametric factorial analyses[203] were conducted with a two-way design to test for differences between groups and across tournament dates: 1) in-flight duration group x date, and 2) in-flight efficiency group x date. The non-parametric factorial approach is analogous to the parametric ANOVA, and its primary output is the F-type statistic. Where significant main or interaction effects were identified, pairwise comparisons were performed with Dunn-Bonferroni corrections to reduce the risk of Type I errors.

Descriptive statistics were calculated and plotted to show how the team's sleep, perceived jetlag, and self-reported well-being changed over the course of the tournament. Further context was added to the description and visualisation of tournament sleep by incorporating team means for habitual sleep, to illustrate where nightly sleep deviated from habitual values.

Spearman's correlation coefficients (rho) were calculated to assess the bivariate associations between i) sleep measures and internal training and/or playing loads incurred on the subsequent day, ii) sleep measures and self-reported well-being recorded on the subsequent day, iii) sleep and perceived ratings of jetlag recorded on the subsequent day.

Chapter 4: Study One - Competition Sleep Is Not Compromised Compared To Habitual In Elite Australian Footballers.

Publication statement:

This chapter is comprised of the following paper in the form published (with some minor textual edits) in the *International Journal of Sports Physiology and Performance.*

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. No compromise of competition sleep compared with habitual sleep in elite Australian footballers. Int J Sports Physiol Perform. 2018;13(1):29-36.

Linking Paragraph

In an attempt to optimise performance and well-being, there is an increased focus to objectively measure athletes sleep quality and quantity in High Performance Sport. However, the analysis of the objective sleep characteristics of elite team sport athletes prior to and during important competition periods is limited. There are a number of investigations that fail to compare findings during competition periods to how athletes sleep in their habitual sleep and training environment, which may lead to incorrect conclusions regarding the impact competition has on athletes sleep. Previous research in AF has focused on the sleep characteristics relating extreme match start time comparisons (e.g., day vs. night), or assessed a single match start time in isolation, without the consideration of other match start times in the competition schedule. Chapter 4 aimed to assess the sleep characteristics of elite AF players during the competitive season in response to different match start times and compare in-season sleep characteristics to habitual sleep characteristics.

Abstract

To assess the impact of match start time and days relative to match compared to the habitual sleep characteristics of elite Australian Football (AF) players. Forty-five (45) elite male AF players were assessed during the pre-season (habitual) and across four home matches during the season. Players wore an activity monitor the night before (-1), night of (0), one night after (+1), and two nights (+2) after each match and completed a self-reported rating of sleep quality. A two-way ANOVA with Tukey's post hoc was used to determine differences in sleep characteristics between match start times and days relative to the match. Two-way nested ANOVA was conducted to examine differences between competition and habitual phases. The Effect size ± 90% confidence interval (ES ± 90% CI) was calculated to quantify the magnitude of pairwise differences. Differences observed in sleep onset latency (ES=0.11 ± 0.16), sleep rating (ES=0.08 ± 0.14) and sleep duration (ES=0.08 ± 0.01) between competition and habitual periods were trivial. Sleep efficiency (%) was almost certainly higher during competition than habitual, however this was not reflected in the subjective rating of sleep quality. Elite AF competition does not cause substantial disruption to sleep characteristics compared to habitual sleep. Whilst match start time has some impact on sleep variables, it appears that the match itself is more of a disruption than the start time. Subjective ratings of sleep from well-being questionnaires appear limited in their ability to accurately provide an indication of sleep quality.

Key Words: Actigraphy, Recovery, Team Sport, Performance.

Introduction

Australian Football (AF) is an intermittent team sport in which players cover large distances at high speed, including frequent accelerations, decelerations and collisions.[205] The season can produce high levels of fatigue, and optimising recovery in order to maximise performance is critical.[205] Numerous strategies are commonly implemented in an attempt to maximise the rate of recovery including hydrotherapy, compression garments, and individualised nutrition programs. Often under-utilised in high performance environments, given its restorative role, sleep has the potential to assist with optimising recovery in team sport athletes. Although the exact role of sleep in the recovery in team sport athletes has been questioned,[206] developing an understanding of both the habitual and competition sleep characteristics of AF players may influence recovery practices.

Shift work patterns typified by extremely early or late start times which can lead to individuals incurring a sleep debt have been shown to negatively impact sleep and recovery.[66] The AF competition schedule includes a variety of day, twilight, and evening match start times that may have similar effects on sleep quality and quantity in AF players. However, limited objective data exists with regard to the effect of different match start times on sleep when compared to habitual sleep characteristics.[90]

In previous research, sleep duration and onset have been shown to be altered in AF players during pre-season competition, although these findings may have been confounded by interstate travel.[30] Furthermore, the pre-season period may not be a reflection of sleep/wake characteristics exhibited during the competitive season. Regardless of phase, analysis of sleep characteristics should include comparisons to the habitual sleep environment during non-competition periods in order to avoid under- or over-estimating changes in sleep characteristics.

Understanding how match start time impacts objective and subjective measures of sleep compared to habitual sleep characteristics may assist with optimising training programs and recovery protocols. Therefore, the aims of the study were to (1) assess the sleep characteristics of elite AF players during the competitive season in response to different match start times, and (2) compare in-season sleep characteristics to habitual sleep characteristics.

Methods

Data was obtained from 45 elite male AF players from the same team. Participant characteristics were as follows (mean ± SD): height = 188.2 ± 7.3 cm; body mass = 87.0 ± 8.1 kg; age = 22.1 ± 3.3 years; AFL experience = 60 ± 59 games played. Ethics approval was obtained from the university human research ethics committee.

Participants undertook sleep monitoring using wrist-worn activity monitors (Philips Respironics, Inc., Bend, Oregon, USA), which are a valid alternative to polysomnography.[21] Participants recorded the start and end of each sleep period (including daytime naps) in a sleep diary. Activity monitors were worn continuously (except during games, contact training, and when in water) and recorded data in 1-min epochs.

Sleep characteristics were assessed over a consecutive 10-day period in the pre-season (habitual) and across four home matches during the Australian Football League season. Baseline data was collected at the end of the pre-season training block. This period was chosen to be the most representative of habitual sleep characteristics, as players were accustomed to the training load and schedule. The same sleeping environment was maintained throughout the monitoring period. Preparation phase training consisted of three on field trainings sessions, two strength sessions and a recovery session, all with consistent start times. In season there were 2-3 field sessions, depending on the match day fixture. The start time of these sessions were also dependent on the match day fixture (start time ranging from 8.00am-10.00am).

Matches were played at the following times: Early PM (1:40 PM start), Mid-PM (2:10 PM start), Twilight (4:40 PM start), and Evening (7:10 PM start). All matches were played at home. Competition sleep characteristics were measured in the player's home environment. For each match start time, the 22 participants who were selected to play were assigned an activity monitor to be worn the night before (-1), night of (0), one night after (+1), and two nights (+2) after each match. The same team-based recovery (hydrotherapy and immediate nutrition protocols) were implemented after each game. A team recovery session was scheduled the morning after all matches at 8.30am. No sleep education was provided prior to or during the sleep monitoring period.

Self-report and activity monitor data was used to determine when participants were awake or asleep. Time was scored as "sleep" when the following two conditions were met 1) the participant reported in the sleep diary that they were attempting sleep and 2) the activity count recorded on the activity monitor fell below the activity threshold set.[21] Epochs with activity scores that are above the threshold setting used were scored as "wake".[21] The scoring procedure was completed using the Philips Respironics' Actiwatch Algorithm with sensitivity set at "medium".[21] The following information was collected from the activity monitors: bed time (hh:mm), wake-up time (hh:mm), sleep onset latency (min), sleep duration (h), wake time (min), number of wake bouts, and sleep efficiency (%). The sleep diary was used by participants to record sleep location, bedtime (hh:mm), and wake-up time (hh:mm). Players completed a self-reported rating of sleep quality, measured on a 1–10 Likert point scale (1 = poor quality, 10 = high quality).

Statistical Analysis

Statistical analyses were conducted using JMP Pro (version 12, SAS Institute, USA). Exploratory data analysis confirmed that the data met parametric assumptions. A two-way ANOVA with Tukey's post hoc was used (factors: match start time × number of days to game) to examine whether sleep characteristics (e.g., sleep duration, sleep quality) varied between different match start times and different numbers of days relative to a match. A two-way nested ANOVA with Tukey's post hoc was conducted (factors: phase × match start time[phase]) to examine whether differences in sleep characteristics existed between phases (competition vs. habitual) and between each match start time, relative to the habitual phase (i.e., match start time nested within phase). In each case, the effect size ± 90% confidence interval (ES ± 90% CI) was calculated to quantify the magnitude of pairwise differences. Differences were considered practically important where there was > 75% likelihood of exceeding the smallest important ES value (0.2) and classified as: 75–94%, '*likely*'; 95–99%, '*very likely*'; and > 99%, '*almost certainly*'. Effects with less certainty were considered '*trivial*', and where the 90% CI simultaneously crossed substantially positive and negative values, the effect was deemed *'unclear'*.[179]

Results

Habitual and Competition Sleep Characteristics

Table 2: Habitual and Competition Sleep Characteristics (mean ± SD).

Sleep Variable	Habitual Period	Competition Period
Sleep onset latency (min)	12.0 ± 0.9	11.0 ± 1.3
Sleep duration (hr:min)	533.0 ± 0.07	485.0 ± 0.09
Sleep efficiency (%)	81.35 ± 0.38	85.56 ± 0.50
Total wake time (min)	79.0 ± 1.69	57.0 ± 2.25
Rating of sleep quality	7.6 ± 0.1	7.5 ± 0.1
Bed time (hh:mm)	22:35 ± 0:07	23:02 ± 0:08
Wake time (hh:mm)	7:20 ± 0:06	7:35 ± 0:08

Table 2 shows sleep characteristics exhibited in habitual and competition periods. Players went to bed later during competition (ES = 0.33 ± 0.12, *likely*). There was *almost certainly* (ES = 0.55 ± 0.21) greater sleep efficiency during the competition period and *likely* (ES = 0.29 ± 0.13) lower number of wake bouts, however the difference in wake time was *unclear* (ES = 0.20 ± 0.45). Differences between the competition and habitual periods in sleep onset latency, sleep rating, sleep duration, and wake-up time were *trivial*.

Comparisons of sleep characteristics between competition and habitual periods for different match start times are displayed in Table 3. There were *almost certain* increases in sleep efficiency and total wake time when comparing Early PM, Mid-PM, and Twilight match start times to habitual sleep profiles. Sleep efficiency (%) was *almost certainly* higher during the competition phase than habitual, but this was not reflected in subjective ratings of sleep quality where differences were *trivial.* All other differences in sleep characteristics between competition and habitual periods were *trivial*, regardless of match start time.

Table 3: Differences in Sleep Characteristics Between Habitual and Competition Phases for Different Match Start Times (mean ± SD and ES ± 90% CI).

Sleep Variable	Early PM	Mid-PM	Twilight	Evening
Sleep onset latency (min)	3.5 ± 2.5 ES = 0.18 ± 0.22 Trivial	3.3 ± 3.6 ES = 0.18 ± 0.32 Trivial	2.2 ± 2.7 ES = 0.11 ± 0.23 Trivial	1.3 ± 2.0 ES = 0.07 ± 0.18 Trivial
Sleep duration (min)	18.1 ± 11.2 ES = 0.22 ± 0.22 Trivial	23.3 ± 16.3 ES = 0.31 ± 0.33 Trivial	0.1 ± 12.14 ES = 0.00 ± 0.13 Trivial	18.4 ± 9.1 ES = 0.22 ± 0.17 Trivial
Sleep efficiency (%)	6.3 ± 1.0 ES = 0.81 ± 0.31 Almost Certainly ↑	7.3 ± 1.4 ES = 0.94 ± 0.35 Almost Certainly ↑	8.3 ± 1.1 ES = 1.10 ± 0.40 Almost Certainly ↑	0.2 ± 0.8 ES = 0.02 ± 0.14 Trivial
Total wake time (min)	25.6 ± 4.3 ES = 0.82 ± 0.31 Almost Certainly ↓	31.5 ± 6.3 ES = 0.9 ± 0.34 Almost Certainly ↓	40.0 ± 4.7 ES = 1.2 ± 0.45 Almost Certainly ↓	7.0 ± 3.5 ES = 0.2 ± 0.16 Trivial
Number of wake bouts	1.5 ± 2.0 ES = 0.10 ± 0.22 Trivial	7.8 ± 2.9 ES = 0.54 ± 0.32 Very Likely ↓	3.7 ± 2.1 ES = 0.25 ± 0.24 Trivial	3.7 ± 1.6 ES = 0.25 ± 0.17 Trivial
Rating of sleep quality	0.01 ± 0.20 ES = 0.01 ± 0.15 Trivial	0.50 ± 0.30 ES = 0.36 ± 0.34 Likely ↓	0.09 ± 0.18 ES = 0.07 ± 0.24 Trivial	0.08 ± 0.10 ES = 0.06 ± 0.16 Trivial
Bed time (hh:mm)	0.16 ± 0.11 ES = 0.19 ± 0.22 Trivial	0.14 ± 0.16 ES = 0.17 ± 0.32 Trivial	0.17 ± 0.12 ES = 0.2 ± 0.24 Trivial	0.42 ± 0.09 ES = 0.5 ± 0.19 Almost Certainly ↑
Wake-up time (hh:mm)	0.19 ± 0.10 ES = 0.25 ± 0.23 Trivial	0.25 ± 0.15 ES = 0.33 ± 0.33 Likely ↑	0.01 ± 0.11 ES = 0.01 ± 0.17 Trivial	0.11 ± 0.08 ES = 0.14 ± 0.18 Trivial

Difference in means between habitual and competition periods as an ES ± 90% CI. ES change direction refers to difference in competition phase compared to habitual. A difference between habitual and competition values was considered practically important (↑ = increase/later, ↓ = decrease/earlier) when there was a > 75% likelihood exceeding the smallest important ES value (0.2) Differences with a likelihood of 75-95% were considered “likely”, 95-99% “very likely”, and >99.5% almost certainly. Smaller changes were considered “trivial” and where the 90% CI simultaneously overlapped substantially positive and negative values the difference was considered “unclear”.

Table 4 shows sleep variables in the habitual period compared to the competition period, based on the number of days relative to the match. There was an *almost certain* reduction in sleep duration and increased wake time for +2 days post-match. Similar to the comparison between match start times, the objective measure of sleep efficiency and subjective rating of sleep quality displayed different magnitudes of change.

Table 4: Differences in Sleep Characteristics Between Habitual and Competition Phases for Different Days Relative to Match (mean ± SD and ES ± 90% CI).

Sleep variable	**-1**	**0**	**+1**	**+2**
Sleep onset latency (min)	0.98 ±17.31 ES= -0.47 ± 0.71 Unclear	2.28 ± 29.69 ES= -0.25 ± 0.78 Unclear	1.42 ± 18.8 ES= 0.38 ± 0.46 Trivial	0.53 ± 11.9 ES=0.78 ± 0.96 Likely ↑
Sleep duration (min)	51.45 ±50.25 ES= 1.31 ± 0.36 Almost Certainly ↑	77.12 ± 78.68 ES=-2.56 ± 0.85 Almost Certainly ↓	21.15 ± 91.79 ES=-0.24 ± 0.49 Unclear	5.75 ±60.17 ES=2.51 ± 1.00 Almost Certainly ↓
Sleep efficiency (%)	3.58 ± 4.62 ES= 0.77 ± 0.29 Almost Certainly ↑	4.58 ±6.73 ES=0.97 ± 0.47 Almost Certainly ↑	2.35 ± 9.67 ES=0.77 ± 0.42 Very Likely ↑	3.6 ±6.58 ES=-0.13 ± 0.43 Unclear
Total wake time (min)	11.94 ± 25.94 ES=-0.72 ±0.40 Very Likely ↓	30.57 ± 32.47 ES=-2.72 ± 1.08 Almost Certainly ↓	15.83 ± 36.86 ES=-1.77 ± 1.01 Very Likely ↓	21.13 ±29.81 ES=0.79 ± 1.56 Unclear
Number of wake bouts	0.49 ± 7.60 ES=-0.09 ± 0.38 Unclear	7.33 ± 9.05 ES=-2.17 ± 1.23 Very Likely ↓	3.98 ± 9.93 ES=-0.71 ± 0.53 Likely ↓	3.18 ±9.80 ES=1.72 ± 1.35 Very Likely ↓
Rating of sleep quality	-0.26 ± 0.97 ES=0.67 ± 0.95 Unclear	0.14 ± 1.35 ES=-0.90 ± 1.64 Unclear	-0.08 ± 1.14 ES=-3.06 ± 1.44 Almost Certainly ↑	0.77 ± 1.34 ES=-1.29 ± 1.97 Unclear
Bed time (hh:mm)	0.04 ± 0.36 ES=0.11 ± 0.30 Trivial	0.56 ± 0.26 ES=3.20 ± 0.72 Almost Certainly ↑	-0.14 ±1.27 ES=-0.22 ± 0.33 Trivial	0.08 ± 0.39 ES=-3.39 ± 0.79 Almost Certainly ↓
Wake time (hh:mm)	1.11 ± 3.10 ES=0.98 ± 0.51 Very Likely ↑	1.18 ± 3.28 ES=0.98 ± 0.38 Almost Certainly ↑	0.54 ± 2.54 ES=-0.85 ± 0.40 Almost Certainly ↑	1.19 ± 2.28 ES=-1.80 ± 0.61 Almost Certainly ↑

Difference in means between habitual and competition periods as an ES ± 90% CI. ES change direction refers to difference in competition phase compared to habitual. A difference between habitual and competition values was considered practically important (↑ = increase/later, ↓ = decrease/earlier) when there was a > 75% likelihood exceeding the smallest important ES value (0.2) Differences with a likelihood of 75-95% were considered “likely”, 95-99% “very likely”, and >99.5% almost certainly. Smaller changes were considered “trivial” and where the 90% CI simultaneously overlapped substantially positive and negative values the difference was considered “unclear”.

Differences Between Match Start Times and Days Relative to Match

Figure 7 shows sleep characteristics based on match start time and the number of days to match. Comparisons between match start times are displayed in Table 5. In many cases, the differences between match start times were *trivial* or *unclear*. The evening match start time, compared to all other start times, resulted in the clearest differences (e.g., evening matches had a *likely* longer sleep latency and *almost certainly* lower sleep efficiency).

Figure 7: Sleep Characteristics for Different Match Start Times and Days Relative to the Match (mean ± SD).

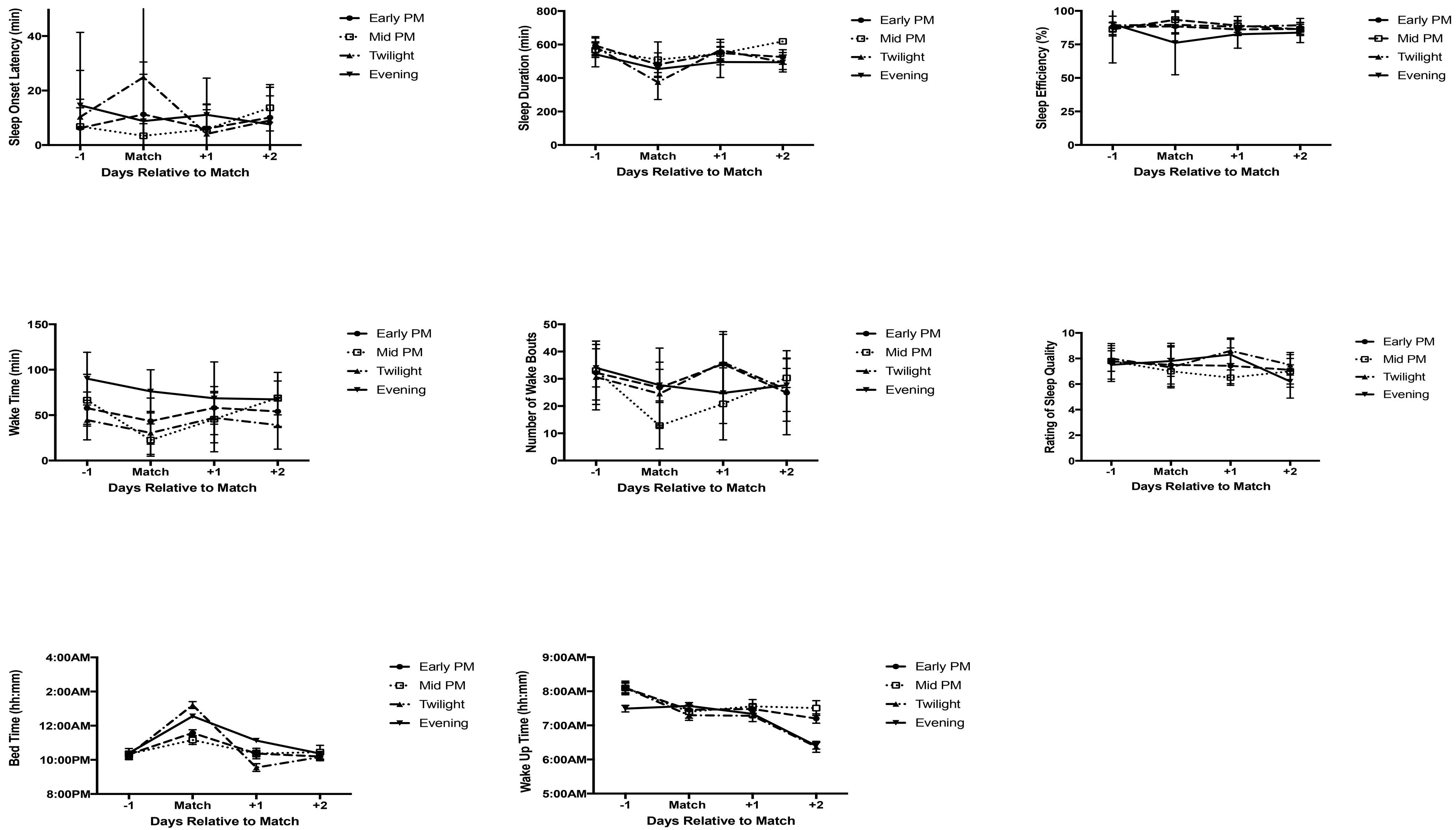

Table 5: Pairwise Differences in Sleep Characteristics by Match Start Time (mean ± SD and ES ± 90% CI).

Sleep Variable	Mid-PM vs. Early PM	Twilight vs. Early PM	Evening vs. Early PM	Twilight vs. Mid-PM	Evening vs. Twilight	Evening vs. Mid-PM
Sleep onset latency (min)	1.2 ± 4.5 ES = 0.06 ± 0.40 Unclear	0.04 ± 3.8 ES = 0.08 ± 0.27 Trivial	8.3 ± 3.0 ES = 0.45 ± 0.25 Likely ↑	1.2 ± 4.7 ES = 0.07 ± 0.47 Unclear	8.3 ± 3.3 ES = 0.45 ± 0.28 Likely ↑	9.5 ±4.0 ES = 0.50 ± 0.35 Likely ↑
Sleep duration (min)	8.0 ± 10.3 ES = 0.09 ± 0.19 Trivial	19.5 ± 8.5 ES = 0.21 ± 0.14 Trivial	35.3 ± 7.1 ES = 0.38 ± 0.14 Very Likely ↓	27.5 ± 10.7 ES = 0.30 ± 0.18 Likely ↓	15.8 ± 7.7 ES = 0.17 ± 0.13 Trivial	43.3 ± 9.7 ES = 0.47 ± 0.18 Very Likely ↓
Sleep efficiency (%)	2.8 ±1.7 ES = 0.37 ± 0.36 Likely ↑	0.2 ± 1.4 ES = 0.02 ± 0.27 Unclear	9.0 ± 1.1 ES = 1.20 ± 0.45 Almost Certainly ↓	3.0 ± 1.7 ES = 0.39 ± 0.37 Likely ↑	9.2 ± 1.2 ES = 1.20 ± 0.45 Almost Certainly ↓	6.2 ± 1.5 ES = 0.80 ± 0.30 Almost Certainly ↓
Total wake time (min)	13.6 ± 6.7 ES = 0.44 ± 0.35 Likely ↓	1.7 ± 5.7 ES = 0.05 ± 0.28 Unclear	37.3 ± 4.4 ES = 1.20 ± 0.45 Almost Certainly ↑	15.3 ± 7.0 ES = 0.49 ± 0.36 Likely ↓	39.1 ± 4.9 ES = 1.26 ± 0.48 Almost Certainly ↑	23.8 ± 6.0 ES = 0.76 ± 0.29 Almost Certainly ↑
Number of wake bouts	1.5 ± 2.8 ES = 0.12 ± 0.38 Unclear	2.9 ± 2.4 ES = 0.24 ±0.33 Trivial	0.2 ± 1.9 ES = 0.02 ± 0.30 Unclear	1.5 ± 2.9 ES = 0.12 ± 0.40 Unclear	2.7 ± 2.0 ES = 0.22 ± 0.28 Trivial	1.2 ± 2.5 ES = 0.10 ± 0.34 Unclear
Rating of sleep quality	0.2 ± 0.3 ES = 0.13 ± 0.38 Unclear	0.2 ± 0.3 ES = 0.19 ± 0.35 Trivial	0.2 ± 0.2 ES = 0.13 ± 0.26 Trivial	0.1 ± 0.3 ES = 0.05 ± 0.37 Unclear	0.1 ± 0.2 ES = 0.05 ± 0.26 Unclear	0.0 ± 0.26 ES = 0.00 ± 0.00 Trivial
Bed time (hh:mm)	0.25 ± 0.34 ES = 0.29 ± 0.72 Unclear	0.03 ± 0.29 ES = 0.03 ± 0.45 Unclear	0.07 ± 0.25 ES = 0.08 ± 0.41 Unclear	0.28 ± 0.35 ES = 0.32 ± 0.68 Unclear	0.10 ± 0.25 ES = 0.12 ± 0.45 Unclear	0.25 ± 0.34 ES = 0.29 ± 0.72 Unclear
Wake time (hh:mm)	0.02 ± 0.19 ES = 0.08 ± 0.39 Unclear	0.01 ± 0.15 ES = 0.2 ± 0.3 Trivial	0.26 ± 0.12 ES = 0.11 ± 0.26 Trivial	0.02 ± 0.19 ES = 0.32 ± 0.37 Trivial	0.26 ± 0.13 ES = 0.12 ± 0.27 Trivial	0.28 ± 0.17 ES = 0.19 ± 0.35 Trivial

Difference in means between habitual and competition periods as an ES ± 90% CI. ES change direction refers to difference in first mentioned match time compared to second mentioned match time. A difference between habitual and competition values was considered practically important (↑ = increase/later, ↓ = decrease/earlier) when there was a > 75% likelihood exceeding the smallest important ES value (0.2) Differences with a likelihood of 75-95% were considered “likely”, 95-99% “very likely”, and >99.5% almost certainly. Smaller changes were considered “trivial” and where the 90% CI simultaneously overlapped substantially positive and negative values the difference was considered “unclear”.

Table 6 shows differences in sleep characteristics based on days relative to the match. Differences were primarily *trivial*, however there were *almost certain* decreases in sleep duration for the night of the match compared to +1 and +2 nights post-match.

Table 6: Differences in Sleep Characteristics for Days Relative to Match (mean ± SD and ES ± 90% CI).

Sleep variable	-1 vs 0	-1 vs +1	-1 vs +2	0 vs +1	0 vs +2	1 vs +2
Sleep onset latency (min)	3.9 ± 1.9 ES = 0.20 ± 0.20 Trivial	1.5 ± 2.0 ES = 0.08 ± 0.18 Trivial	2.0 ± 2.0 ES = 0.11 ± 0.18 Trivial	5.4 ± 2.0 ES = 0.29 ± 0.17 Likely ↑	1.9 ± 2.0 ES = 0.10 ± 0.18 Trivial	3.5 ± 2.0 ES = 0.19 ± 0.18 Trivial
Total sleep time (min)	123.9 ± 7.9 ES = 1.40 ± 0.51 Almost Certainly ↑	23.4 ± 8.2 ES = 0.26 ± 0.14 Likely ↑	40.8 ± 8.4 ES = 0.45 ± 0.17 Very Likely ↑	100.6 ± 8.1 ES = 1.10 ± 0.41 Almost Certainly ↓	83.1 ± 8.2 ES = 0.91 ± 0.34 Almost Certainly ↓	17.5 ± 8.5 ES = 0.19 ± 0.15 Trivial
Sleep efficiency (%)	0.9 ± 0.7 ES = 0.11 ± 0.15 Trivial	0.003 ± 0.8 ES = 0.00 ± 0.05 Trivial	0.3 ± 0.8 ES = 0.04 ± 0.17 Trivial	0.9 ± 0.7 ES = 0.11 ± 0.16 Trivial	1.2 ± 0.7 ES = 0.15 ± 0.16 Trivial	0.3 ± 0.8 ES = 0.04 ± 0.17 Trivial
Total wake time (min)	3.9 ± 1.9 ES = 0.21 ± 0.17 Trivial	1.5 ± 2.0 ES = 0.07 ± 0.16 Trivial	2.0 ± 2.0 ES = 0.11 ± 0.18 Trivial	5.4 ± 2.0 ES = 0.29 ± 0.17 Likely ↓	1.9 ± 2.0 ES = 0.10 ± 0.18 Trivial	3.5 ± 2.1 ES = 0.19 ± 0.18 Trivial
Number of wake bouts	9.0 ± 1.2 ES = 0.75 ± 0.28 Almost Certainly ↑	3.9 ± 1.3 ES = 0.32 ± 0.16 Likely ↑	4.1 ± 1.3 ES = 0.34 ± 0.16 Likely ↑	5.2± 1.2 ES = 0.43 ± 0.16 Very Likely ↓	4.9 ± 1.2 ES = 0.41 ± 0.15 Very Likely ↓	0.2 ± 1.3 ES = 0.02 ± 0.19 Trivial
Rating of sleep quality	0.2 ± 0.1 ES = 0.13 ± 0.17 Trivial	0.3 ± 0.1 ES = 0.24 ± 0.17 Trivial	0.5 ± 0.1 ES = 0.36 ± 0.16 Likely ↑	0.1 ± 0.1 ES = 0.11 ± 0.18 Trivial	0.3 ±0.1 ES = 0.22 ± 0.17 Trivial	0.1 ± 0.1 ES = 0.11 ± 0.17 Trivial
Bed Time (hh:mm)	1.44 ± 0.14 ES = 1.20 ± 0.45 Almost Certainly ↓	0.04 ± 0.15 ES = 0.04 ± 0.28 Unclear	0.16 ± 0.06 ES = 0.19 ± 0.29 Trivial	1.47 ± 0.14 ES = 1.20 ± 0.45 Almost Certainly ↑	2.00 ± 0.15 ES = 1.40 ± 0.52 Almost Certainly ↑	0.13 ± 0.16 ES = 0.15 ± 0.30 Trivial
Wake-up Time (hh:mm)	0.13 ± 0.10 ES = 0.22 ± 0.27 Trivial	0.25 ± 0.10 ES = 0.4 ± 0.24 Likely ↑	1.05 ± 0.10 ES = 1.2 ± 0.40 Almost Certainly ↑	0.12 ± 0.24 ES = 0.21 ± 0.28 Trivial	0.52 ±0.10 ES = 0.92 ± 0.35 Almost Certainly ↑	0.40 ± 0.10 ES = 0.72 ± 0.27 Almost Certainly ↑

Difference in means between habitual and competition periods as an ES ± 90% CI. ES change direction refers to difference in first mentioned day to match compared to second mentioned day to match. A difference between habitual and competition values was considered practically important (↑ = increase/later, ↓ = decrease/earlier) when here was a > 75% likelihood exceeding the smallest important ES value (0.2) Differences with a likelihood of 75-95% were considered “likely”, 95-99% “very likely”, and >99.5% almost certainly. Smaller changes were considered “trivial” and where the 90% CI simultaneously overlapped substantially positive and negative values the difference was considered “unclear”

Discussion

A major finding of this work was that sleep efficiency (an indirect objective measure of sleep quality) was higher during the competition period compared to habitual. The evening match caused the most disruptions to sleep characteristics during the competition period and the night of the match had lower sleep duration when compared to other nights relative to the match. Furthermore, the subjective sleep rating was not aligned with the objective measure of sleep quality in either the habitual or competition period.

When in their home environment, AF players sleep longer than other athletic populations.[18] The habitual sleep duration of 533.0 ± 0.07 minutes observed in the present study is higher than has been reported in rugby union[31], Olympic athletes[18], endurance cycling [32], and Olympic swimmers[22], but is similar to previous findings in AF.[26] [2] Despite the apparently longer sleep durations of the athletes in this study, previously reported values may not be a true reflection of habitual sleep characteristics. In some instances, habitual sleep values have been determined using a short baseline period and prior to competition.[31] Critically, this study established habitual sleep characteristics over ten consecutive nights, as five or more nights are required to obtain reliable measures.[74] As a result, our findings suggest habitual sleep duration in AF players is not compromised.

Despite sleeping longer than other athletic populations, habitual sleep efficiency (81.35%) was considerably lower than previously observed in AF (~90%) [2,26] and below the recommendation for healthy adults (90%).[207] This may indicate that players are experiencing sleep difficulties, potentially impairing their ability to obtain sufficient restorative sleep. This lower sleep efficiency compared to other findings in AF may be due to an increased exposure to technology (e.g., smart phones) over the last decade. Device use prior to bed may negatively affect sleep quality through sleep disturbances[208] and increase awakenings[209]. Poor sleep habits, lack of a pre-bed routine, and / or disturbances in the sleep environment (e.g., light, temperature, and noise) may also have contributed to the differences observed between the present study's findings and the existing literature. [70] It may also be that the players were instinctively extending their sleep duration as a result of poor sleep efficiency. Adjusting environmental conditions, implementing sleep routines and other sleep hygiene strategies may improve the quality and quantity of AF players' sleep, and have been previously shown to be effective for team sport athletes.[210] In agreement with previous findings[86], these results revealed large individual variation in habitual sleep variables (e.g., sleep duration range 142–699 minutes), which highlights the importance of evaluating sleep in athletes on an individual-specific basis.

It appears that it is particularly challenging for AF players to obtain optimal sleep after evening matches[53]. Longer sleep onset latency, lower sleep efficiency, and increased wake time were exhibited in our study for the evening match compared to other match start times. Shorter sleep duration and longer sleep latency after an evening match compared to a day match has been observed previously in AF.[30] However, these findings from the existing literature may have been confounded by the change in time zone and unfamiliar sleep environment.[24] In contrast, no difference was evident in any measures of sleep observed in a night match compared to a day match and non-match days in a national youth soccer team.[211] Given the potential disruption to sleep characteristics after an AF match played in the evening, avoiding an early start time for morning sessions in the days following may be advisable.

While it might be assumed that players would exhibit better sleep characteristics after day matches than later match start times,[53] the highest sleep efficiency occurred after the Twilight match. Previous research in AF has compared more extreme match start times (e.g., day vs. night), or assessed a single match start time in isolation, which limits the ability to make comparisons between the available literature and results from the current study. Disruptions in sleep efficiency following day matches suggest that any match, rather than the start time, may cause disrupted sleep.[53] As a result, practitioners should not focus solely on late matches when implementing strategies to optimise sleep.

Sleep duration was longer on the night before a match than on other nights before and after a match. The morning of the match was the only day the players did not have to attend a morning training session, and this may have provided an opportunity for players to extend their sleep duration. Athlete sleep behaviour has been observed to change depending on the time of training[23], including a later bed time and wake time when not required to attend training until the early evening.[85] Despite no commitments in the morning, AF players in this study actively went to bed earlier on the night before a match compared to the night of a match. A novel finding was that, despite a longer sleep duration than all other days relative to match, AF players exhibited shorter sleep latency (9minutes) the night before the match, which is similar to population norms (11minutes).[212] The precise reason for this is not clear, although this result suggests that the potential impact of pre-match anxiety on prolonging time to fall asleep prior to competition was not a factor here.[54]

Similar to previous findings in elite rugby union, this study revealed a *likely* longer sleep latency on the night of the match compared to the night after the match, and shorter sleep duration on the night of the match compared to all other nights during the competition period.[31] Despite an early morning recovery session scheduled after each match, a later bed time was observed compared to all other nights. Interestingly, players did not use the earlier finish time of day matches to extend their sleep by going to bed closer to their habitual bed time. This may be due to the players using the post-match period as a time to socialise.[86] Another possible explanation is that the psycho-physiological effects of the match (e.g., arousal, pain) may have delayed the drive to go to bed.[54] Providing sleep education to improve bed time habits, encourage players to bring forward their bed time following day time matches may increase sleep duration, assist with sleep onset latency and sleep quality[210], which may reduce perceptions of fatigue over the season.[17]

Sleep duration remains shorter on +1 night after (544 ± 6 minutes) and +2 nights after a match (526 ± 7 minutes), compared to the night before a match (567 ± 6 minutes). Combined with reduced sleep duration on the night of the match, there is potential for individual players to accumulate a sleep debt during competition periods[54], however comparison with habitual values suggests this is unlikely (see following discussion). Despite disruptions to sleep efficiency on the night of the match, no players napped in the days following an evening match or extended their total sleep time. Extending sleep from 7 to 9h per night reportedly improves performance and wakefulness in athletes[136], and this may be a focus for sleep hygiene education.[17] However, the impact of sleep extension strategies during competition has not been empirically investigated in this population.

Although an AF match scheduled in the evening provides a challenge to obtaining optimal sleep, differences in sleep duration, latency, and efficiency were *trivial* compared to habitual values. This highlights that competition sleep characteristics of AF players were not compromised when compared to habitual sleep values. Interestingly, sleep efficiency was higher for all match start times compared to habitual values. In contrast, differences between the rating of sleep quality for the Early PM, Twilight and Evening match start time and habitual values were *trivial,* emphasising that subjective ratings of sleep quality were not aligned with objective measures[62]. Despite anecdotal concerns, practitioners should not assume that sleep during competition periods is compromised. Furthermore, competition sleep characteristics should be evaluated in combination with habitual sleep values from an appropriate baseline period. Critically, due to the mismatch between subjective and objective measures of sleep quality in both phases, actigraphy should be used to evaluate sleep in athlete populations.

The shorter sleep duration on the night of the match can be attributed to a later bed time for the reasons previously discussed. The *unclear* difference in sleep duration between 1 night after the match and habitual values appears to be due to substantial inter-individual variation. As sleep duration and time taken to fall asleep was *almost certainly* shorter 2 nights after the match compared to habitual values, the greatest opportunity to influence AF players sleep duration occurs within the two nights following a match.

Due to the large inter-individual variability observed, differences in sleep onset 1 night before the match and on the night of the match compared to habitual values were *unclear*. Feelings of anxiety or excitement may impact players on an individual level, and in turn, influence their ability to fall asleep prior to a match.[54] Therefore, strategies to enhance sleep should be customised to the individual.

The *almost certainly* higher sleep efficiency 1 night before, on the night of, and 1 night after the match than observed in the habitual period appears to be due to an increased wake time in the habitual period. This further supports the contention that sleep characteristics of AF players is not compromised during competition periods. Habitual sleep quality may be improved by reducing wake time through establishing bed time/wake time routines, adjusting the habitual sleep environment, or limiting electronic device use before bed.[213]

While sleep efficiency on days relative to the match was higher than habitual values, the differences between the habitual rating of sleep quality to ratings on the night before, the night of, and 2 nights after a match were *unclear*. It has been acknowledged that individuals have difficulties assessing their own sleep patterns[214], further highlighting the limitations of subjective ratings. Although validated sleep questionnaires are inexpensive and non-invasive, they are too lengthy for routine use in high-performance environments.[54] As a result, practitioners often implement shortened questionnaires similar to the one used in this study, however these findings indicate that such an approach may not provide accurate measures of sleep quality.[60]

Limitations

The limitations of this study should be taken into account when interpreting results. Firstly, only one match per start time was included in the analysis. A longitudinal investigation may provide further insight into the effect of match start time, days to game and travel during the AF season. It is acknowledged that numerous factors may influence the sleep characteristics of AF players, including training and match day load. Further research examining the interactions between training load, well-being, and sleep characteristics may be beneficial.

Practical Applications

Sleep characteristics during AF competition periods do not appear to be compromised compared to habitual sleep characteristics. Strategies to enhance sleep quality and quantity should focus on the nights immediately following a match when the most disruption is evident. Due to the apparent inaccuracy of subjective ratings of sleep quality obtained from shortened questionnaires, practitioners should aim to collect objective sleep data using validated techniques.

Conclusions

In general, elite AF competition does not appear to impart substantial disruption to sleep characteristics when compared to habitual sleep. Whilst match start time has some impact on sleep variables, it appears that any match, irrespective of match start time may cause disruptions to players sleep characteristics. As a result, the clearest interruption to sleep occurs in the nights immediately following a match, and this provides the ideal opportunity for intervention. Importantly, subjective ratings of sleep from shortened well-being questionnaires appear limited in their ability to accurately provide an indication of sleep quality.

Chapter 5: Study Two - A Complex Relationship: Sleep, External Training Load, and Well-Being in Elite Australian Footballers.

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Linking Paragraph

Study 1 revealed that the competition sleep characteristics of elite AF players were not compromised when compared to habitual sleep characteristics. Whilst it appears that it is particularly challenging for AF players to obtain optimal sleep after evening matches, all matches, irrespective of start time caused some disruption to sleep. The clearest interruption to sleep occurred in the nights immediately following a match. In addition to the match start time and the night following an AF match, numerous factors may influence the sleep characteristics of AF players, including player well-being and training and match day load. Despite the known restorative effects of sleep and the important role it may play in minimising fatigue, optimising recovery and well-being, the relationship between load, well-being and sleep prior to and following training and matches is not clear.[1] Chapter 5 aimed to the assess the association between objective sleep characteristics, self-reported measures of well-being and external load of AF players.

Abstract

To assess relationships between objective sleep characteristics, external training loads, and subjective ratings of well-being in elite Australian Football (AF) players. Thirty-eight elite male AF players recorded objective sleep characteristics over a 15-day period using an activity monitor. External load was assessed during main field sessions and ratings of well-being were provided each morning. Canonical correlation analysis was used to create canonical dimensions for each variable set (sleep, well-being and external load). Relationships between dimensions representing sleep, external load and well-being were quantified using Pearson's *r*. Canonical correlations were moderate between pre training sleep and external training load (*r* range = 0.32–0.49), pre training sleep and well-being (*r* = 0.32), and well-being and post training sleep (*r* = 0.36). Moderate-to-strong correlations were observed between dimensions representing external training load and post training sleep (*r* range = 0.31 to 0.67) and well-being and external training load (*r* range = 0.32 to 0.67). Player Load (PL) and Player Load 2D (PL2D) showed the greatest association to pre and post training objective sleep characteristics and well-being. Fragmented sleep was associated with players completing the following training with a higher PL2D. Maximum speed, PL and PL2D were the common associations between objective sleep characteristics and well-being in AF players. Improving pre training sleep quality and quantity, may have a positive impact on AF players' well-being and movement strategy during field sessions. Following training sessions that have high maximum speed and PL2D, the increased requirement for sleep should be considered by ensuring that subsequent sessions do not start earlier than required.

Key Words: Actigraphy, Team Sport, Fatigue, Player Load ™.

Introduction

Australian Football (AF) is a high-intensity, intermittent team sport involving tackling and collisions.[155] Monitoring training and competition loads is imperative to optimise performance[205] and can be conducted using session-RPE (sRPE), and microtechnology devices.[155] Self-report well-being questionnaires are a practical tool that can provide insight to an athlete's status in areas such as muscle soreness, stress and injury.[165] The perceived well-being of AF players has been shown to influence the exercise intensity of subsequent field-based training sessions[60] and therefore may provide coaches an indication of the external load that can be expected during a AF training session.[205] A common component in these questionnaires is a subjective rating of sleep quality, however recent work has demonstrated that this may have limited accuracy as an indicator of sleep quality in AF players.[215]

The prevalence of poor sleep in elite athletes is high[54], although the objective sleep characteristics of AF players prior to and during competition has been shown to not be compromised compared to habitual sleep.[215] However, habitual sleep efficiency, an objective measure of sleep quality was suboptimal (81.35%) in this population compared to recommendations for healthy adults (90%).[83] Whilst numerous factors including training and competition load may influence AF players habitual sleep, the interaction between internal and external load and the sleep characteristics of AF players has only been explored in a camp setting, where changes in sRPE showed a moderate negative correlation with sleep duration.[36] Importantly, the relationship between load and the sleep characteristics following the training session were not investigated. Higher training loads have been associated with small increases in sleep quality and quantity in other football codes during the pre-season period.[25] However, this investigation did not include measures of subjective athlete well-being, and the commercially available sleep device utilised does not measure key characteristics of sleep, including sleep onset latency.

The aim of the study was to assess the relationships between objective sleep characteristics, external training load, and subjective ratings of well-being in elite AF players. Specifically, we aimed to: (1) assess the association between sleep characteristics during sleep prior to a main training session and subsequent ratings of well-being and external load in the training; (2) determine if subjective ratings of well-being and measures of external load from training are associated with objective sleep characteristics in the subsequent sleep opportunity; and (3) assess if ratings of well-being are associated with the external loads during AF training.

Methods

Subjects

Data was obtained from 38 elite male AF players from the same team (mean ± SD): height = 188.2 ± 7.3 cm; body mass = 87.0 ± 8.1 kg; age = 22.1 ± 3.3 years; AFL experience = 60 ± 59 games played. Ethics approval was obtained from the university human research ethics committee, conducted to conform to the recommendations of the Declaration of Helsinki.

Objective Sleep Characteristcs

Participants undertook sleep monitoring over a consecutive 15-day period during the preparation phase of the season. Validated wrist-worn activity monitors, were used to measure sleep (Philips Respironics, Inc., Bend, Oregon, USA)[21]. Activity monitors were worn continuously (except during contact training and when in water) and data was recorded in 1-min epochs. Participants recorded the start and end of each sleep period in a sleep diary.[216] The same sleeping environment was maintained throughout the monitoring period.

The combination of paper sleep-diary and activity monitor data was used to determine when participants were awake or asleep. A detailed description of the scoring of sleep using the sleep diary and activity monitor has been previously provided.[215] The following information was collected from the activity monitors: bed time (hh:mm), wake up time (hh:mm), sleep onset latency (min), sleep duration (h), wake time (min), number of wake bouts, wake bouts average duration (mm:ss) and sleep efficiency (%). The sleep diary was used by participants to record sleep location, bed time (hh:mm), and wake up time (hh:mm). The sleep diary was reviewed at regular intervals during the monitoring period.

External Training Load

A total of 14 training sessions occurred during the 15-day period. This included five main field, three conditioning, two cross training (boxing and cycling) and four strength training sessions. External training load was assessed for main field sessions only which all started at 9am and were followed by the same hydrotherapy and nutrition recovery protocols. Main field sessions consisted of a standardised warm up, 2 closed skill drills, 2 full ground skill drills, followed by 3 match simulation drills. No players were modified from drills during the monitoring period.

During the field-based training sessions, players wore the same microtechnology device (MinimaxX V4, Catapult Innovations, Melbourne Australia), sampling at 10 Hz. [155,180]The device sat firmly between the shoulder blades in a vest worn underneath the training jumper. Each device also housed an internal triaxial accelerometer sampling at 100 Hz. The summation of the triaxial accelerations is determined as Player Load™ (PL).[155] PL and Player Load ™ 2D (PL2D); an accumulation of data from the anterioposterior and mediolateral axes only and Player Load ™ Slow (PL_{slow}); a metric representing activity (e.g., grappling) performed at velocities < 2m.s^{-1}were also recorded. These variables are demonstrated to have acceptable levels of reliability. Catapult Sprint (version 5.1.0.3) software was used to download data. External training load metrics were expressed in absolute form and relative to training duration, as outlined in Table 1.

Self-Reported Measures of Well-Being

Self-reported measures of soreness (calf, quad/knee, groin/hip and lower back), mood, sleep quality, sleep duration, leg heaviness, and energy levels were collected each morning prior to any training. Well-being questions were completed (95% compliance) using a likert scale (ranging from 1 poor to 10 good) via an application (Smartabase, Fusion Sport) on players' phones.[181]

Statistical Analysis

Exploratory data analysis confirmed that most variables met parametric assumptions. Visual inspection of quantile-quantile plots showed that those variables that did not meet parametric assumptions presented with increasing residuals as the values of the variable increased. Square-root transformations can be effective for variables with such a data structure, so variables that violated parametric assumptions were transformed and then re-tested. The following variables did not meet parametric assumptions even after transformation, and thus were excluded from the primary analysis: activity monitor measured bed time, PL_{slow}/min, HIR m, and HIR m/min. Descriptive statistics (median ± interquartile range) were calculated for all sleep, well-being, and external load variables.

Figure 8 outlines the associations tested in the canonical correlation analysis. The variables used in each 'variable set' are presented in Table 7.

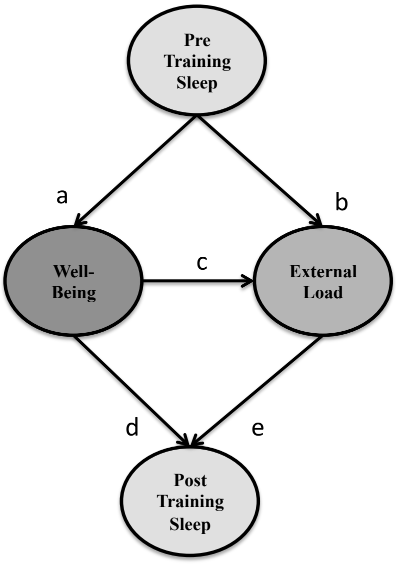

Figure 8: Associations Tested in the Canonical Correlation Analysis. Canonical correlations were used to examine the associations between: a) pre training sleep and subsequent pre training well-being, b) pre training sleep and subsequent external training load, c) pre training well-being and subsequent external training load, d) well-being and post training sleep and e) external training load and post training sleep.

Table 7: Variable Sets Used in Canonical Correlation Analysis

External Training Load	**Objective Sleep Characteristics**	**Self-Reported Measures of Well-being**
Absolute loads	Sleep Onset Latency (min)	Mood (AU)
Total Distance (m)	Sleep Duration (hh:mm)	Calf Soreness (AU)
Player Load (AU)	Sleep Efficiency (%)	Leg Heaviness' (AU)
Player Load 2D (AU)	Wake Time (min)	Quad/Knee Soreness (AU)
Player Load Slow (AU)	Wake Bouts (number)	Groin/Hip Soreness (AU)
Maximum Speed (km/h)	Wake Bouts Av Duration (mm:ss)	Lower Back Soreness (AU)
HIR Distance (m)	Wake Up Time (hh:mm)	Sleep Duration (AU)
Loads relative to training duration		Energy Levels (AU)
Average Velocity (m/min)		Hamstring Soreness (AU)
Player Load (AU/min)		Sleep Quality (AU)
Player Load 2D (AU/min)		
HIR Distance (m/min)		

HIR: High Intensity Running > 24 km/h. Wake Bouts Av Duration: Wake Bouts Average Duration.

Canonical correlation analysis is a multivariate approach that quantifies the relationships between two sets of variables and is used to quantify relationships between multiple variables simultaneously.[182] This multivariate technique was selected because each of the primary measures in this study comprise multiple variables that, in combination, represent a person's sleep, external load, or well-being. To quantify relationships between two variable sets, the canonical correlation analysis procedure produces functions that are akin to multiple linear regressions.[182] Each function uses the variables from each variable set as inputs to two regressions (one for each variable set). Each regression produces one synthetic variable (i.e., one canonical dimension, or simply, dimension) for each variable set. The aim of these functions is to maximise the correlation strength between any pair of dimensions. Additionally, this analysis will produce as many dimensions as there are variables in the smaller variable set.[182] The dimensions are distinct from each other as they arise from different linear combinations of the same input variables, and must meet the condition of *double orthogonality*, where 'both synthetic variables in subsequent canonical functions must be uncorrelated with both synthetic variables in all preceding functions'.[182] Readers seeking more details about this procedure and its application are encouraged to review the primer on canonical correlation analysis written by Sherry & Henson.[182]

For example, consider a canonical correlation analysis of the sleep and well-being variables. The first canonical function will produce Sleep Dimension 1 and Well-being Dimension 1. Sleep Dimension 1 is a linear combination of multiple sleep variables; the same concept applies for the Well-being Dimension 1. The weighting or contribution of each variable to its dimension is adjusted in the analysis to maximise the correlation strength between Sleep Dimension 1 and Well-being Dimension 1. The second canonical function will produce Sleep Dimension 2 and Well-being Dimension 2. In this function, the analysis again adjusts the weighting of each input variable to satisfy the condition of double orthogonality. Because of this condition, the strongest possible canonical correlation will always present between the Dimension 1 pairing, while subsequent canonical correlations express relationships given the residual variance in the variable sets that were unexplained by the preceding canonical function(s).

Key results produced by a canonical correlation analysis include: i) tests of dimensionality, ii) canonical loadings (also known as structure coefficients), and iii) cross-loadings. Tests of dimensionality produce the canonical dimensions, the canonical correlation coefficients between dimensions, and the statistical significance of each canonical correlation. The strength of relationships between dimensions (i.e., canonical correlations) is expressed using Pearson's correlation coefficient (r), interpreted in accordance with established thresholds[183] where: weak = -

$0.3 > r \leq -0.1$ and $0.1 \geq r < 0.30$; moderate = $-0.5 > r \leq -0.3$ and $0.3 \geq r < 0.50$; and strong = $r \leq -0.5$ and $r \geq 0.5$. Canonical correlations that are statistically significant ($p < 0.05$) are presented in the results. Canonical loadings are also expressed as Pearson's *r*, where the coefficient represents the relationship between each variable in a variable set and the canonical dimension for the same variable set. The loading of each variable onto its canonical dimension is calculated in the presence of all other contributing variables to the same canonical dimension; as a result, canonical loadings are not affected by multicollinearity.[184] Cross-loadings represent the relationship between each variable in one variable set and the canonical dimension for the other variable set.[182]

All analyses were conducted using R (version 3.5.1)[185] and the following packages: 'dplyr' and 'reshape2' for data preparation[186] [187] 'MVN' for assumption testing {Korkmaz S, 2014 #146} and 'CCA' for the canonical correlation analyses.[188]

Results

Sleep Characteristics, External Training Load and Well-Being

Sleep characteristics, external load from five on-field training sessions, and self-reported measures of well-being are shown in Table 8.

Table 8: Objective Sleep Characteristics, External Training Load and Self-Reported Measures of Well-Being.

Parameter	Median ± IQR
Sleep Characteristics	
Sleep onset latency (min)	5 ± 19
Sleep duration (hr:min)	8:32 ± 1.29
Sleep efficiency (%)	81.90 ± 9.14
Wake time (min)	77 ± 40
Wake Bouts (number)	31 ± 11
Wake Bouts Av Duration (mm:ss)	02.30 ± 0.39
Bed time (hh:mm)	22:43 ± 1.17
Wake up time (hh:mm)	07:23 ± 1.14
External Load Field Training Sessions	
Absolute loads	
Total Distance (m)	5997 ± 2572
Player Load (AU)	593 ± 304
Player Load 2D (AU)	355 ± 175
Player Load Slow (AU)	174 ± 100
Maximum Speed (km/h)	27.9 ± 3.2
HIR Distance (m >24/km/hr)	266 ± 342
Loads relative to training duration	
Player Load (AU/min)	10.31 ± 5.80
Player Load 2D (AU/min)	6.31 ± 3.67
Player Load Slow (AU/min)	2.98 ± 1.22
Average Velocity (m/min)	111 ± 58
HIR Distance (m/min>24/km/hr)	3.33 ± 5.93
Self-Reported Measures of Well-Being	
Mood (AU)	7 ± 1
Calf Soreness (AU)	7 ± 2
Leg Heaviness (AU)	7 ± 1
Quad/Knee Soreness (AU)	7 ± 1
Groin/Hip Soreness (AU)	7 ± 1
Lower Back Soreness (AU)	7 ± 2
Sleep Duration (AU)	8 ± 1
Energy Levels (AU)	7 ± 2
Hamstring Soreness (AU)	7 ± 1
Sleep Quality (AU)	8 ± 1

IQR:Interquartile Range, HIR: High Intensity Running, Wake Bouts Av Duration: Wake Bouts Average Duration.

Pre Training Sleep and External Training Load

The relationships between pre training sleep and external training load metrics are represented by three canonical correlations. The strongest canonical correlation was between Sleep Dimension 1 and External Training Load Dimension 1 (r = 0.49, P = 4.26 x10^{-28}). Figure 9A shows the variables with the highest loadings onto each dimension; wake time was the stronger contributor to the Sleep Dimension 1 (r = 0.90), while PL2D and PL2D/min contributed similarly to External Training Load Dimension 1 (r = 0.38 and 0.36, respectively).

Pre Training Sleep and External Training Load Dimension 2 and 3 are presented in Table 9.

Figure 9B presents the cross-loadings of each variable onto Dimension 1 for the other variable set.

Table 9: Pre Training Sleep and External Training Load Canonical Correlations.

	Dimension 2* (r=0.46, P=2.99x10^{-15})		**Dimension 3* (r=0.32, P=6.91x10^{-5})**	
	Canonical Loading	**Cross Loading**	**Canonical Loading**	**Cross Loading**
Sleep Characteristics				
Sleep onset latency (min)	-0.81#	-0.18	-0.23	
Sleep duration (min)			0.54	
Sleep efficiency (%)				
Wake time (min)	0.15			
Wake bouts (number)		-		
Wake Bouts av duration (mm:ss)	0.21		0.27	
Wake up time (hh:mm)	-0.40		0.68#	0.11
External Load Variables				
Absolute loads				
Total Distance (m)	0.13		-0.48#	-0.18
Player Load (AU)	0.30	0.14	-0.13	
Player Load 2D (AU)	0.29	0.13		
Player Load Slow (AU)			0.16	
Maximum Speed (km/h)	0.59#	0.27		
Loads relative to training duration				
Average Velocity (m/min)	0.12			
Player Load/min (AU)	0.57	0.27	0.39	0.15
Player Load 2D/min (AU)	0.56	0.26	0.47	0.18

The relationship between external training load metrics and pre training sleep characteristics. Data are expressed as canonical correlations with the canonical loading and cross loading of each variable presented for each dimension. * Indicates the dimension is statistically significant. # Highlights the variables from each data set that had the strongest contribution to each dimension. HIR: High Intensity Running, Wake Bouts Av Duration: Wake Bouts Average Duration.

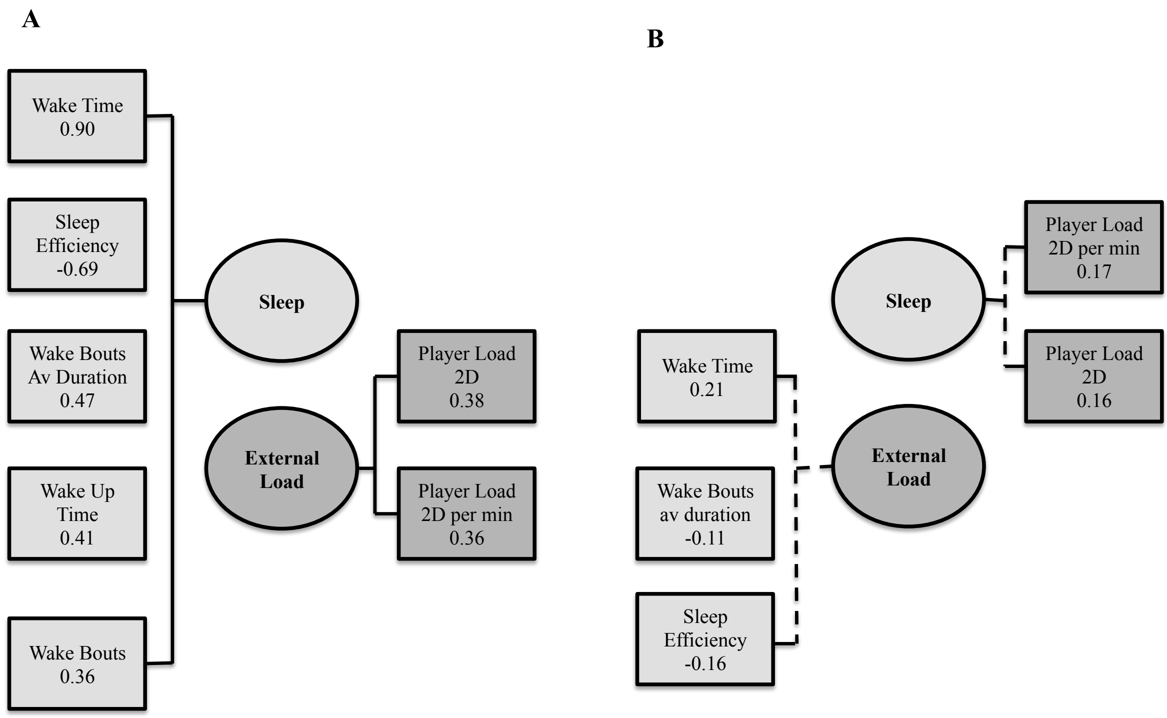

Figure 9: A) Pre Training Sleep and External Training Load Dimension 1* (r = 0.49, P = 4.26 x 10^{-28}) and (B) Pre Training Sleep and External Training Load 1 Cross Loadings. * Indicates the dimension is statistically significant ($p < 0.05$).

Pre Training Sleep and Well-Being

The relationship between pre training sleep and well-being are represented by one canonical dimension ($r = 0.32$, $P = 0.002$). Figure 10A shows the variables with the highest loadings onto the dimension; wake up time was the strongest contributor to the Sleep Dimension 1 ($r = 0.63$), while self-reported sleep quantity contributed most to the Well-Being Dimension 1 ($r = 0.60$).

Figure 10B presents the cross-loadings for this dimension.

External Training Load and Post Training Sleep

The relationship between external training load and post training sleep are represented by four canonical correlations. The strongest canonical correlation was between External Training Dimension 1 and Sleep Dimension 1 ($r = 0.67$, $P = 5.06 \times 10\text{-}43$). Figure 11A shows the variables with the highest loadings onto each dimension; wake up time was the strongest contributer to Sleep Dimension 1 ($r = -0.55$) and total distance was the strongest contributor to External Training Load Dimension 1 ($r = -0.82$). The cross-loadings for Dimension 1 are presented in Figure 11B. Total distance ($r = -0.46$) showed a moderate negative correlation with Sleep Dimension 1. Dimensions 2, 3, and 4 are presented in Table 10.

Well-Being and Post Training Sleep

The relationship between pre training well-being ratings and post training sleep are represented by one canonical correlation ($r=0.36$, $P = 0.002$).

Figure 12A shows the variables with the highest loadings onto Dimension 1; wake up time was the strongest contributer to Sleep Dimension 1 ($r=0.61$), whilst self-reported sleep quality contributed most to Well-Being Dimension 1($r=-0.61$). Figure 12B presents the cross-loadings of each variable into Dimension 1 for the other variable set.

Well-Being and External Training Load

The relationship between pre training well-being and subsequent external training load measures are represented by four canonical correlations. The strongest canonical correlation was between Well-Being Dimension 1 and External Training Load Dimension 1 ($r = 0.67$, $P = 3.6 \times 10^{-58}$). Figure 13A shows the variables with the highest loadings onto each dimension; hamstring soreness was the strongest contributer to well-being Dimension 1 ($r = -0.55$) and PL was the strongest contributor to external training load Dimension 1 (r = -0.74). Figure 13B presents the cross-loadings of each variable into Dimension 1 for the other variable set. Player Load (r = -0.48) showed a moderate negative correlation with well-being Dimension 1. Dimensions 2, 3, and 4 are presented in Table 11.

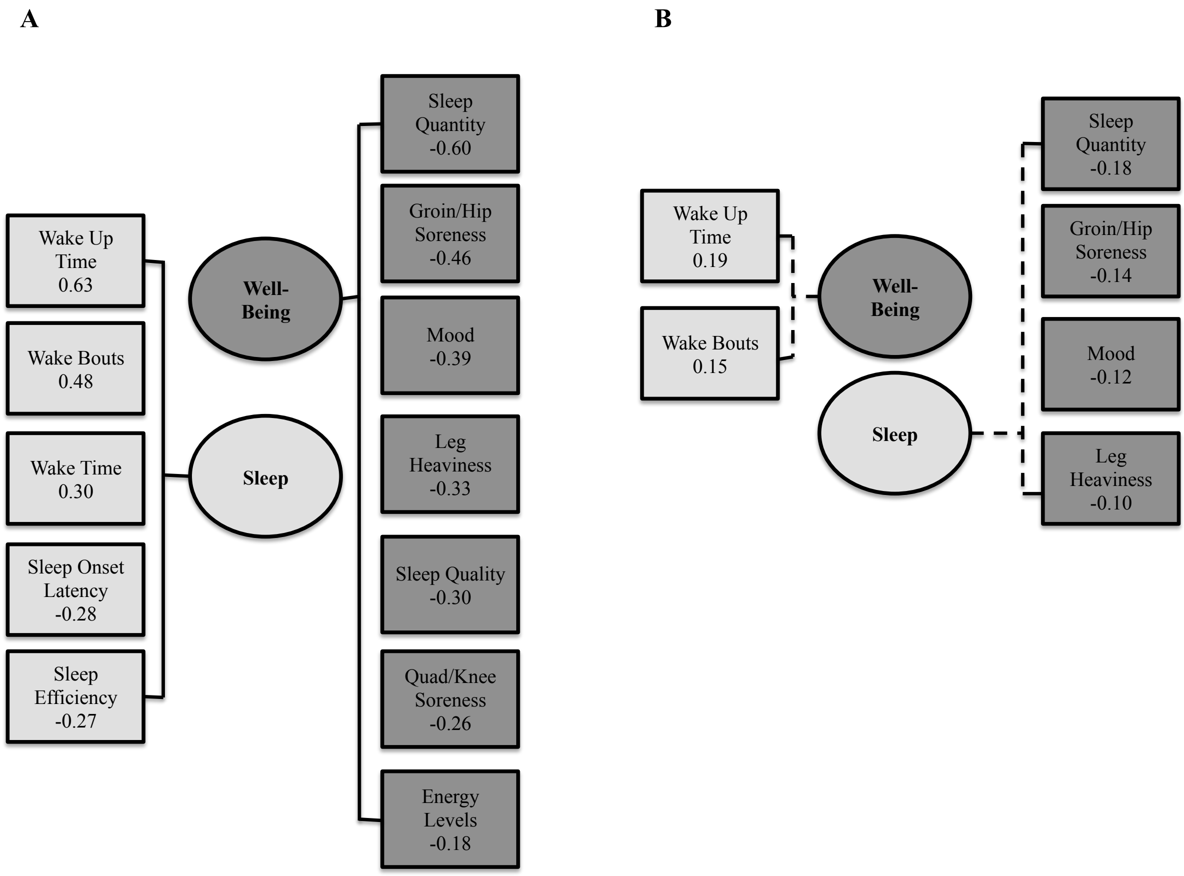

Figure 10: (A) Pre Training Sleep and Well-Being Dimension 1 (r = 0.32, P = 0.002) and (B) Pre Training Sleep and Well-Being Dimension 1 Cross Loadings.

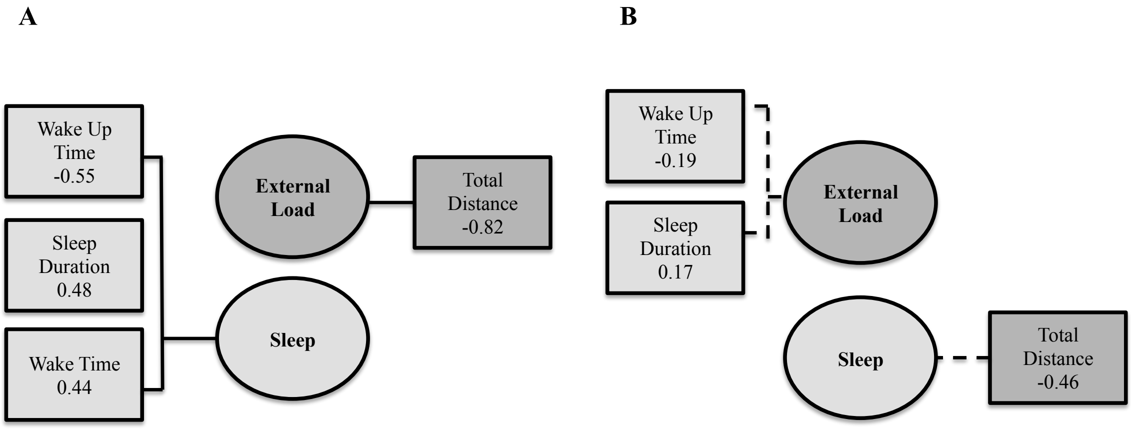

Figure 11: (A) External Training Load and Post Training Sleep Dimension 1* (r = 0.67, P = 5.06 x 10^{-43}) and (B) External Training Load and Post Training Sleep and Dimension 1 Cross Loadings. * Indicates the dimension is statistically significant ($p < 0.05$).

Table 10: External Training Load and Post Training Sleep Canonical Correlations.

	Dimension 2* (r=0.50, P=1.85x10^{-17})		Dimension 3* (r =0.43, P=4.27x10^{-8})		Dimension 4* (r= 0.31, P=1.28x10^{-2})	
	Canonical Loading	**Cross Loading**	**Canonical Loading**	**Cross Loading**	**Canonical Loading**	**Cross Loading**
Sleep Characteristics						
Sleep onset latency (min)	-0.80#	-0.21	-0.42		-0.12	
Sleep duration (min)			-0.21		0.64#	0.10
Sleep efficiency (%)	0.55	0.14	-0.43	-0.10	0.49	
Wake time (min)	-0.49	-0.13	0.65#	0.14		
Wake bouts (number)	-0.29		0.10		-0.11	
Wake Bouts av duration (mm:ss)	-0.11		0.57	0.13		
Wake up time (hh:mm)			0.27		0.60	
External Load Variables						
Absolute loads						
Total Distance (m)			0.24	0.10	0.16	
Player Load (AU)	0.14				0.14	
Player Load 2D (AU)			0.24	0.10	0.21	
Player Load Slow (AU)			-0.15			
Maximum Speed (km/h)	0.43	0.22	0.60#	0.25	-0.45#	-0.14
Loads relative to training duration						
Average Velocity (m/min)					-0.39	-0.13
Player Load/min (AU)	0.54#	0.27			0.33	0.11
Player Load 2D/min (AU)	0.38	0.19	0.29	0.12	0.40	0.13
HIR Distance (m/min>24/km/hr)	0.29	0.15				

The relationship between external training load metrics and post training sleep characteristics. Data are expressed as canonical correlations with the canonical loading and cross-loading of each variable presented for each dimension. * Indicates the dimension is statistically significant. # Highlights the variables from each data set that had the strongest contribution to each dimension. HIR: High Intensity Running, Wake Bouts Av Duration: Wake Bouts Average Duration.

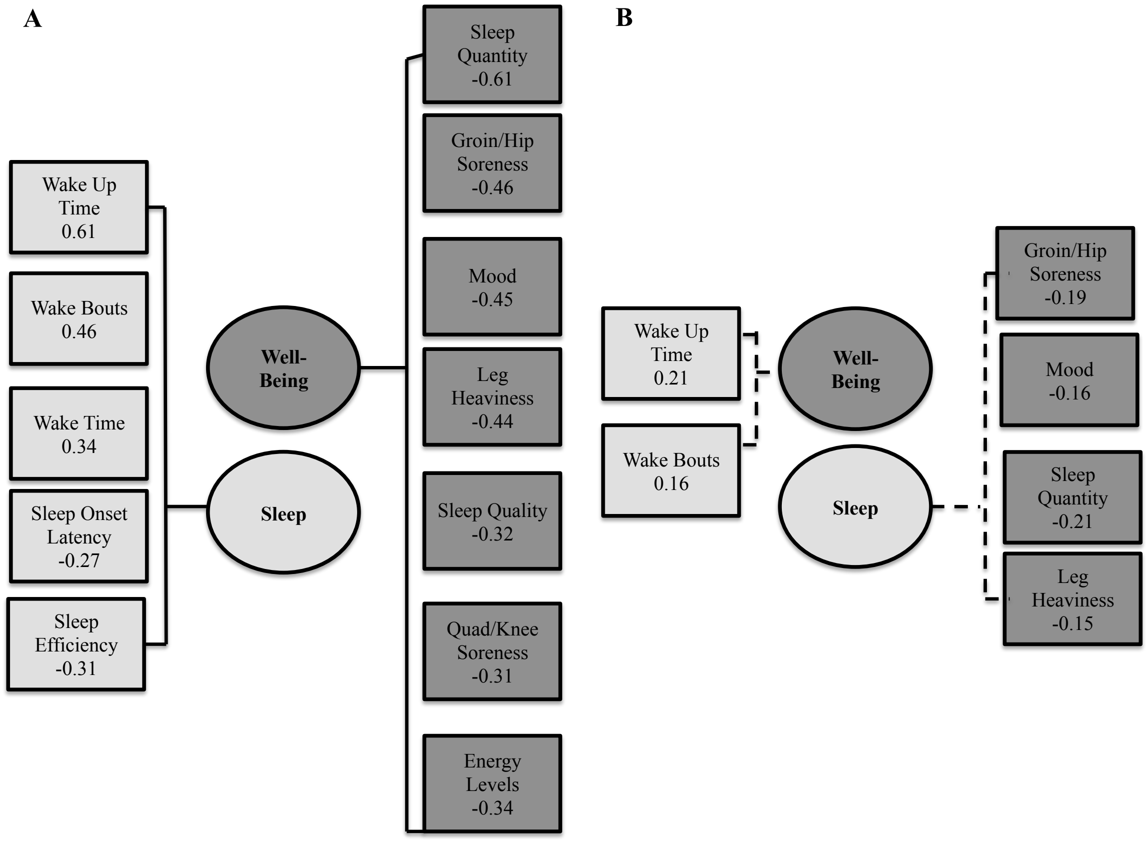

Figure 12: (A) Well-Being and Post Training Sleep and Dimension 1* (r = 0.36, P = 0.002) and (B) Well-Being and Post Training Sleep 1 Cross Loadings. * Indicates the dimension is statistically significant ($p < 0.05$).

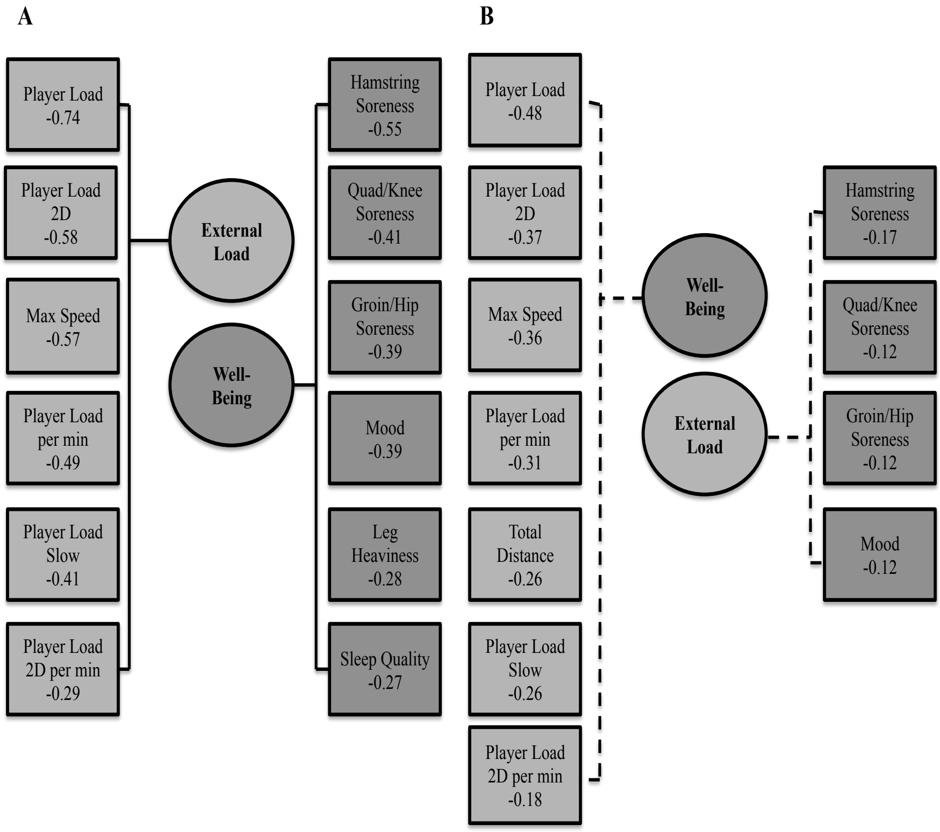

Figure 13: (A) Well-Being and External Training Load Dimension 1* ($r = 0.67$, $P = 3.6 \times 10^{-58}$) and (B) Well-Being and External Training Load Dimension 1 Cross Loadings. * Indicates the dimension is statistically significant ($p < 0.05$)

Table 11: Well-Being and External Training Load Canonical Correlations.

	Dimension 2* (r=0.48, P=1.69x10^{-25})		Dimension 3* (r=0.42, P =3.29x10^{-14})		Dimension 4* (r= 0.37, P =1.21x10^{-6})	
	Canonical Loading	**Cross Loading**	**Canonical Loading**	**Cross Loading**	**Canonical Loading**	**Cross Loading**
Well-Being						
Mood (AU)	0.63#	0.13	-0.17		-0.26	
Calf Soreness (AU)	0.16		-0.21		-0.12	
Leg Heaviness (AU)	0.47	0.10			0.12	
Quad/knee Soreness (AU)	0.23		-0.29		0.25	
Groin/Hip Soreness (AU)	0.14		0.17		0.11	
Lower Back Soreness (AU)	0.47	0.10			0.19	
Sleep Duration (AU)	0.13		-0.34#		0.61#	
Energy Levels (AU)	0.51	0.11	0.24		0.18	
Hamstring Soreness (AU)	0.15		-0.22			
Sleep Quality (AU)	0.47	0.10	-0.31		0.15	
External Load Variables						
Absolute loads						
Total Distance (m)	-0.14		0.49	0.22	-0.11	
Player Load (AU)	-0.22	-0.11	0.37	0.16		
Player Load 2D (AU)	-0.23	-0.12	0.37	0.16	-0.13	
Player Load Slow (AU)	0.14		0.50	0.22	-0.13	
Loads relative to training duration						
Maximum Speed (km/hr)	0.31#	0.15	-0.11		-0.51#	-0.20
Average Velocity (m/min)	0.23	0.12	0.52#	0.23	0.26	0.10
Player Load/min (AU)	0.28	0.14	0.23		0.28	0.11
Player Load 2D/min (AU)	0.27	0.12	0.12		0.14	

The relationship between well-being measures and external training load metrics. Data are expressed as canonical correlations with the canonical loading and cross-loading of each variable presented for each dimension. * Indicates the dimension is statistically significant. # Highlights the variables from each data set that had the strongest contribution to each dimension. Wake Bouts Av Duration: Wake Bouts Average Duration.

Discussion

This study revealed that complex relationships exist between sleep, external training load and well-being measures in AF players. Fragmented sleep the night prior to training was associated with lower mood, increased soreness and players completing the following training session with higher PL2D. Furthermore, players who completed training with a lower total distance was associated with a later wake up time in the next sleep opportunity. Our findings highlight that the relationship between objective sleep characteristics, external training load and well-being are not defined by one measure (e.g., sleep duration). Instead, the contribution of a number of sleep variables including wake time, number of wake bouts and wake up time may influence both external load and the well-being of AF players. These findings have implications for practitioners, particularly when choosing variables to monitor AF players' sleep to assist in the planning and evaluation of training.

The strongest canonical dimensions for pre training sleep and external training load, indicated AF players with a lower sleep efficiency and a longer wake time in the pre training sleep, had a higher PL2D during training. These associations may be due to players entering the training session tired from fragmented sleep or from an accumulated sleep debt, resulting in players performing high intensity movements to compensate for inefficient running or poor positioning.[205] In support of this, AF players are shown to have an altered activity profile in a fatigued state, resulting in players becoming inefficient in the production of load (greater lateral or vertical movements).[205] In addition to changes in movement strategy when tired, extended wake periods have been associated with effects on brain function (including attention lapses), cognitive function and performance.[42] There is potential for players with a low sleep efficiency, due to extended wake time, to experience impaired cognitive function during the training session.[42] Even relatively moderate sleep restriction, if sustained night after night, can impact neurobehavioral functioning.[217] In contrast, extending total sleep time can improve reaction time, daytime sleepiness and mood in collegiate athletes.[17] As a result, improving sleep quality and quantity may have a positive impact on AF players performance, particularly when psychomotor vigilance is required.[17] Objective monitoring of sleep characteristics of AF players may also provide an indication of the external load that might be expected in the subsequent training session and provide practitioners with the ability to make adjustments to training drill participation if warranted. Practitioners should specifically monitor PL and PL2D in players who have reported poor sleep and potentially modify training participation.

The canonical correlation between pre training Sleep Dimension 1 and Well-Being Dimension 1 highlighted the potential impact of fragmented pre training sleep on subjective well-being. An increased number of wake bouts in the sleep opportunity prior to the main training session was associated with lower mood and increased soreness. Similar findings have been observed in elite cyclists during an intensive training period where cyclists who experienced an increased number of wake bouts reported disruptions to mood state, increased tension, fatigue, confusion, depression and stress.[178] An increase in total sleep time has also been associated with an improved self perception of performance during training and competition.[17] This supports the idea that obtaining extra, good quality sleep is likely to have beneficial effect on an athletes overall well-being and mental readiness to train.[17] Practitioners may improve well-being and reduce perceptions of fatigue during the pre-season training period by optimising both the quality and quantity of AF player's sleep. This may be achieved through minimising sleep disturbances and wake time by prioritising sleep hygiene strategies.[70]

The second aim of this study was to examine the associations between well-being, external training load, and post training sleep charactertistics. The canonical correlation between Well-Being Dimension 1 and Post Training Sleep Dimension 1 indicated that higher ratings of soreness and shorter subjective sleep quantity were associated with fragmented sleep in the post training sleep oppourtunity. This was due to longer wake duration and longer wake bouts. There is limited information regarding the interactions between external training load, muscle soreness, and sleep characteristics in elite sport and this warrants further investigation. To assist athletes in improving the quality of sleep following a training session, practitioners should consider strategies that may improve the recovery from sessions involving contact (e.g., cold-water therapy, use of compression garments, massage, and nutrition strategies).[218] The relationship between External Training Load Dimension 1 and 2 and Sleep Dimension 1 and 2 highlighted that the content of the training session may affect the requirement for sleep following the session in AF players. Firstly, lower total distance in training was associated with a later wake up time in the sleep opportunity following the training session. Our findings also indicated that a higher maximum speed and higher PL/min in training were associated with a shorter sleep onset latency and higher sleep efficiency in the post training sleep. A similar relationship was observed in youth soccer players, where an increased sleep duration and later time of final awakening was observed in the sleep opportunity following a training session involving an increased high-speed distance.

A similar relationship was observed in youth soccer players, where an increased sleep duration and later time of final awakening was observed in the sleep opportunity following a training session involving an increased high-speed distance. It is possible that training that produces higher maximum speed increases an AF player's requirement for sleep. However, it is acknowledged that these associations could also be due to between player variation in both training design factors, such as role within a training drill or positional group requirements and also inter-individual differences in sleep characteristics. Further research is required to understand the associations between external training load in intermittent team sports and objective sleep characteristics. Practitioners should maximise the opportunity for sleep following sessions that have high speed by ensuring that sessions the next day do not start earlier than required.

The final aim of this study was to assess the relationship between pre training perceived well-being and the external load produced in the main training session. Previous work has demonstrated the influence of pre training well-being scores on the external load (specifically PL and PL_{slow}) during AF skill-based training sessions.[60] Our results suggest players who reported an increased lower body soreness (hamstring, quad/knee, groin/hip) and lower rating of mood prior to the main training session was associated with a higher PL, PL2D and a higher maximum speed when compared to other players in the team. This supports the suggestion that pre training well-being (specifically lower body soreness and low mood) may also be associated with an inefficient production of load (greater lateral or vertical movements or increased sprinting to compensate poor decision making) during the session. For an AF player, mood alteration also has the potential to affect motivation to train and willingness to give maximal effort in both training and competition.[11] It has also been demonstrated that perception of effort increases under sleep deprivation, which can influence an athlete's time to fatigue during training and competition.[11] Collection of these measures prior to AF training may provide practitioners an indication of the external load that can be expected during the session and may guide strategies to improve player mood and subsequent training and competition output.

Practical Applications

Pre training sleep characteristics impact the movement strategy of AF players during main field sessions. Practitioners can expect PL and PL2D to be modified in AF players who have slept poorly. Following training sessions that have high maximum speed , practitioners should maximise the opportunity for sleep following the session by ensuring that subsequent sessions do not start earlier than required. Prioritising sleep hygiene and recovery strategies to minimise wake episodes may improve the well-being and perceptions of fatigue of AF players. Pre training well-being may provide some insight into the objective sleep characteristics that may be exhibited in the post training sleep opportunity.

Conclusions

Maximum speed, PL and PL2D were the common associations between both objective sleep characteristics and well-being measures in AF players. This relationship was observed in pre and post training sleep and well-being measures. Improving pre training sleep quality and quantity, ideally through minimising wake time, may have a positive impact on AF players' well-being, movement strategy and perceptions of fatigue during training. Reviewing maximum speed, total distance, PL, PL2D from AF main field sessions may provide the ability to modify the schedule (to allow later wake up time) to assist players need for increased sleep following the session.

Chapter 6: Study Three – Business Class Travel Preserves Sleep Quality & Quantity and Minimises Jet-Lag During The Women's T20 World Cup Cricket Tournament

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Linking Paragraph

Study 2 revealed that complex relationships exist between sleep, external training load and well-being measures in AF players. Our findings highlighted that the relationship between objective sleep characteristics, external training load and well-being are not defined by one measure (e.g., sleep duration). Instead, the contribution of a number of sleep variables including wake time, number of wake bouts and wake up time may influence both external load and the well-being of AF players. Fragmented sleep the night prior to training was associated with lower mood, increased soreness and players completing the following training session with higher PL2D. Therefore improving pre training sleep quality and quantity, ideally through minimising wake time, may have a positive impact on team sport athletes well-being, movement strategy and perceptions of fatigue during training. Study 1 and 2 assessed the impact of match start time, days relative to a match, well-being and training load on the impact of players sleep characteristics. However, these relationships were assessed in the players habitual sleep environment. The schedule of a high performance athlete often requires international travel for both training and competition, therefore to gain a further understanding of elite team sport athletes sleep characteristics, assessing the players competition sleep environment, including the sleep characteristics exhibited following an international flight is required. Considering the challenge to obtaining good quality and quantity of sleep during plane travel, the fragmented and truncated sleep experienced in-flight sleep may have an impact on the players training load, sleep characteristics and self-reported measures of well-being upon arrival at the competition destination. Study 3 aimed to determine the impact of the quality and quantity of sleep obtained during an international flight on subsequent objective sleep characteristics, self-reported well-being, and perceptions of jetlag upon arrival at the competition destination. In addition, Study 3 aimed to explore the relationships between training and match day load, perceptions of well-being and jetlag, and objective sleep characteristics during an international tournament.

Abstract

To determine the impact of the quality and quantity of sleep during an international flight on subsequent objective sleep characteristics, training and match day load, self-reported well-being, and perceptions of jetlag of elite female cricketers during an International Cricket Council T20 Women's World Cup. In-flight and tournament objective sleep characteristics of eleven elite female cricketers were assessed using activity monitors. Seated in business class, players travelled west from Melbourne, Australia to Chennai, India. The outbound flight departed Melbourne at 0330h with a stopover in Dubai for 2h. The arrival time in Chennai was 2010h local time (0140h Melbourne). The total travel time was 19h 35 minutes. Perceptual ratings of jetlag, well-being and training and competition load were collected. To determine the impact of in-flight sleep on tournament measures, a median split was used to create sub-samples based on 1) in-flight sleep quantity and 2) in-flight sleep quality (two groups: higher vs. lower). Spearman's correlation coefficients were calculated to assess the bivariate associations between sleep measures, self-reported well-being, perceptual measures of jetlag and internal training and match day load. Mean duration and efficiency of in-flight sleep bouts was 4.72h and 87.45%. Aggregated in-flight sleep duration was 14.64 + 3.56h. Players with higher in-flight sleep efficiency reported higher ratings for fatigue (i.e., lower perceived fatigue) during the tournament. Tournament sleep duration was longer, and bed and wake times were earlier compared to habitual. Compared to other nights during the tournament, sleep duration was shorter following matches. Maximising in-flight sleep quality and quantity appears to have implications for recovery and sleep exhibited during competition. Sleep duration was longer than habitual except for the night of a match, which suggests that T20 matches may disrupt sleep duration.

Key Words: Team Sport, Jetlag, Travel, Female Athlete

Introduction

Elite female cricketers travel domestically and internationally and changes in time zones, sleep environment, sleep/wake routines and circadian rhythms can all impact sleep characteristics, well-being and performance.[4] Travel fatigue in combination with the mismatch between players body clock and local time may impact sleep, self-reported fatigue and symptoms of jetlag upon arrival at the international destination.[8] Considering international travel forms a large part of an elite cricket players schedule, developing an understanding of the sleep patterns of players during and following an international flight may provide insights into opportunities to optimise performance.[5]

The challenge of obtaining good sleep quality and quantity during plane travel is well documented.[8] Professional football players reported 5.5h of sleep during 18h of long-haul travel, well below the recommendation for the general population and the players self-reported habitual sleep duration.[4] A shorter mean sleep duration (2.5h) during 24h of simulated long-haul travel was associated with reduced intermittent-sprint performance, possibly due to sleep disruption during travel and subsequent physiological and perceptual fatigue.[7] Consideration of the timing of international travel prior to competition on perceptions of jetlag, well-being and sleep characteristics may be beneficial.[5]

No study has investigated in-flight objective sleep characteristics of elite female cricketers, nor the response to international travel. Work has shown the negative effect of fragmented sleep prior to on-field training, including the influence on mood, ratings of soreness and the external load of elite team sport athletes.[220] However, these relationships have not been thoroughly explored during competition, nor following international travel.[4,125] Understanding and improving in-flight sleep duration and quality during international travel may improve player's well-being and capacity to train and compete upon arrival at the competition destination. Therefore the study aims were to: 1) determine the impact of the quality and quantity of sleep obtained during an international flight on objective sleep characteristics, self-reported well-being, and perceptions of jetlag during the tournament; 2) examine how objective sleep characteristics, perceptions of jetlag, and self-reported well-being change over the course of a tournament following an international flight; and 3) examine the relationships between training load, perceptions of well-being and jetlag, and objective sleep characteristics during the tournament.

Methods

Participants

Data was obtained from 11 elite female cricketers from the national team (mean ± SD): height = 168.4 ± 6.9 cm; body mass = 62.7 ± 4.7 kg; age = 24.1 ± 3.3 y. Ethics approval was obtained from the university human research ethics committee, and the study protocols conformed to the recommendations of the Declaration of Helsinki.

Study Overview

This study was conducted prior to and during the 2016 International Cricket Council Women's T20 World Cup. The team were seated in business class and travelled west from Melbourne, Australia (GMT + 10) to Chennai, India (GMT + 5.5); crossing 5.5 time zones. The outbound flight departed Melbourne at 0330h with a stopover in Dubai for 2h. The arrival time in Chennai was 2010h local time (0140h Melbourne). The total travel time was 19h 35 minutes (Flight 1 Melbourne to Dubai: 13h 20 minutes, Transit: 2h, Flight 2 Dubai to Chennai: 4h 15 minutes). Refer to Figure 14 for travel timeline and schedule). General sleep hygiene education was provided players prior to departure. This included recommendations on electronic device use prior to bed, optimal room environment (e.g., light and temperature) and the importance of maintaining habitual sleep and wake routines. Prior to departure, players were encouraged to sleep when possible during travel. No sleep medication was used during flights or the tournament. Objective sleep characteristics, subjective well-being, perceived jetlag and training and competition internal load were collected.

IF1	IF2		N1		N2		N3		N4		N5		N6		N7		N8		N9		N10		N11		N12	
Depart	Transit	Arrive																								
Melbourne Wed 03:30 (Chennai Wed 21:00) ^	**Arrive 12:55** (Melb Wed 19:55 Chennai Wed 14:15) **Depart 14.55** (Melb Wed 20:45 Chennai Wed 16:15)	**Chennai Thurs 20:10** (Melb Fri 1:40)		**9:00 Train * ^ #**		**9:30 Train 15:00 Strength * ^ # >**		**8:30 Train * ^ #**		**15:30 * ^ #**		**Rest *^ >**		**9:30 Depart ***		**14:30 Train * #**		**19:30 * # >**		**11:00 Pool * >**		**9:00 Train 17:30 Function * #**		**15:30 * #**		**6:30 Depart 14:00 Strengt h * #**

Figure 14: Study Design. IF1 and IF2 indicates the two in-flight sleep bouts over the two dates during the travel period from Melbourne, Australia to Chennai, India. Objective Sleep collection period. N1-N12 Indicates the night of the objective sleep monitoring during the tournament period. * Indicates self-reported measures of well-being were collected. ^ Indicates perceptions of jetlag were collected # Indicates training/or match load was collected. > Indicates team ‘no communication zone’.

Represent match played and domestic flight respectively.

Objective Sleep Measures

Validated wrist-worn activity monitors were used to measure sleep (Actical, Philips Respironics, Inc., Bend, Oregon, USA) over three monitoring periods; habitual (n = 11), in-flight (n = 10) and tournament (n = 11).[7] For all periods, participants recorded the start and end of each sleep in a sleep diary. Activity monitors were worn continuously (except during training and matches), set at the medium threshold and data was recorded in 1-min epochs. Sleep-diary and activity monitor data was used to determine when participants were awake or asleep. A detailed description of the scoring of sleep has been previously provided.[8] The following information was collected from the activity monitors: bed time (hh:mm), wake-up time (hh:mm), sleep onset latency (min), sleep duration (h), wake time (min), number of wake bouts and sleep efficiency (%). The sleep diary was used by participants to record sleep location, bed time (hh:mm) and wake-up time (hh:mm).

Habitual Sleep

Habitual sleep was measured in the players home sleep environment over a consecutive 5-day training period, 8 weeks post-tournament. This period was selected due to the travel and domestic competition commitments prior to departure. No travel or competition was scheduled during this period.

In-Flight Sleep

Players wore an activity monitor at all times during the international flights and transit. Players were seated in business class with seats that could recline to a flat bed. In addition to the procedures outlined above, players used the time stamp function on the activity monitor to assist identifying sleep periods.

Tournament Sleep

Day-time naps and night-time sleep periods were measured for twelve consecutive days. The team travelled once domestically (Chennai to Nagpur, no change in time zone), staying at two different five-star hotels. Players had their own room and could control conditions (e.g., light and temperature). There were no team curfews in place.

Assessment of Training and Competition Load

Training load was calculated as the product of session RPE (s-RPE) and training session duration (min). This information was collected via the Cricket Australia Athlete Management System (AMS, Fair Play Pty Ltd) as part of normal monitoring.

Self-Reported Measures of Well-Being

Self-reported measures of soreness, fatigue, sleep, stress and a total wellness score were collected daily. These questions were completed using a Likert scale (ranging from 1 = poor to 5 = excellent) via the AMS application on players' phones.[9]

Perceptions of Jetlag

Subjective ratings of jetlag (AM and PM) were assessed using a visual analogue scale (ranging from 1 very bad jetlag to 5 no jetlag) at 0900h and 1800h local time for six days after arrival.

Statistical Analysis

Most variables violated parametric assumptions, so non-parametric techniques were used. Statistical significance was set at $p < 0.05$.

To determine the impact of in-flight sleep on tournament measures, a median split was used to create sub-samples based on 1) in-flight sleep quantity (two groups: higher vs. lower) and 2) in-flight sleep quality (two groups: higher vs. lower). Two non-parametric factorial analyses[11] were conducted with a two-way design to test for differences between groups and across tournament dates: 1) in-flight duration group × date, and 2) in-flight efficiency group × date. Model specification also included "athlete" as the random effect to account for within-individual variance given the repeated measures design, as per the F1-LD-F1 model.[203] The non-parametric factorial approach is analogous to mixed modelling approaches that specify both fixed and random effects, and its primary output is the F-type statistic. Where significant main or interaction effects were identified, pairwise comparisons were performed with Dunn-Bonferroni corrections to reduce the risk of Type I errors.

Descriptive statistics were calculated to show how the team's sleep, perceived jetlag, and self-reported well-being changed over the course of the tournament. Further context was added to the description and visualisation of tournament sleep by incorporating team means for habitual sleep, to illustrate where nightly sleep deviated from habitual values.

Spearman's correlation coefficients (rho) were calculated to assess the bivariate associations between i) sleep measures and internal training and / or playing loads incurred on the subsequent day, ii) sleep measures and self-reported well-being recorded on the subsequent day, iii) sleep and perceived ratings of jetlag recorded on the subsequent day.

Results

In-Flight Sleep Characteristics

Figure 15 summarises the players' in-flight sleep duration and sleep efficiency on each date (IF1 and IF2) of the international transit period.

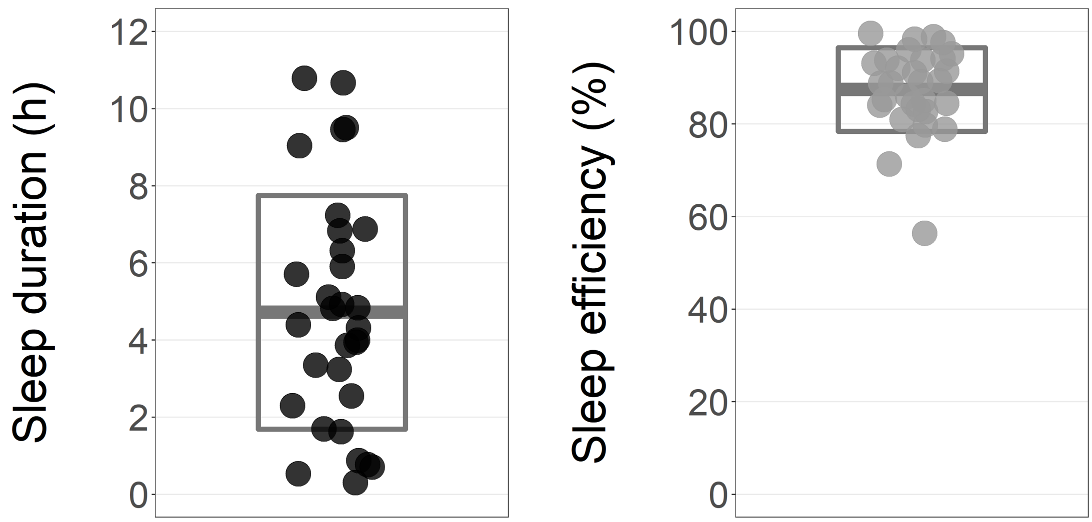


Figure 15: Sleep Duration and Sleep Efficiency of In-Flight Sleep Bouts During the International Transit Period. For each plot, the grey crossbar represents the mean (midline of the cross bar) ± 1 standard deviation (upper / lower limits of the cross bar). Each dot point represents one player's mean sleep duration and efficiency during each in-flight sleep bout.

Figure 16 displays the duration and efficiency of sleep bouts during the international transit period.

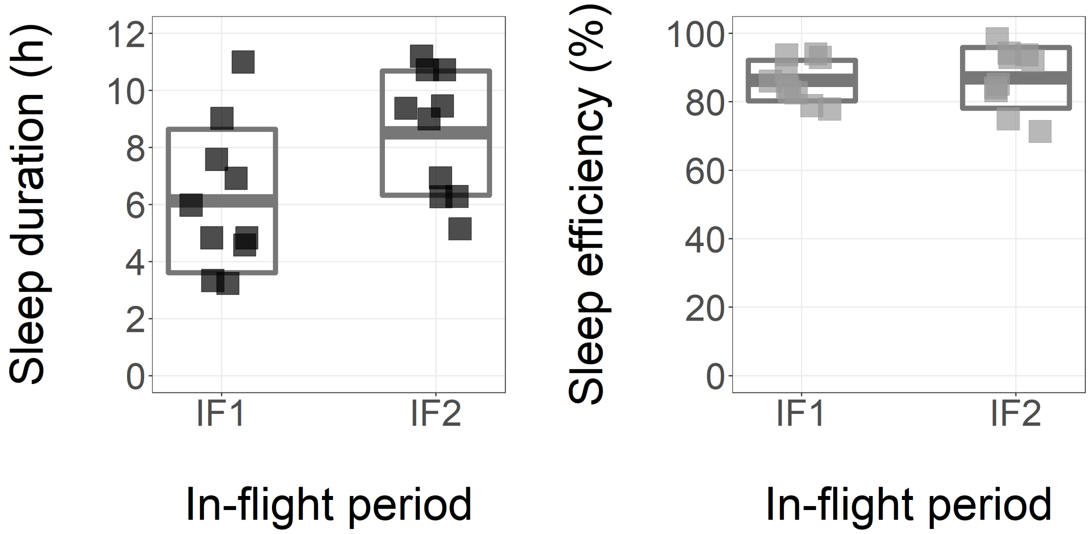


Figure 16: Sleep Duration and Sleep Efficiency on Each of the Two Days (IF1 and IF2) of the International Transit Period. For each day, the grey crossbar represents the mean (midline of the cross bar) ± 1 standard deviation (upper / lower limits of the cross bar). Each dot point represents one player's sleep measures on a given date.

Tournament Sleep Characteristics, Jetlag, and Well-being

Sleep characteristics, jetlag ratings, and well-being measures during the tournament are displayed in Figures 17-19.

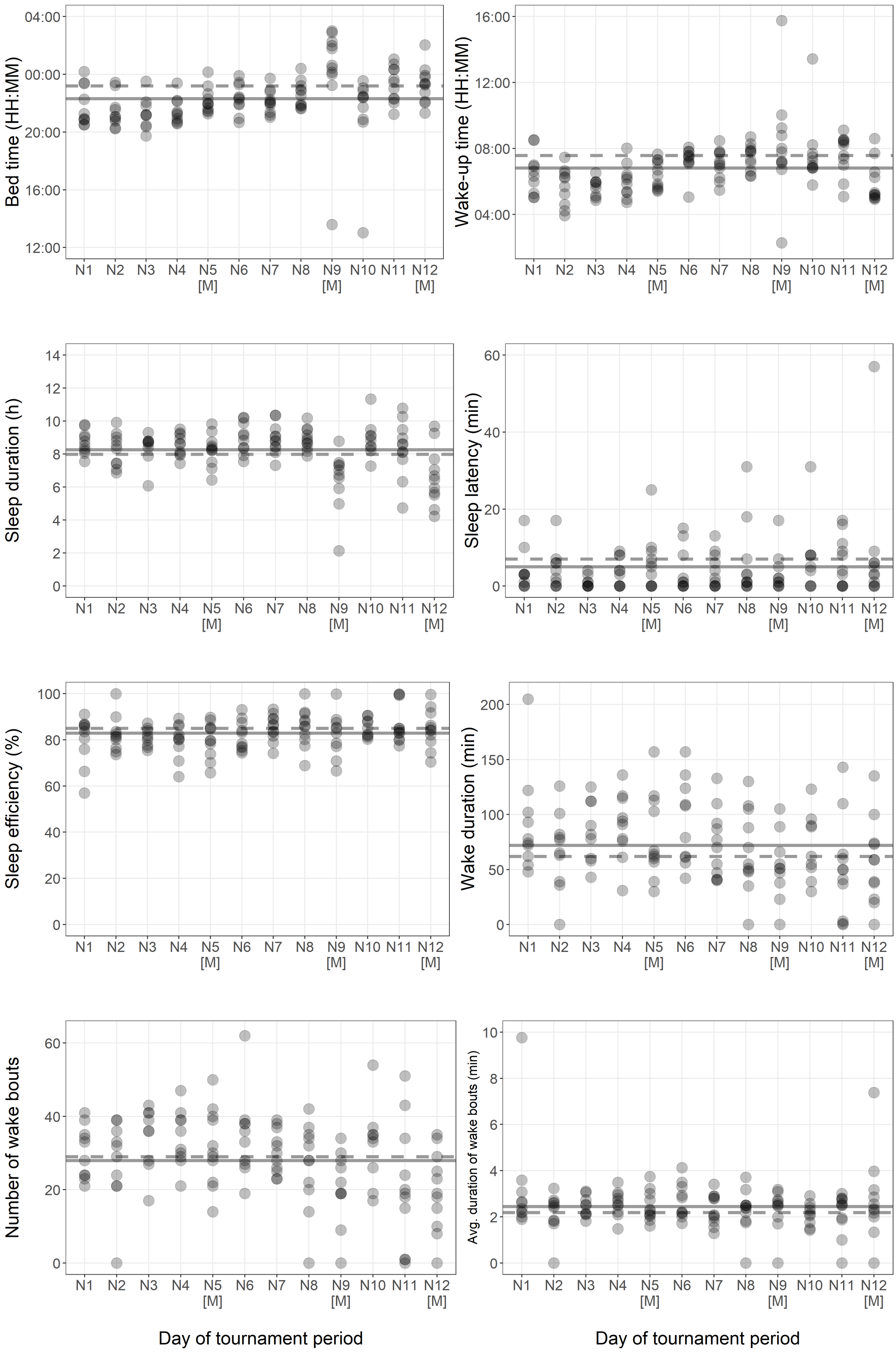


Figure 17: Tournament Sleep Characteristics. Each dot point represents one player's sleep characteristics on a given date. The horizontal dashed lines represent the team's mean for habitual sleep. N1 – N12 = night of the tournament period.

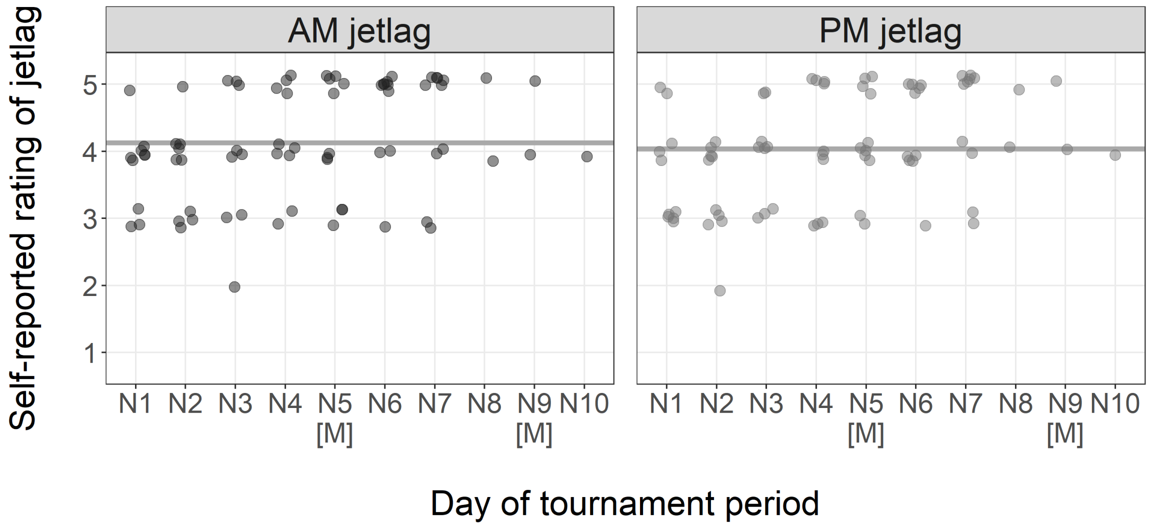


Figure 18: Jetlag Ratings Across the Tournament Period. Each dot point represents one player’s jetlag rating on a given date. The horizontal unbroken lines represent the team's mean for each jetlag variable across the tournament. [M] is used to indicate dates on which matches were played.

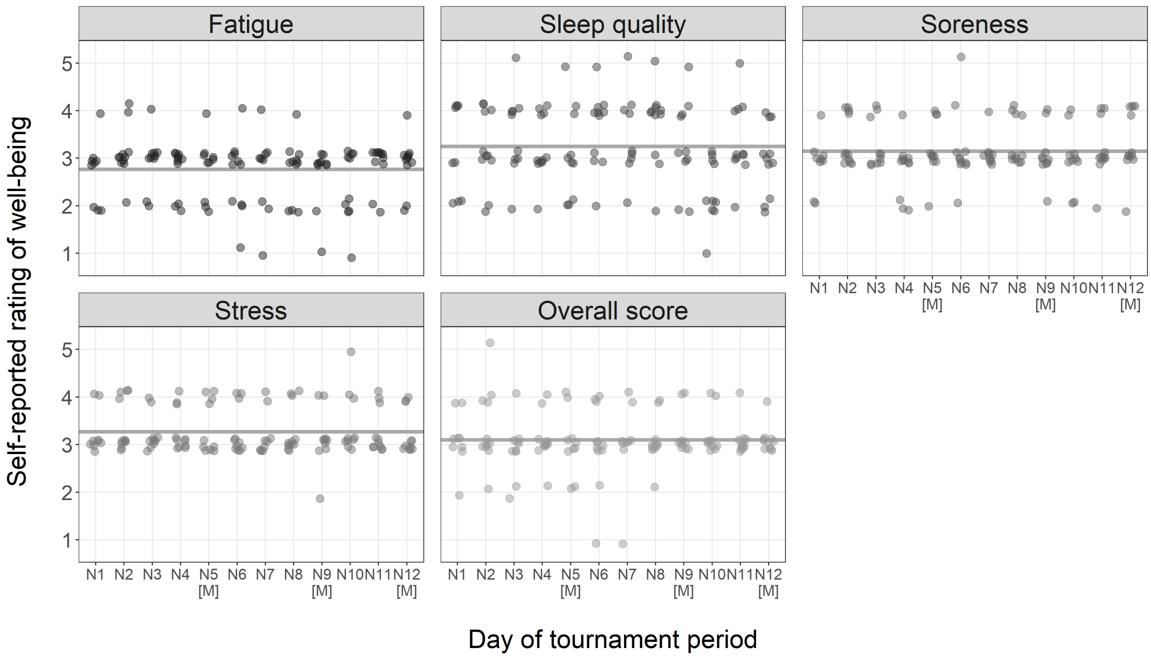


Figure 19: Well-Being Ratings Across the Tournament Period. Each dot point represents one player’s well-being rating on a given date. The horizontal unbroken lines represent the team's mean for each well-being variable across the tournament period. [M] is used to indicate dates on which matches were played.

Impact of Flight on Tournament Sleep

Tournament sleep characteristics did not differ between the groups of players who obtained higher vs. lower sleep quantity in-flight, nor between those groups who obtained higher vs. lower sleep efficiency in-flight (see Table 12).

Table 12: Mixed Model Outputs: Impact of In-Flight Sleep on Tournament Sleep. Note: * indicates statistically significant test effects.

Tournament sleep variable	Impact of in-flight sleep duration			Impact of in-flight sleep efficiency		
	Test effect	F-type statistic	p	Test effect	F-type statistic	p
Sleep duration	Duration group	0.019	0.89	Efficiency group	0.154	0.69
	Date	3.780	0.00*	Date	3.530	0.00*
	Duration group x Date	1.297	0.27	Efficiency group x Date	0.880	0.49
Sleep latency	Duration group	0.095	0.76	Efficiency group	0.456	0.50
	Date	0.877	0.48	Date	0.840	0.52
	Duration group x Date	0.612	0.66	Efficiency group x Date	0.291	0.91
Sleep efficiency	Duration group	0.858	0.35	Efficiency group	2.156	0.14
	Date	1.343	0.25	Date	1.354	0.25
	Duration group x Date	1.040	0.39	Efficiency group x Date	1.556	0.19
Wake duration	Duration group	1.237	0.27	Efficiency group	1.684	0.19
	Date	2.527	0.04*	Date	2.700	0.03*
	Duration group x Date	1.005	0.40	Efficiency group x Date	1.293	0.27
Number of wake bouts	Duration group	0.138	0.71	Efficiency group	0.543	0.46
	Date	2.994	0.01*	Date	2.914	0.01*
	Duration group x Date	1.077	0.37	Efficiency group x Date	0.700	0.62
Average duration of wake bouts	Duration group	2.211	0.14	Efficiency group	1.266	0.26
	Date	1.094	0.36	Date	1.120	0.34
	Duration group x Date	1.665	0.16	Efficiency group x Date	1.695	0.15

There was a main effect for date for nightly sleep duration, wake duration, and number of wake bouts. Compared to other nights during the tournament, sleep duration was shorter following matches. Wake duration (mean 93 minutes) was highest following a rest day. Table 13 presents team-level summary statistics for habitual and tournament sleep.

Table 13: Summary Statistics: Habitual and Tournament Sleep. Note: SD = standard deviation, diff. = difference, HH:MM = Hour Hour:Minute Minute time format. No statistical comparison between habitual and tournament measures was performed due to the small sample size.

Sleep variable	**Habitual sleep**		**Tournament sleep**		**Habitual minus tournament**	
	Mean	**SD**	**Mean**	**SD**	**Mean diff.**	**SD diff.**
Bed time (HH:MM)	23:12	01:11	22:19	01:52	53	-41
Wake-up time (HH:MM)	07:35	02:21	06:49	01:37	46	44
Sleep duration (h)	7.98	1.16	8.26	1.40	0.27	1.68
Sleep latency (min)	7	14	5	8	-3	10
Sleep efficiency (%)	84.98	7.57	82.92	7.72	-2.12	9.13
Wake duration (min)	62	36	72	38	11	43
Number of wake bouts (#)	29	13	28	12	0	15
Average duration of wake bouts (min)	2.19	1.01	2.45	1.10	0.28	1.27

Impact of Flight on Perceptual Ratings of Jetlag

Table 14 presents mixed model outputs from analysing the impact of in-flight sleep on subsequent jetlag ratings, while Figure 20 displays the impact of the in-flight duration on the perceived ratings of AM jetlag over the tournament. There was a significant (F-type statistic = 4.6 p = 0.002) main effect for date on the AM jetlag rating. Player AM jetlag rating was higher on day 1-3 compared to day 6 of the tournament.

Table 14: Mixed Model Outputs: Impact of In-Flight Sleep on Jetlag Ratings. Note: * indicates statistically significant test effects.

Jetlag variable	**Impact of in-flight sleep duration**			**Impact of in-flight sleep efficiency**		
	Test effect	**F-type statistic**	**p**	**Test effect**	**F-type statistic**	**p**
AM jetlag	Duration group	0.358	0.55	Efficiency group	3.166	0.08
	Date	4.660	0.00*	Date	2.983	0.03*
	Duration group x Date	3.076	0.02*	Efficiency group x Date	1.612	0.18
PM jetlag	Duration group	0.077	0.78	Efficiency group	5.675	0.02*
	Date	4.852	0.00*	Date	3.477	0.02*
	Duration group x Date	3.840	0.01*	Efficiency group x Date	2.253	0.09

There was a significant (F-type statistic = 3.08 p = 0.02) interaction for in-flight sleep duration group × date on AM jetlag rating. There were significant differences between in-flight sleep duration (higher vs lower) AM jetlag rating on day 2 and day 5.

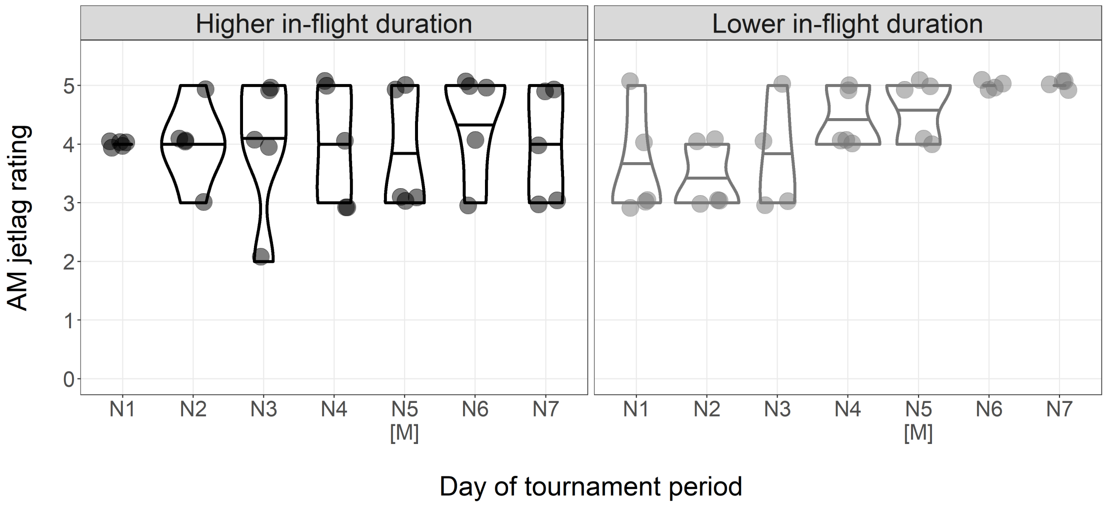


Figure 20: Perception of AM Jetlag Categorised by In-Flight Duration Group and Date During the Tournament Period. Each dot point represents one player's AM jetlag rating on a given date. For each in-flight sleep duration group on any given date, the outer boundary of the violin plot represents the distribution of data, while the horizontal line within the violin plot is the median AM jetlag rating.

Figure 21 displays the impact of the in-flight sleep duration on perceived ratings of PM jetlag. There was a significant (F-type statistic = 4.85 p = 0.002) main effect for date on PM jetlag rating. Player PM jetlag rating was higher on day 2 compared to day 5 and 6 of the tournament.

There was a significant (F-type statistic = 3.84 p = 0.009) interaction for in-flight sleep duration group x date on PM jetlag rating. There were significant differences in AM jetlag rating on day 2 and 5 between the high and low in-flight sleep duration groups.

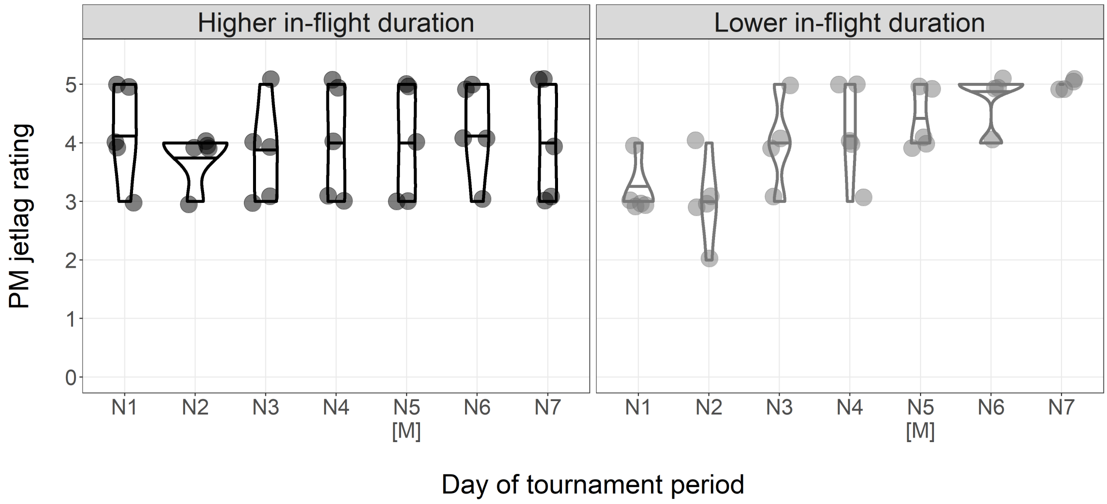


Figure 21: Perception of PM Jetlag Categorised by In-Flight Duration Group and Shown Across Dates. Each dot point represents one player's PM jetlag rating on a given date. For each in-flight sleep duration group on any given date, the outer boundary of each violin plot represents the distribution of the data, while the horizontal line within the violin plot is the median PM jetlag rating.

Impact of Flight on Self-Reported Measures of Well-Being

Table 15 presents mixed model outputs from analysing the impact of in-flight sleep on subsequent well-being ratings, while Figure 22 displays the impact of the in-flight sleep efficiency on self-reported fatigue. Players that obtained higher in-flight sleep efficiency perceived themselves as less fatigued than players in the lower in-flight sleep efficiency group. No differences were observed in in-flight sleep efficiency groups in other self-reported measures. There were no differences between in-flight sleep duration groups in any self-reported measures of well-being.

Table 15: Mixed Model Outputs: Impact of In-Flight Sleep on Self-Reported Well-Being. Note: * indicates statistically significant test effects.

Well-being variable	Impact of in-flight sleep duration			Impact of in-flight sleep efficiency		
	Test effect	F-type statistic	p	Test effect	F-type statistic	p
Fatigue	Duration group	0.087	0.77	Efficiency group	5.433	0.02*
	Date	1.643	0.16	Date	1.448	0.22
	Duration group x Date	1.742	0.13	Efficiency group x Date	1.077	0.36
Sleep	Duration group	3.689	0.05	Efficiency group	0.075	0.78
	Date	2.205	0.06	Date	2.243	0.06
	Duration group x Date	0.785	0.54	Efficiency group x Date	1.207	0.30
Soreness	Duration group	1.047	0.31	Efficiency group	0.220	0.64
	Date	1.411	0.24	Date	1.379	0.25
	Duration group x Date	0.847	0.46	Efficiency group x Date	0.379	0.76
Stress	Duration group	0.438	0.51	Efficiency group	0.134	0.71
	Date	0.772	0.54	Date	0.559	0.63
	Duration group x Date	2.162	0.07	Efficiency group x Date	0.721	0.53
Overall score	Duration group	0.307	0.58	Efficiency group	0.473	0.49
	Date	0.749	0.54	Date	0.771	0.51
	Duration group x Date	0.396	0.78	Efficiency group x Date	0.582	0.63

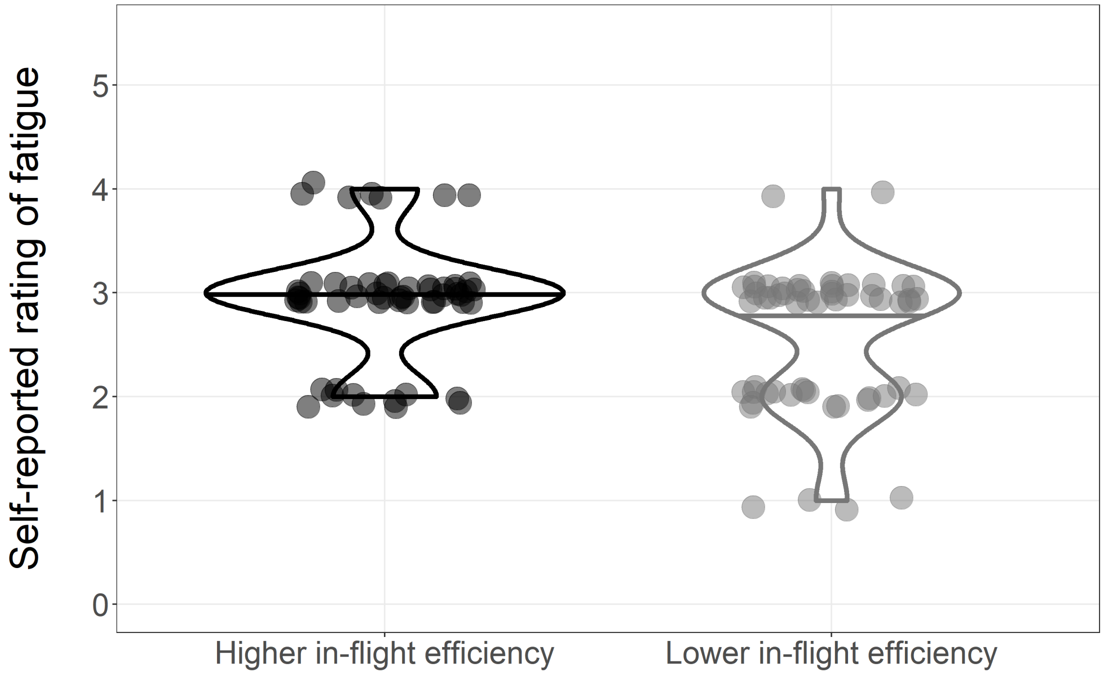


Figure 22: Self-Reported Perceptions of Fatigue Categorised by In-Flight Efficiency Group. Each dot point represents each player's ratings of fatigue across the tournament period. The outer boundary of each violin plot indicates the distribution of the data points within each in-flight sleep efficiency group. The horizontal line within each violin plot indicates the median fatigue rating for each group.

The Relationship between Objective Sleep, Well-being and Training Load and Perceptual Measures of Jetlag

There were no significant bivariate relationships between training load, match load, and total daily load and objective measures of subsequent sleep.

A scatterplot matrix of self-reported well-being ratings versus measures of subsequent sleep is presented in Figure 23. Higher ratings for stress were correlated with longer total wake duration (rho = 0.21, p = 0.02) and longer average duration of wake bouts (rho = 0.29, p = 0.00). Higher ratings for soreness were correlated with lower sleep efficiency (rho = -0.20, p = 0.02) and longer average duration of wake bouts (rho = 0.23, p = 0.01). Higher well-being scores was correlated with longer average duration of wake bouts (rho = 0.18, p = 0.04).

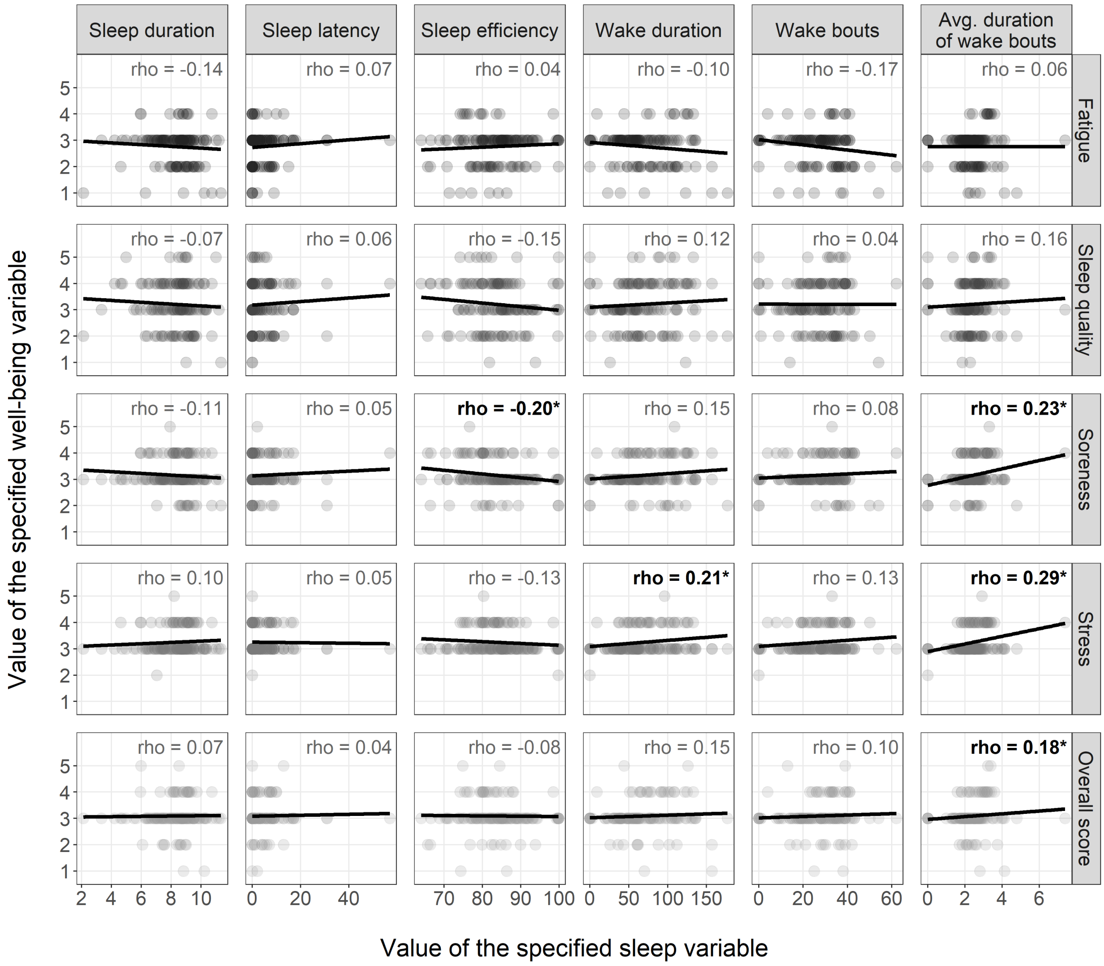


Figure 23: Relationships Between Self-Reported Measures of Well-Being and Sleep Variables of Subsequent Sleep During the Tournament Period. Note: Black trendlines show the linear relationship between any two variables; * indicates statistically significant correlations. Weak correlations were observed between: soreness and sleep efficiency; soreness and average duration of wake bouts; stress and total wake duration; stress and average duration of wake bouts; and overall well-being score and average duration of wake bouts.

A scatterplot matrix of self-reported AM jetlag and measures of subsequent sleep are displayed in Figure 24. Higher AM jetlag ratings were correlated with lower sleep efficiency (rho = -0.26, p = 0.04) and longer total wake duration (rho = 0.28, p = 0.03) in subsequent sleep bouts.

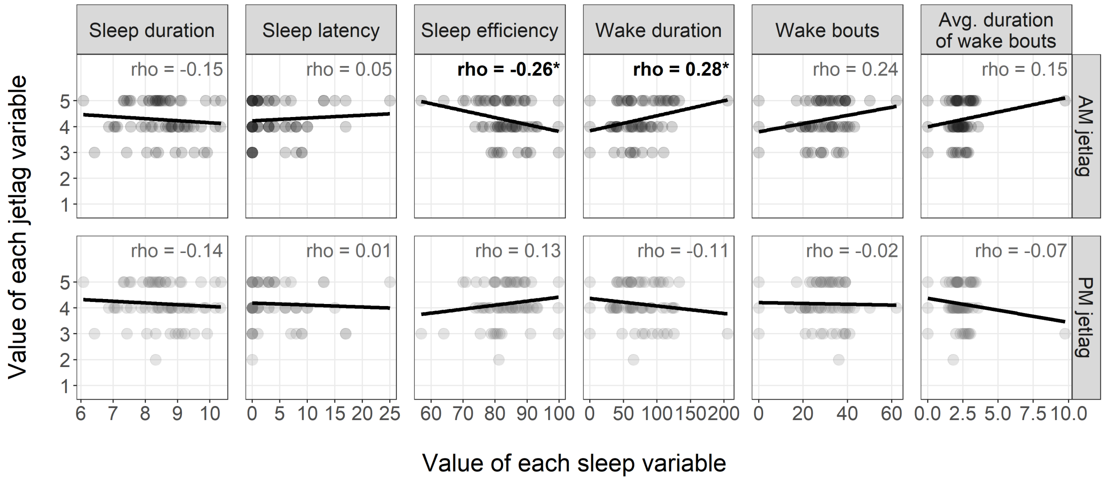


Figure 24: Relationships Between Perceived Jetlag and Measures of Subsequent Sleep During the Tournament Period. Note: Black trendlines show the linear relationship between any two variables; * indicates statistically significant correlations. Weak correlations were observed between AM jetlag rating and sleep efficiency, and between AM jetlag rating and total wake duration.

Discussion

This study revealed elite female cricketers slept for longer and obtained better quality sleep during an international flight compared to other national team sport athletes, travelling west with a similar flight time.[4] Upon arrival, player's experienced negligible perceptions of jetlag, which was reflected in the maintenance of habitual sleep. In some instances player sleep characteristics during the tournament were better than habitual. It is possible that the hotel sleep environment was more conducive for players to optimise sleep (own room, temperature control, minimal noise and block out blinds) than their home.[70] Specifically, nightly sleep duration during the tournament period was longer than habitual, except for nights following matches. This highlights that T20 cricket matches cause disruption to the sleep characteristics of elite female cricketers, irrespective of the time the match is played. The planned departure time and business class seat selection to maximise the opportunity for sleep quality and quantity appears to have implications for recovery and sleep upon arrival.

The westward travel between Melbourne and Chennai presented two sleep opportunities. The in-flight mean sleep duration of 14.64 ± 3.56h is higher than reported in other sports.[4,5,27] The mean in-flight sleep efficiency (86.66 $\pm$ 6.60%) is higher in comparison to elite athletes seated in economy class.[4,7] There is limited research in general or athletic populations assessing objective sleep characteristics during a business class flight. However, both quantity and quality of sleep when seated increase as seat angle increases.[95] Potential mechanisms for poor sleep in an upright position (i.e. economy class) include difficulty maintaining head position and an increase in sympathetic and decreases parasympathetic activity, resulting in heightened physiological arousal.[95] It is possible that players in this study were able to achieve higher sleep quality and quantity than previously reported due to the ability to lie flat to sleep in business class. The departure time (0330h Australian Eastern Standard Time) may have also increased the homeostatic drive to sleep on the flight, further increasing sleep quality and quantity.[219] However, it is unknown whether the players entered the flight with an accumulated sleep debt, which may have also increased sleep need during travel.[220] The financial investment to achieve sleep quality and quantity similar to habitual values by travelling business class may be partially offset by the costs associated with the alternative approach of arriving days earlier (e.g., accommodation) to recover from travel.

Although players maximised the opportunity to sleep during travel, there was no observed effect of in-flight sleep duration (high vs low) on self-reported well-being. However, the quality of sleep obtained in-flight had an impact on self-reported fatigue, with players from the lower efficiency group reporting higher fatigue. Findings on the impact of international travel on perceived well-being of elite athletes are mixed.[4,7] For example, no significant differences were observed in the well-being of professional footballers following westward travel, despite reports of truncated sleep durations in-flight.[4] This may be due to the travel experience of the playing group, or players intentionally not reporting changes in well-being measures through fear of non-selection.[4] In contrast, greater perceived anger, confusion, depression, and fatigue were reported following a reduction in both sleep quality and quantity during simulated international travel.[7] Improving the quality of in-flight sleep has the potential to impact self-reported fatigue which could influence exercise intensity in subsequent sessions.[60]

Preserving sleep quality and quantity during long-haul travel may also be an important strategy of jetlag management.[3,8] Players that slept for longer during the flight presented with minimal perceived jetlag. In contrast, players with lower in-flight sleep duration reported some perceptions of jetlag, which improved two days after arrival. However, travelling west may produce reduced symptoms of jetlag when compared to east, where the length of the day is shortened and the circadian rhythm must shorten to re-establish a normal routine.[221] Based on estimated rates of circadian rhythm adaptation being a half a day per hour of the time difference westwards (5.5h time difference), jetlag symptoms would likely have been negligible after approximately three days.[5] Our findings are consistent with this, suggesting that arrival four days prior to the warm up match was adequate (regardless of in-flight sleep characteristics) to recover from the flight. Furthermore, our results suggest that minimising time spent awake during travel, may reduce the severity and duration of jetlag symptoms.[8]

The preservation of habitual sleep characteristics during the tournament suggests that jetlag symptoms did not impact sleep.[8] Due to the change in time zone, players sleep environment,[36] training and match day load,[67] the evening time of some matches[30] and possible competition anxiety,[54] it was expected that the sleep onset, duration and quality could have been impacted. However, in some instances, sleep characteristics were better than habitual. Sleep disruption, which is one of the main symptoms of jetlag, includes difficulty initiating and maintaining sleep and early awakenings, is a common occurrence after westward travel.[5] The mean onset of sleep (5±8minutes) during the tournament was shorter than habitual s (7±14minutes), suggesting players did not have difficulty initiating sleep. The number of wake episodes during the tournament were the same as habitual, also suggesting that the players did not experience increased wake episodes as a symptom of jetlag.

During the tournament, the average nightly sleep duration was greater than habitual, with the exception of the night of the first and second match of (played at 1930h and 1530h). Whilst players were encouraged to maintain habitual routines, the typical bedtime and wake-up time during the tournament was 53±41 and 46±44 minutes earlier than habitual, respectively. The earlier bed time and wake time is most likely due to the circadian rhythm changes and sleep propensity associated with the direction of travel and the number of time zones crossed (habitual bed time in Melbourne 2300h Chennai 1800h increasing drive to go to bed earlier at competition destination).[123] Despite these changes, players' habitual sleep duration was maintained during the tournament period. Similar to previous findings,[215] the shorter sleep duration observed on the night of a match reinforces the disruption that a match, irrespective of start time, has on sleep characteristics.[215] This suggests the importance of organising the team schedule following matches to allow opportunity for players to obtain sufficient sleep. However, a decrease in sleep duration was not observed on the night of the warm-up match. This match may have been associated with less arousal and post-match socialising and therefore resulted in less disruption to sleep.[222] Where possible during the tournament, an hour was scheduled from 1430h to 1530h as a 'no team communication period' to allow players to disconnect from their phones or nap. Despite the inclusion of this period in the schedule, the total naps reported during the tournament was low, suggesting players did not need to supplement their nightly sleep duration.[135] It is likely that the habitual sleep duration of the playing group was maintained during the tournament due to the minimal sleep disruptions as a result of jetlag, in addition to the team schedule (minimal evening commitments) allowing players adequate opportunity to sleep. Similar strategies are recommended when planning team sport travel in order to maximise sleep duration.

In addition to maintaining habitual sleep duration, the number and average duration of wake bouts were also similar to habitual. Although players recorded a similar number of wake bouts in habitual and tournament sleep, a slight increase in wake duration was observed (11 ± 106 min more time awake in tournament sleep bouts than habitual). The large standard deviation for wake duration indicates individual differences in sleep patterns and some players experiencing difficulties maintaining sleep. The highest wake duration was observed on the sixth night of the tournament following a rest day. Based on the next day being a non-match day, the increased wake duration is therefore unlikely due to pre-match anxiety.[54] It is also unlikely related to jetlag, based on estimated rates of circadian rhythm adaptation.[5] There is a possibility that the stress associated with the looming selection for the first match of the tournament may have been a disruption to players' sleep.[54]

During the tournament period, higher ratings for stress (i.e., lower perceived stress) were correlated with longer duration of wake bouts and longer total wake duration in subsequent sleep. Similarly, higher ratings for soreness (i.e., less perceived soreness) were associated with lower sleep efficiency and longer average duration of wake bouts. These observations indicate that sleep fragmentation can occur even when athletes perceive that they are experiencing low stress and low soreness. While this study examined the effects of well-being on subsequent sleep, previous research suggests that fragmented sleep can, in turn, have an impact on subsequent ratings of well-being, including mood and soreness.[220] Similar findings have also been observed in elite cyclists during an intensive training period, where athletes who experienced an increased number of wake bouts reported disruptions to mood, and increased tension, fatigue, and stress.[178] Reducing the number and duration of wake episodes in both habitual and competition environments, may improve self-reported stress and soreness.

It was unexpected that the lower perceived rating of AM jetlag was correlated with lower sleep efficiency and longer wake duration. It is possible the AM jetlag correlations may be coincidental: that is, lower perceived AM jetlag just happened to coincide with lower sleep efficiency and longer total wake duration in subsequent sleep bouts, when in reality, other factors contributed to changes in sleep efficiency and total wake duration. This is plausible because stress, soreness, and overall well-being showed some (weak) correlations with the same / similar sleep variables.

The finding of minimal perceptions of jetlag and the maintenance of sleep characteristics could possibly be explained by the westward flight, and associated circadian rhythm operating ahead of local time.[41,6,127] The quality and quantity of sleep obtained in-flight and the familiarity of the group with international travel may also be contributing factors.[4] It is also possible that players have intentionally underreported symptoms of jetlag through concerns of not being selected for matches.[4] It has been suggested that the development of an athlete specific jetlag questionnaire that takes into account the impact of training demands on subjective jetlag symptoms, may increase the precision of measurement of jetlag in elite athletes.[5] However, given the maintenance of sleep characteristics, the quality and quantity of sleep obtained in-flight and travel experience of the playing group, it is reasonable to assume that the self-reported measures are a reflection of the players true state.

Limitations

The lack of training and match performance measures to quantify the impact of the international flight is a potential limitation. Furthermore, activity monitors have some limitations when measuring athletes sleep[223] as they are based on the principle that people move when they are awake, therefore the limited movement whilst seated on a plane presents a challenge to measure sleep accurately.[21] However, players were diligent with the use of the time stamp function on the activity monitor in-flight and the completion of the sleep diary to identify when sleep was being attempted.

Furthermore, body temperature and/or melatonin concentrations were not assessed to confirm circadian rhythm adaptation upon arrival.[8] We acknowledge that the small sample size is a limitation that may have some impact on the analyses. For example, in modelling the effect of in-flight sleep on subsequent tournament measures, it may have been worth including covariates such as tournament training load. However, even with relatively simple models specified in this study, observed statistical power was low; for detecting large main effects (F-type statistic = 0.4)[183] observed power varied from 30–70% based on 1,000 simulations per model.[224] Adding covariates would increase model complexity and further reduce statistical power. In addition, it was not possible in practice to recruit a larger sample for this study because participant numbers were confined to players on the National team who were selected to travel.

Practical Applications

Strategies to minimise the impact of the flight should focus on enhancing the in-flight sleep quality and quantity, including cabin class selection. Consideration of flight departure time close to or following habitual bedtime may increase both the sleep quantity and quality of sleep obtained during travel. Improving fragmented sleep by reducing wake bouts may improve sleep, self-reported stress and soreness in elite female cricketers. Scheduling strategies including minimal evening commitments and training sessions not starting unnecessarily early are recommended in order to maximise sleep duration, particularly following matches.

Conclusions

Maximising the opportunity for in-flight sleep quality and quantity by planning departure time and business class travel appears to have implications for recovery and sleep after arrival. Players experienced negligible perceptions of jetlag, which was reflected in the preservation of habitual sleep characteristics throughout the tournament. Sleep duration was longer than habitual except for the night of matches, suggesting T20 cricket matches cause disruption to the sleep duration of elite female cricketers, regardless of match start time. Team schedules should minimise early morning activity to assist players to achieve optimal sleep quality and quantity.

Chapter 7: Discussion and Conclusion

The main aim of this thesis was to investigate the objective sleep characteristics of elite male and female team sport athletes during competition. A series of studies was conducted in a high performance environment to assess a number of factors that impact the sleep of elite team sport athletes: (1) the impact of match start time and days relative to a match on sleep; (2) the relationships between sleep, training load and well-being; and (3) the impact of the quality and quantity of sleep obtained during a long-haul flight on competition sleep and perceptual measures including well-being and jetlag. This broad focus has enabled a number of factors that may impact sleep to be investigated within an elite cohort, with direct application for high performance programs, coaches and practitioners. The focus of previous work has compared competition sleep during extreme match start times (e.g., day vs. night)[30], or assessed a single match start time in isolation.[53,70,71] However, the competition schedule of elite team sport athletes often involves matches in a variety of timeslots, therefore Study One assessed the impact of a range of match start times on post-competition sleep. Previous assessments of the impact that competition has on sleep have not always included a comparison with a habitual baseline.[30,59] Without an understanding of how an athlete usually sleeps, it is difficult to make a relevant comparison to the sleep characteristics exhibited during competition. How an athlete 'usually' sleeps may however fall into a number of periods including the offseason (no training or competition), the pre-season (training with no competition) and in season (training and competition). Selecting an appropriate baseline period was a critical focus of this research, in order to clearly identify the impact that competition and travel had on an elite team sport athlete's sleep. Therefore, Study One and Three included a comparison of competition sleep to a 5-10 consecutive day habitual baseline during the preseason.[74] This period was selected as the athletes were accustomed to the training load, there was no domestic or international travel and the athletes were sleeping in their home environment. Despite the known restorative effects of sleep and the important role it may play in minimising fatigue, optimising recovery and well-being, the relationship between load, well-being and sleep prior to and following training and matches is not clear.[1] Subsequently, Study Two assessed the relationship between external training load, self-reported measures of well-being and objective sleep characteristics both prior to and following a main training session. The sleep characteristics for both Study One and Two were assessed in players' habitual sleep environment, however it is often a requirement for an elite team sport athlete to travel both domestically and internationally for competition.[2-5] In order to investigate the impact of international travel on the sleep characteristics, well-being and performance of elite team sport athletes,[6] the participant group for Study Three was extended to elite female cricket players, as players are required to travel both domestically and internationally for competition. There have been no previous assessments of objective in-flight sleep characteristics when athletes have the ability to lie flat whilst travelling in business class, despite difficulties obtaining good quantity and quantity of sleep during long-haul travel being well documented.[4,7] As a result, Study Three assessed the impact of the in-flight sleep obtained whilst seated in business class on the sleep characteristics, well-being and perceptual measures of jetlag during an ICC Women's World Cup tournament.

The following section presents the key findings from the three studies within this thesis.

Subjective Sleep Ratings May Not Provide Accurate Measures of Sleep Quality

The mismatch between objective and subjective sleep was a key finding in all three studies. A major finding of Study 1 was the subjective sleep rating was not aligned with the objective measure of sleep quality in either the habitual or competition period.

It has been acknowledged that individuals have difficulties assessing their own sleep patterns[214], which highlights the limitations of the use of subjective ratings of sleep in the athletic population. The findings of this work suggest that the implementation of shortened questionnaires, similar to the one used in this study, may not provide accurate measures of sleep quality.[60] Therefore due to the apparent inaccuracy of subjective ratings of sleep quality obtained from shortened questionnaires, practitioners should aim to collect objective sleep data using validated techniques.

Sleep is Disrupted Irrespective of Match Start Time.

A novel finding from Study One was that any match, irrespective of match start time, caused disruptions to players' sleep during the AFL season. These findings were supported in Study Three, where it was observed that with the exception of the nights following a match, sleep duration was longer than habitual during competition, regardless of start time. The competition schedule of an elite team sport athlete often involves a variety of day, twilight, and evening matches, however the impact of an evening match start time on the sleep characteristics of elite team sport athletes has received the most attention.[53,70,71] Research in AF has compared extreme match start times (e.g., day vs. night), or assessed a single match start time in isolation, which limits the ability to assess the effect of competition on sleep. Study One revealed a longer sleep latency and shorter sleep duration on the night of the match compared to all other nights during competition, similar to findings in elite Rugby Union.[31] An early morning recovery session was scheduled at the same time (0900h) the morning after each match, despite a later bedtime observed on the night of all matches compared to all other nights during the monitoring period. Subsequently, players were unable to extend their wake time and sleep duration following a match. These findings reinforce the impact of the team schedule on players' sleep duration, particularly following a match.[22]

The results of Study One indicate that it is particularly challenging for AF players to obtain optimal sleep after evening competition, which is consistent to previous findings in team sport athletes.[30,31,70,71] Compared to other match start times, a longer sleep onset latency, lower sleep efficiency, and increased wake time were exhibited following the evening match. Although not measured, the pre-sleep arousal following the night match may have influenced the longer sleep onset latency observed.[71] It has been suggested that athletes who have a tendency toward a high trait arousal (measured via a hyper arousal scale) may be vulnerable to sleep disruptions in the sleep opportunity following a night game.[71] To date, there has been mixed findings in the assessment of sleep characteristics following matches played in the evening.[30,70,71,211] A shorter sleep duration and longer sleep latency has been previously observed in AF,[30] and a lower sleep efficiency has been observed in elite female netball players and elite amateur football players following an evening match.[71,211] In contrast, no differences were observed in measures of sleep after a night match compared to a day match and non-match days in a national youth soccer team.[53,211] However, these investigations have been undertaken either during pre-season competition,[30] following a 'friendly' practice match,[53] or the participants have been youth/development athletes[211] and may not provide a true reflection of the impact that evening matches have on elite team sport athletes.

Interestingly, players did not use the earlier finish time of day matches to extend their sleep by going to bed closer to their habitual bed time. This may be due to the players using the post-match period as a time to socialise.[86] Another possible explanation is that the psycho-physiological effects of the match including arousal or pain or the use of caffeine during the match may have delayed the drive to attempt sleep.[54,225] Study One revealed a clear interruption to sleep occurred in the nights immediately following a match, thus providing an ideal opportunity for an intervention to optimise the sleep of elite team sport athletes. In comparison to the night prior to the match, the sleep duration remained shorter for two nights following matches. Combined with reduced sleep duration on the night of the match, there is potential for individual players to accumulate a sleep debt around competition.[54] There have been similar observations following elite volleyball competition, where the night following the match sleep duration was also the most disrupted.[83] Despite the disruptions to both sleep duration and sleep efficiency on the night of all matches', no players in Study One napped in the days following an evening match, or extended their total sleep time. Extending sleep from 7 to 9 h per night reportedly improves performance and wakefulness in athletes,[136] and this may be a focus for sleep hygiene education for elite team sport athletes.[17] It is acknowledged that there was only one match time per start time during the competition period analysis for Study One and that a longitudinal investigation with more than one sample for each match start time may provide further insight into the effect of a match start time, days relative to the match and the impact of domestic travel during the AF competitive season.

Players Slept for Longer and Did Not Experience Difficulties Initiating Sleep the Night Prior to Competition

The sleep duration the night before a match was longer than other nights relative to the match in Study One which is consistent to previous findings in AF[26] and Rugby Union.[31] The morning of the match was the only day the players did not have to attend a scheduled team session during the monitoring period, which may have provided an opportunity for players to extend their sleep duration. Previous work has observed athletes' sleep behaviour changed depending on the time of training,[23] including a later bed time and wake time when they are not required to attend training until the early evening.[85] Despite no commitments in the morning, AF players in Study One actively went to bed earlier the night before the match compared to the night of the match. The increase in sleep duration when compared to other nights relative to the match in previous research has been attributed to the players' perception that a good sleep will optimise performance the following day.[26] The performance benefits of increasing sleep duration over an extended period of time has been demonstrated in collegiate athletes and students with improvements in cognitive performance, reaction time, mood, lower daytime sleepiness and fatigue.[17,65] However, the performance impact of short term sleep extension i.e. one night before the match in AF has not been explored. Players may have had the intention of going to bed earlier to increase sleep duration, however due to the variation in sleep propensity across a 24 h day, it has been suggested that there may be some difficulties initiating sleep during a period termed the 'forbidden zone' in the hours prior to night time sleep onset.[22] A novel finding of Study One was that compared to all other nights relative to the match (1 day prior, 1 night following and 2 nights following), AF players exhibited shorter sleep latency (9 minute) the night prior to the match, which is similar to population norms (11 minute).[212] This finding was supported in Study Three where, on average, the players' sleep latency during the tournament period was 3 min shorter than habitual. Qualitative assessments have reported that athletes experience sleep difficulties before competition, in particular, athletes have reported a longer sleep onset latency due to sleep due to nervousness and thoughts prior to competition.[28,54,55] Athletes reported that sleep was worse than usual the night before competition or a match in the previous 12 months.[54] There were no significant differences reported between gender or sport (individual vs. team).[54] The disparity between the objective sleep onset latency measures and the self-reported sleep difficulties outlined in the qualitative assessments from Study One and Three may be due to the limitations associated with the use of self-report measures to assess sleep, which are known for their inability to accurately assess sleep onset latency and wake after sleep onset.[28]

Later Training Start Times Provides Opportunity To Achieve Optimal Sleep Duration

The mean sleep duration observed in Study One and Three during both the habitual and competition sleep monitoring periods are decidedly higher compared to previous findings.[18,22,50] Despite a small decrease in the competition sleep duration compared to habitual sleep observed in Study One, both the habitual (8h 52min) and competition (8h 04min) sleep durations fell within the general population recommendations of 7-9 hours of sleep each night.[207] In Study Three, the mean nightly habitual (7h 58min) and competition (8h 15min) sleep duration values also fell within these recommended guidelines.[207] Despite an earlier wake time compared to habitual in Study Three, possibly due to pre training preparation, the players' total sleep duration was not compromised during the tournament, suggesting players may have been instinctively going to bed earlier to achieve their habitual sleep duration.[22] Sleep durations between 6-7 h have been observed in individual and team sport athletes, albeit these assessments have been during different conditions including a competitive season,[17] heavy training periods[211] and prior to major performances.[50] Investigations that have included out of competition sleep patterns of both individual and team sport athletes have also observed nightly sleep durations falling below the recommended targeted 8 h per night.[18,22,29] The major disrupter to obtaining sufficient sleep has been reported to be early morning training sessions, which has been demonstrated to decrease the athletes' sleep duration and increase the pre training fatigue levels.[22,23] The training and competition schedule of professional team sport athletes in Study One and Three may have been more conducive to obtaining more sleep when compared to athletes in previous investigations.[22,23] Previous research has demonstrated a reduction in sleep duration depending on training start times, highlighting that for every hour that training was advanced from 0800h to 0500h, sleep duration was decreased by 6 minutes (0700h), 48 minutes (0600h) and 102 minutes (0500h).[22] Training sessions in Study One and Three did not start prior to 0800h and 0900h, respectively, and appear to have limited the impact of players achieving optimal sleep duration.[207] The results of Study One and Three reinforce the importance of high performance staff and coaches' consideration of training start times to allow opportunity for players to obtain sufficient sleep.

Focus Attention on Optimising Habitual Sleep Efficiency

A key finding of Study One was that the sleep efficiency of players was higher during competition compared to habitual. These findings are comparable to an assessment of netball players where, compared to training, an increase in competition sleep efficiency was observed.[213] The authors suggested that the increase in sleep quality during the competition may be due to the increased homeostatic drive for sleep due to an increased workload during competition.[213] However, this suggestion was not confirmed by the inclusion of training or competition load.[213] Future research should aim to further explore the relationship between training load and objective measures of sleep quality. In contrast, there was no change in the sleep efficiency of Rugby Union players between baseline night sleep (two nights prior to the match) and competition (one night prior, night of the match and two nights following the match), with the sleep efficiency recorded for all nights (average 78%) below population norms.[31] The baseline night used in this assessment was two days prior to the match, therefore may not necessarily represent players' usual sleep efficiency. Although the sleep efficiency of players during competition was higher than habitual in Study One, it does not suggest that the habitual characteristics of players were optimal.[207] For example, the habitual sleep efficiency of AF players in Study One (81.35%) was considerably lower than previously observed in AF (~90%)[26] and below the recommendation for healthy adults (90-85%).[207] This may indicate that players are experiencing sleep difficulties, potentially impairing their ability to obtain sufficient restorative sleep during training. By developing an understanding of out of competition sleep, there is an opportunity to optimise the sleep quality of players in their habitual sleeping and training environment. Adjusting environmental conditions, implementing sleep routines and other sleep hygiene strategies may improve the quality and quantity of sleep, and have been shown to be effective in team sport athletes.[210] Based on the findings from Study Two, improving quality of sleep may have an impact on player self-reported measures of well-being and the players' movement strategy during training sessions.[60] In addition to an emphasis on competition, practitioners should also focus attention on increasing the quality and quantity of sleep in the athlete's habitual sleep and training environment.

A Change in Sleep Environment Did Not Impact Sleep Quality

It has been suggested that a change in sleep environment may contribute to the sleep disruptions experienced by athletes during both training and competition.[51] Players remained in their habitual sleep environment for the duration of the competition sleep monitoring period in Study One, which may be a possible explanation for AF players initiating sleep without difficulties prior to competition. Previous work in AF has observed that players with higher sleep quality at home have poorer sleep in camp, while players that slept poorer at home exhibited similar sleep/wake behaviours during the camp.[36] Despite no difference in mean training load, this investigation suggested that a change in sleep environment negatively impacted players' sleep quality,.[36] However, these observations may have been confounded by the requirement of players to share a room with a teammate.[36] The findings from Study Three are in contrast to the suggestion that a change in sleep environment contributes to sleep disruptions, with a shorter tournament sleep onset compared to habitual and tournament sleep quality only 2% lower than habitual values (84.98%) despite two changes in sleep environment during the competition period (home to hotel and a change of hotel mid-tournament). It is possible that the hotel sleep environment in Study Three was conducive for players to implement sleep hygiene strategies in order to optimise sleep (own room, temperature control, minimal noise and block out blinds). This change in sleep environment may have facilitated players to achieve sleep close to, or better than, habitual sleep during the tournament period. Although not an explicit aim of this research, the results of Study Three suggest that a change in sleep environment did not affect the sleep quality of female team sport athletes.

Fragmented Sleep is Associated With Lower Self-Reported Well-Being.

Following the findings of Study One, it was hypothesised that there are numerous factors that influence the sleep characteristics of elite team sport athletes, including player well-being and external load. The findings of Study Two indicate a complex interaction of a number of sleep variables that influence both the external load and the well-being of AF players. Fragmented sleep prior to the main training session was associated with lower ratings of mood and increased ratings of soreness, highlighting the impact of increased wake time prior to a main training session. Similar findings have been reported in elite cyclists during an intensive training period where cyclists who experienced fragmented sleep reported disruptions in mood, fatigue and stress.[178] For an elite team sport athlete, mood alteration has the potential to influence motivation to train and willingness to give maximal effort in competition.[18] Investigations have also revealed that pre training well-being influences exercise intensity in subsequent field-based training sessions in AF.[60] The findings from Study Two suggest that fragmented sleep is an aspect of sleep that could be targeted for improvement. It has however been suggested that athletes move differently during sleep compared with the general population, particularly during heavy training phases.[52] Therefore, it is also possible that the wake episodes experienced by an elite athlete may be overestimated if there are high levels of movement during light sleep.[21] Nonetheless, prioritising sleep hygiene strategies to minimise wake episodes may improve sleep, in addition to optimising the well-being of players. Optimising sleep quality and quantity through sleep extension strategies has been associated with an improved percieved performance, daytime sleepiness and reaction time.[17] This reinforces that obtaining additional, good quality sleep is likely to have a positive impact on an athletes' overall recovery and readiness to train.[17] There are numerous internal and external factors that may contribute to the fragmented sleep in athletes including anxiety, noise, temperature, soreness, and the need to use the bathroom (due to hydration practices) during the night.[28] Through minimising the time awake during pre training sleep oppourtunities, practitioners may improve the self-reported well-being measures of team sport athletes. This has the potential to impact self-reported measures of mood and soreness which may influence the players' exercise intensity in subsequent training sessions.[60]

Sleep Quality the Night Prior to Training May Impact the External Load in the Subsequent Training Session

Study Two found that players with a lower sleep efficiency and a shorter time to fall asleep in the pre training sleep had a higher PL2D (i.e. from the anterioposterior and mediolateral accelerometer axes only) during training. These associations may be due to players entering the training session fatigued from fragmented sleep (low sleep efficiency) or from an accumulated sleep debt (identified by short sleep onset latency), resulting in the need to perform more high intensity movements to compensate for inefficient running due to impaired decision-making, cognitive functioning and poor positioning.[205] Extended wake periods may have effects on brain function and performance and sleep deprivation impacts higher cognitive functioning (including attention lapses).[42] Although not measured in the current study, there is potential that players with a low sleep efficiency (due to extended wake time) may experience impaired cognitive function during the training session.[42] Even relatively moderate sleep restriction, if sustained night after night, can impact neurobehavioral functioning in healthy young adults.[91] In contrast, extending total sleep time has been shown to improve reaction time, daytime sleepiness and mood in collegiate athletes.[17] As a result, improving sleep quality and quantity may have a positive impact on AF players performance, particularly when sustained attention, reaction time and cognitive tasks are required.[17] Practitioners should monitor external load (specifically PL2D) during AF training in players who have reported poor sleep, and potentially modify training participation if values for these variables differ from pre-determined thresholds.

The Content of the Training Session May Increase the Need For Sleep in the Following Sleep Opportunity

Findings from Study Two suggest that higher acceleration loads (e.g., increased contested style of play and increased contact) in AF training may increase the drive to sleep and result in shorter sleep latency. These findings are consistent to those previously reported in elite Rugby League players, where there appeared to be an increased drive to sleep following intensified periods of training.[173] Specifically, increased acceleration/decelerations were associated with small increases in sleep duration and quality.[25] The authors suggested that elite Rugby League training that involves greater acceleration/deceleration efforts might increase players' perceptions of fatigue, which may result in an increased drive to sleep following the session.[25] Practitioners should be aware of the impact that the content of the training session may have on the subsequent night's sleep. In particular, it is recommended that practitioners allow adequate opportunity for additional sleep. This may be achieved by scheduling the following day's training session no earlier than necessary.

Sleep Quality and Quantity Achieved When Travelling Has Implications for Recovery and Sleep During International Competition.

To our knowledge, Study Three is the first objective assessment of the in-flight sleep of elite team sport athletes seated in business class during an international flight. The results of Study Three indicate that maximising the opportunity for in-flight sleep quality and quantity by planning the team departure time and business class seat selection appeared to have a positive influence on elite female cricket players' recovery and sleep exhibited during competition. Previous work has outlined the challenge of obtaining good quality and quantity of sleep during plane travel.[8] However, to date the investigation of athletes' in-flight sleep has been undertaken when athletes have been seated in economy class,[4] during simulated travel,[7] or sleep has been assessed via self-report measures, which due to an athletes' inability to report sleep quality as previously highlighted has some limitations.[5] The potential mechanisms for poor sleep in an upright position (i.e. in economy class) include difficulty maintaining head position and an heightened physiological arousal when attempting to sleep in an upright position.[95] Study Three demonstrated that players were able to achieve higher sleep quality and quantity than previously reported in other elite team sport athletes.[4,7,27] These findings are likely attributed to the players' ability to lie flat whilst travelling in business class.

The quality of sleep obtained in-flight had an impact on the self-reported measures of fatigue during the tournament. Players with a lower in-flight sleep efficiency reported higher levels of fatigue during the tournament. Study Two highlighted that fragmented sleep prior to a main training session was associated with lower ratings of mood and increased ratings of soreness. This further supports the suggestion that the quality and quantity of in-flight sleep may have had a positive impact on an athlete's overall well-being and readiness to train upon arrival at the competition destination. The preservation of both the sleep quality and quantity during long-haul travel may also be an important strategy to manage jetlag.[3,8] Players that slept for longer during the flight presented with minimal perceptions of jetlag and this was maintained across the monitoring period. In contrast, players with lower in-flight sleep duration reported some perceptions of jetlag, which improved two days after arrival at the destination.

It was expected that sleep onset, sleep duration and sleep quality of players could have been impacted following an international flight during the tournament, due to the change in time zone, players' sleep environment,[36] the evening time schedule of some matches[30] and possible competition anxiety.[54] However, as highlighted in previous sections of the discussion, in some instances sleep characteristics of players in Study Three were better than habitual. Sleep disruption, which is one of the main reported symptoms of jetlag and includes difficulty initiating and maintaining sleep along with early awakenings, is a common occurrence after westward travel.[5] The preservation of habitual sleep characteristics observed in Study Three across the tournament suggests the jetlag symptoms that players did experience did not impact their sleep.[8] Whilst the financial constraints of travelling business class may be a limitation for elite team sporting organisations, the investment to achieve sleep quality and quantity similar to habitual values prior to an important international competition may outweigh the costs (e.g., of accommodation) associated with the alternative approach of arriving days earlier to facilitate recovery from travel.

Conclusions

- Due to the apparent inaccuracy of subjective ratings of sleep quality obtained from shortened questionnaires, practitioners should aim to collect objective sleep data using validated techniques.

- Any match, irrespective of start time (Early PM, Mid PM, Twilight and Evening), caused disruptions to elite male and female team sport athletes' sleep during competition.

- The sleep duration of elite male AF players was longer on the night prior to competition relative to all other nights. In addition, players did not experience difficulties initiating sleep the night prior to competition, and the precise reason for this is not clear, although it appears that the potential impact of pre-match anxiety on prolonging time to fall asleep prior to competition was not a factor for the playing group.

- Fragmented sleep, characterised by an increase in wake episodes and wake duration, is associated with lower self-reported well-being in elite team sport athletes.

- The quality of sleep in the sleep opportunity prior to training may impact the external load of elite male AF players in the subsequent training session.

- Training sessions that have high speed and PL2D may increase the need for sleep in the following sleep opportunity in elite team sport athletes. Practitioners should maximise the opportunity for sleep following the session by ensuring that subsequent sessions do not start earlier than necessary.

- A change in sleep environment from home to a number of international hotels did not impact sleep quality of elite female team sport athletes during a T20 international cricket tournament.

- The sleep quality and quantity achieved during business class travel has implications for the perceptions of jetlag, self-reported well-being measures (particularly fatigue) and the sleep/wake behaviour exhibited during international competition.

Limitations

All three studies that form the body of this thesis were completed in an elite high performance environment and therefore there are some limitations identified.

- There was only one match time per start time during the competition period included in the analysis for Study One. A longitudinal investigation which includes more than one match per start time may provide further insight into the effect of a match start time and the impact of domestic travel on players' sleep during the AF competitive season.

- There was no objective measure of fatigue included prior to the main training session in Study Two. A measure of neuromuscular fatigue (NMF) was not routinely collected in the playing group. In addition to the self-reported measures of fatigue, the inclusion of an objective measurement of NMF may provide further insight into the impact of fragmented sleep on fatigue in elite team sport athletes.

- It was hypothesised that the movement strategies of players during AF main training sessions may have been due to impaired cognitive functioning as a result of low sleep quality and extended wake time the night prior to the training session. However, no cognitive tests were included in Study Two to confirm this suggestion.

- There are some recognised limitations of the use of actigraphy to accurately measure athletes' sleep.[223] The activity monitors used in all three studies are based on the principle that people move when they are awake.[223] The use of actigraphy facilitated the measurement of sleep of athletes during competition. However, the limited movement whilst seated on a plane during Study Three presented a challenge to measure athletes' in-flight sleep accurately.

- Players were provided with general sleep hygiene education prior to departure for the ICC Women's World Cup Tournament in Study Three. However, there was no assessment of the impact of the sleep hygiene education on the sleep characteristics exhibited during the tournament.

- A number of factors may influence cricket performance (physiological, cognitive and environmental) and measuring performance is an area that warrants further investigtaion.[6] No performance measures (runs scored, wickets taken, etc.) were included in the study design to quantify the impact of the international flight on players, training and match day performance.

- Circadian rhythms (body temperature and/or melatonin concentrations) were not assessed in Study Three to confirm the circadian rhythm adaptation of players upon arrival at the competition destination. This may have provided clarity on the influence of the circadian rhythm on the perceptions of jetlag and the self-reported fatigue during the tournament.

- All three studies were completed in an elite high performance environment, therefore the methodology is somewhat influenced by the environment in which the research was conducted. The inclusion of lower level athletes and/or teams for an intervention study was not considered as this group of athletes do not have the same training, scheduling or travel that impact the sleep of athletes in high performance programs.

- The limitations of observational research are acknowledged. However, all three studies were completed with an elite athlete population group during a competition period. A control group was not considered as the studies were completed during a competition period and withholding strategies (i.e. seating team members in economy class instead of business) that could possibly enhance the performance of some players was considered unethical. It is acknowledged that having a control group would be an ideal study design, but was not possible in the high performance environments this research was completed. The findings of the studies that make up this thesis should be considered within this context.

- Two study populations were used across Study 1 and 2 and in Study 3. Whilst each study addressed specific questions, the limitation of using two different study groups (different sport and gender) is acknowledged.

Practical Applications

There are a number of practical applications for high performance programs as a result of this research. These include:

- It was evident that AF players in Study One and Two were experiencing sleep difficulties, potentially impairing their ability to obtain sufficient restorative sleep during periods of training. Therefore, strategies to enhance the sleep quality and quality of elite team sport athletes should, in the first instance, focus on optimising sleep in the habitual sleep and training environment. This may assist with training adaptations, training quality, recovery and well-being.[22,132,172]

- Practitioners should not assume the sleep characteristics of elite team sport athletes are compromised the night prior to competition or during competition. Our findings revealed that sleep duration remained shorter on the nights (+1 and +2) following matches, therefore strategies to optimise sleep should extend beyond the night prior to and night of the match.

- It was evident from both Study One and Three that there is sleep disruption following matches irrespective of start time. Practitioners should focus on all match start times when planning the schedule, including planning minimal evening commitments and training sessions not starting unnecessarily early, in order to maximise sleep duration of elite team sport athletes during competition.

- Fragmented sleep appears to be an area to target for improvement. Prioritising sleep hygiene strategies such as optimising the sleep environment (temperature, lighting and comfort) to minimise wake episodes may improve the sleep of elite team sport athletes. Improving fragmented sleep primarily through a reduction of wake episodes may assist in optimising the well-being and perceptions of fatigue of players. This may in turn optimise an athlete's readiness to train, movement strategies and RPE during both training and competition.

- Strategies to minimise the impact of an international flight should focus on enhancing the in-flight sleep quality and quantity of players. This may be achieved by travelling business class. Travelling business class, particularly when arrival at the competition destination is close to the commencement of the tournament, may assist with the players' perceptions of jetlag upon arrival. The financial constraints of travelling business class may be a limitation, however the investment to achieve sleep quality and quantity similar to habitual values prior to an important international competition may outweigh the costs (e.g., of accommodation) associated with the alternative approach of an arriving days earlier to facilitate recovery from travel.

Future Research Directions

- Longitudinal monitoring of sleep across a season may provide further insight into the effect of match start time, days relative to the match and the impact of domestic and international travel across a competitive season.

- Fragmented sleep is a common issue with elite athletes. Further investigation into the factors contributing to sleep fragmentation in elite team sport athletes may assist with determining the most appropriate sleep hygiene or recovery strategy to implement to optimise sleep.

- Study Two found that muscle soreness may contribute to the fragmented sleep of elite team sport athletes. Future investigations should assess the interactions between external training load, markers of muscle damage, perceived soreness and sleep characteristics in elite team sport athletes.

- This was the first study assessing the objective in-flight sleep characteristics of team sport athletes whilst seated in business class. It is recommended that the in-flight sleep quality and quantity when travelling business class is further investigated in other elite athletic populations and includes an assessment of circadian rhythms (body temperature and/or melatonin concentrations) to confirm the circadian rhythm adaptation of players upon arrival at the competition destination.

- The menstrual cycle may impact the sleep/wake behaviours of elite female athletes[226] and should be a consideration for future research assessing the sleep/wake behaviours of elite female athletes. Future research should aim to investigate the association between sleep, the menstrual cycle, self-reported measures of well-being and training load measures.

- Several habitual/baseline sleep periods may have been used for comparison for both Study 1 and 3. Future research should also consider other periods to determine athletes ‘usual’ sleep patterns.

- Future research should include an individual assessment of sleep in combination with performance measures to determine the meaningfulness impact of partial sleep restriction or fragmented sleep.

Chapter 8: References

1. Halson S. Sleep in Elite Athletes and Nutritional Interventions to Enhance Sleep. *Sports Medicine*. 2014;44:13-23.
2. Richmond LK, Dawson B, Stewart G, Cormack S, Hillman DR, and Eastwood PR. The effect of interstate travel on the sleep patterns and performance of elite Australian Rules footballers. *Journal of Science and Medicine in Sport*. 2007;10:252-258.
3. Janse van Rensburg DC, Jansen van Rensburg A, Fowler P, Fullagar H, Stevens D, Halson S, Bender A, Vincent G, Claassen-Smithers A, Dunican I, Roach GD, Sargent C, Lastella M, and Cronje T. How to manage travel fatigue and jet lag in athletes? A systematic review of interventions. *British Journal of Sports Medicine*. 2020.
4. Fullagar H, Duffield R, Skorski S, White D, Bloomfield J, Kölling S, and Meyer T. Sleep, Travel, and Recovery Responses of National Footballers During and After Long-Haul International Air Travel. *International Journal of Sports Physiology and Performance*. 2016;11:86-95.
5. Fowler PM, Duffield R, Lu D, Hickmans JA, and Scott TJ. Effects of Long-Haul Transmeridian Travel on Subjective Jet-Lag and Self-Reported Sleep and Upper Respiratory Symptoms in Professional Rugby League Players. *International Journal of Sports Physiology and Performance*. 2016;11:876.
6. McEwan K. Get sleep or get stumped: sleep behaviour in elite South African cricket players during competition. *Journal of Sports Science*. 2020;38:2225-2235.
7. Fowler P, Duffield R, and Vaile J. Effects of simulated domestic and international air travel on sleep, performance, and recovery for team sports. *Scandinavian Journal of Medicine & Science in Sports*. 2015;25:441-451.
8. Reilly T, Atkinson G, Edwards B, Waterhouse J, Åkerstedt T, Davenne D, Lemmer B, and Wirz-Justice A. Coping with jet-lag: A Position Statement for the European College of Sport Science. *European Journal of Sport Science*. 2007;7:1-7.
9. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, and Dodge C. A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*. 2001;15:109.
10. Matveyev L. *Fundamentals of Sports Training*. Moscow: Progress, 1981
11. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, Raglin J, Rietjens G, Steinacker J, and Urhausen A. 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*. 2013;45:186-205.
12. Impellizzeri F, Marcora S, and Coutts A. Internal and External Training Load: 15 Years On. *International Journal of Sports Physiology and Performance*. 2019;14:270-273.
13. McLean BD, Coutts AJ, Kelly V, McGuigan MR, and Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*. 2010;5:367.
14. Saw EA, Main CL, and Gastin BP. Role of a Self-report Measure in Athlete Preparation. *Journal of Strength and Conditioning Research*. 2015;29:685-691.
15. Saw AE, Main LC, and Gastin PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *British Journal of Sports Medicine*. 2016;50:281.

16. Caia J, Thornton HR, Kelly VG, Scott TJ, Halson SL, Cupples B, and Driller MW. Does self-perceived sleep reflect sleep estimated via activity monitors in professional rugby league athletes? *Journal of Sports Sciences*. 2018;36:1492.
17. Mah CD, Mah KE, Kezirian EJ, and Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*. 2011;34:943.
18. Leeder J, Glaister M, Pizzoferro K, Dawson J, and Pedlar C. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *Journal of Sports Sciences*. 2012;30:541-545.
19. Kosmadopolous A. Chapter 4 Two for One? Validating an energy Expenditure Monitor against Polysomnography for Sleep/Wake Measurement. In: *Australasian Chronobiology* 2012.
20. Kosmadopoulos A, Sargent C, Darwent D, Zhou X, and Roach G. Alternatives to polysomnography (PSG): A validation of wrist actigraphy and a partial-PSG system. *Behavior Research Methods*. 2014;46:1032-1041.
21. Sargent C, Lastella M, Halson SL, and Roach GD. The validity of activity monitors for measuring sleep in elite athletes. *Journal of Science and Medicine in Sport*. 2016;19:848-853.
22. Sargent C, Lastella M, Halson SL, and Roach GD. The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiology International*. 2014;31:1160-1168.
23. Sargent C, Halson S, and Roach GD. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *European Journal of Sport Science*. 2014;14:310-315.
24. Pitchford N, Robertson S, Sargent C, Bishop D, and Bartlett J. A pre-season training camp alters sleep behaviour and quality but not quantity in elite Australian Rules football players. *Journal of Science and Medicine in Sport*. 2015;19:e20-e21.
25. Thornton HR, Delaney JA, Duthie GM, and Dascombe BJ. Effects of Pre-Season Training on the Sleep Characteristics of Professional Rugby League Players. *International Journal of Sports Physiology and Performance*.0:1-23.
26. Richmond L, Dawson B, Hillman DR, and Eastwood PR. The effect of interstate travel on sleep patterns of elite Australian Rules footballers. *Journal of Science and Medicine in Sport*. 2004;7:186-196.
27. Thornton HR, Miller J, Taylor L, Sargent C, Lastella M, and Fowler PM. Impact of short- compared to long-haul international travel on the sleep and wellbeing of national wheelchair basketball athletes. *Journal of Sports Sciences*. 2018;36:1476-1484.
28. Lastella M, Lovell GP, and Sargent C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *European Journal of Sport Science*. 2014;14:S123-S130.
29. Juliff EL, Halson LS, Hebert JJ, Forsyth LP, and Peiffer JJ. Longer Sleep Durations Are Positively Associated With Finishing Place During a National Multiday Netball Competition. *Journal of Strength and Conditioning Research*. 2018;32:189-194.
30. Sargent C and Roach GD. Sleep duration is reduced in elite athletes following night-time competition. *Chronobiology International*. 2016;33:667.
31. Shearer DA, Jones RM, Kilduff LP, and Cook CJ. Effects of competition on the sleep patterns of elite rugby union players. *European Journal of Sport Science*. 2015;15:681-686.
32. Lastella M, Roach GD, Halson SL, Martin DT, West NP, and Sargent C. Sleep/wake behaviour of endurance cyclists before and during competition. *Journal of Sports Sciences*. 2015;33:293-299.

33. Caia J, Halson SL, Scott TJ, and Kelly VG. Intra-individual variability in the sleep of senior and junior rugby league athletes during the competitive season. *Chronobiology International*. 2017;34:1239-1247.
34. Knufinke M, Nieuwenhuys A, Geurts SAE, Møst EIS, Maase K, Moen MH, Coenen AML, and Kompier MAJ. Train hard, sleep well? Perceived training load, sleep quantity and sleep stage distribution in elite level athletes. *Journal of Science and Medicine in Sport*. 2018;21:427-432.
35. Sawczuk T, Jones B, Scantlebury S, and Till K. The influence of training load, exposure to match play and sleep duration on daily wellbeing measures in youth athletes. *Journal of Sports Sciences*. 2018;36:2431-2437.
36. Pitchford NW, Robertson SJ, Sargent C, Cordy J, Bishop DJ, and 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;12:75-80.
37. Dattilo M, Antunes HKM, Medeiros A, Mônico Neto M, Souza HS, Tufik S, and de Mello MT. Sleep and muscle recovery: Endocrinological and molecular basis for a new and promising hypothesis. *Medical Hypotheses*. 2011;77:220-222.
38. Hirotsu C, Tufik S, and Andersen ML. Interactions between sleep, stress, and metabolism: From physiological to pathological conditions. *Sleep Science* 2015;8:143-152.
39. Chokroverty S. *Sleep Disorders Medicine Basic Science, Technical Considerations and Clinical Aspects*. 4th ed. 2017. ed. New York, NY: New York, NY : Springer New York : Imprint: Springer, 2017
40. Chaput J-P, Dutil C, and Sampasa-Kanyinga H. Sleeping hours: what is the ideal number and how does age impact this? *Nature and Science of Sleep*. 2018;10:421-430.
41. Tahmasian M, Samea F, Khazaie H, Zarei M, Kharabian Masouleh S, Hoffstaedter F, Camilleri J, Kochunov P, Yeo BTT, Eickhoff SB, and Valk SL. The interrelation of sleep and mental and physical health is anchored in grey-matter neuroanatomy and under genetic control. *Communications Biology*. 2020;3:171-171.
42. Porkka-Heiskanen T, Zitting KM, and Wigren HK. Sleep, its regulation and possible mechanisms of sleep disturbances. *Acta Physiologica*. 2013;208:311-328.
43. Carskadon MA, Dement, W.C. In: *Principles and Practices of Sleep Medicine*. E. Saunders (Ed.) Canada, 2011.
44. Cuesta M. BP, Boivin D.B. Basic Circadian Tiing and Sleep Wake Regulation. In: *Sleep Disorders Medicine* S. Chokroverty (Ed.) New York: Springer, 2017.
45. Roach Gregory D. Interventions to Minimize Jet Lag After Westward and Eastward Flight. *Frontiers in Physiology*. 2019;10.
46. Stevens CJ, Thornton HR, Fowler PM, Esh C, and Taylor L. Long-Haul Northeast Travel Disrupts Sleep and Induces Perceived Fatigue in Endurance Athletes. *Frontiers in Physiology*. 2018;9.
47. Roberts SSH, Teo W-P, and Warmington SA. Effects of training and competition on the sleep of elite athletes: a systematic review and meta-analysis. *British Journal of Sports Medicine*. 2019;53:513.
48. Fuller KL, Juliff L, Gore CJ, Peiffer JJ, and Halson SL. Software thresholds alter the bias of actigraphy for monitoring sleep in team-sport athletes. *Journal of Science and Medicine in Sport*. 2017;20:756-760.
49. Matthew WD, Cheri DM, and Shona LH. Development of the athlete sleep behavior questionnaire: A tool for identifying maladaptive sleep practices in elite athletes. *Sleep science (São Paulo, SP)*. 2018;11:37-44.

50. Fietze I, Strauch J, Holzhausen M, Glos M, Theobald C, Lehnkering H, and Penzel T. Sleep Quality in Professional Ballet Dancers. *Chronobiology International*. 2009;26:1249-1262.
51. Caia J, Scott TJ, Halson SL, and Kelly VG. Do players and staff sleep more during the pre- or competitive season of elite rugby league? *European Journal of Sport Science*. 2017;17:964-972.
52. Taylor SR, Rogers GG, and Driver HS. Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Medicine and Science in Sports and Exercise*. 1997;29:688.
53. Fullagar HHK, Skorski S, Duffield R, Julian R, Bartlett J, and Meyer T. Impaired sleep and recovery after night matches in elite football players. *Journal of Sports Sciences*. 2016;34:1333-1339.
54. Juliff LE, Halson SL, and Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. *Journal of Science and Medicine in Sport*. 2015;18:13-18.
55. Erlacher D, Ehrlenspiel F, Adegbesan O, and Galal El-Din H. Sleep habits in German athletes before important competitions or games. *Journal of Sports Sciences*. 2011;29:859-866.
56. Lastella M, Roach Gregory D, Halson Shona L, and Sargent C. The Chronotype of Elite Athletes. *Journal of Human Kinetics*. 2016;54:219-225.
57. Buysse DJ RC, Monk TH, Hoch CC, Yeager AL and Kupfer DJ. Quantification of subjective sleep quality in healthy elderly men and women using the Pittsburgh Sleep Quality Index (PSQI). *Sleep*. 1991;14:331.
58. Johns MW. A New Method for Measuring Daytime Sleepiness: The Epworth Sleepiness Scale. *Sleep*. 1991;14:540-545.
59. O'Donnell S, Bird S, Jacobson G, and Driller M. Sleep and stress hormone responses to training and competition in elite female athletes. *European Journal of Sport Science*. 2018;18:611-618.
60. Gallo TF, Cormack SJ, Gabbett TJ, and Lorenzen CH. Pre-training perceived wellness impacts training output in Australian football players. *Journal of Sports Sciences*. 2016;34:1445-1451.
61. Jackowska M, Dockray S, Hendrickx H, and Steptoe A. Psychosocial factors and sleep efficiency: discrepancies between subjective and objective evaluations of sleep. *Psychosomatic Medicine*. 2011;73:810.
62. Kawada T. Agreement rates for sleep/wake judgments obtained via accelerometer and sleep diary: A comparison. *Behavior Research Methods*. 2008;40:1026-1029.
63. Halson SL. Nutrition, sleep and recovery. *European Journal of Sport Science*. 2008;8:119-126.
64. Tuomilehto H, Vuorinen V-P, Penttilä E, Kivimäki M, Vuorenmaa M, Venojärvi M, Airaksinen O, and Pihlajamäki J. Sleep of professional athletes: Underexploited potential to improve health and performance. *Journal of Sports Sciences*. 2016:1-7.
65. Kamdar BB, Kaplan KA, Kezirian EJ, and Dement WC. The impact of extended sleep on daytime alertness, vigilance, and mood. *Sleep Medicine*. 2004;5:441-448.
66. Van Dongen HPA, Maislin G, Mullington JM, and Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*. 2003;26:117.
67. Thornton H, Delaney J, Duthie G, and Dascombe B. Effects of Preseason Training on the Sleep Characteristics of Professional Rugby League Players.

International Journal of Sports Physiology and Performance. 2018;13:176-182.
68. Gupta L, Morgan K, and Gilchrist S. Does Elite Sport Degrade Sleep Quality? A Systematic Review. *Sports Medicine*. 2017;47:1317-1333.
69. Fowler P, Duffield R, Howle K, Waterson A, and Vaile J. 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*. 2015;10:648.
70. Fullagar H, Skorski S, Duffield R, and Meyer T. The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players. *Chronobiology International*. 2016;33:490.
71. Juliff L, Peiffer J, and Halson S. Night Games and Sleep: Physiological, Neuroendocrine, and Psychometric Mechanisms. *International Journal of Sports Physiology and Performance*. 2018;13:867-873.
72. Ohayon M, Wickwire EM, Hirshkowitz M. National sleep foundation's sleep quality recommendations:first report. *Sleep Health*. 2017;3:6-19.
73. Hirshkowitz M WK, Albert SM, . National sleep foundation's sleep time duration recommendations: methodology andresults summary. *Sleep Health*. 2015;1:40-43.
74. Acebo C, Sadeh A, Seifer R, Tzischinsky O, Wolfson AR, Hafer A, and Carskadon MA. Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep*. 1999;22:95.
75. Lastella M, Roach GD, Halson SL, and Sargent C. Sleep/wake behaviours of elite athletes from individual and team sports. *European Journal of Sport Science*. 2015;15:94-100.
76. Lastella M, Roach GD, Vincent GE, Scanlan AT, Halson SL, and Sargent C. The Impact of Training Load on Sleep During a 14-Day Training Camp in Elite, Adolescent, Female Basketball Players. *International Journal of Sports Physiology and Performance*. 2020;15:1.
77. Dumortier J, Mariman A, Boone J, Delesie L, Tobback E, Vogelaers D, and Bourgois JG. Sleep, training load and performance in elite female gymnasts. *European Journal of Sport Science*. 2017:1-11.
78. Hausswirth C, Louis J, Aubry A, Bonnet G, Duffield R, and Le Meur Y. Evidence of Disturbed Sleep and Increased Illness in Overreached Endurance Athletes. *Medicine and Science in Sports Exercise*. 2014;46:1036-1045.
79. Whitworth-Turner CM, Di Michele R, Muir I, Gregson W, and Drust B. Training load and schedule are important determinants of sleep behaviours in youth-soccer players. *European Journal of Sport Science*. 2018:1-9.
80. Ehrlenspiel F, Erlacher D, and Ziegler M. Changes in Subjective Sleep Quality Before a Competition and Their Relation to Competitive Anxiety. *Behavioral Sleep Medicine*. 2018;16:553-568.
81. Staunton C, Gordon B, Custovic E, Stanger J, and Kingsley M. Sleep patterns and match performance in elite Australian basketball athletes. *Journal of Science and Medicine in Sport*. 2017;20:786-789.
82. O'Donnell S, Beaven C, and Driller M. Sleep/wake behavior prior to and following competition in elite female netball athletes. *Sport Science Health*. 2018;14:289-295.
83. Vitale JA, Banfi G, Galbiati A, Ferini-Strambi L, and La Torre A. Effect of a Night Game on Actigraphy-Based Sleep Quality and Perceived Recovery in Top-Level Volleyball Athletes. *Int J Sports Physiol Perform*. 2019;14:265-269.

84. Nédélec M, Halson S, Delecroix B, Abaidia A-E, Ahmaidi S, and Dupont G. Sleep Hygiene and Recovery Strategies in Elite Soccer Players. *Sports Medicine*. 2015;45:1547-1559.
85. Robey E, Dawson B, Halson S, Gregson W, Goodman C, and Eastwood P. Sleep quantity and quality in elite youth soccer players: A pilot study. *European Journal of Sport Science*. 2014;14:410-417.
86. Fullagar H, Skorski S, Duffield R, Hammes D, Coutts A, and Meyer T. Sleep and Athletic Performance: The Effects of Sleep Loss on Exercise Performance, and Physiological and Cognitive Responses to Exercise. *Sports Medicine*. 2015;45:161-186.
87. Haack MM and Mullington MJ. Sustained sleep restriction reduces emotional and physical well-being. *Pain*. 2005;119:56-64.
88. Haack M, Scott-Sutherland J, Santangelo G, Simpson NS, Sethna N, and Mullington JM. Pain sensitivity and modulation in primary insomnia. *European Journal of Pain*. 2012;16:522-533.
89. Hainline B, Turner JA, Caneiro JP, Stewart M, and Lorimer Moseley G. Pain in elite athletes-neurophysiological, biomechanical and psychosocial considerations: a narrative review. *British Journal of Sports Medicine*. 2017;51:1259.
90. Samuels C. Sleep, Recovery, and Performance: The New Frontier in High-Performance Athletics. *Physical Medicine & Rehabilitation Clinics of North America*. 2009;20:149-159.
91. Tucker P, Smith L, Macdonald I, and Folkard S. Shift length as a determinant of retrospective on-shift alertness. *Scandinavian Journal of Work, Environment & Health*. 1998;24:49-54.
92. Bonnet M. Performance abd sleepiness following moderate sleep disruptio and slow wave sleep eprivation. *Physiology & Behavior*. 1985;37:915-918.
93. Nuri L, Shadmehr A, Ghotbi N, and Attarbashi Moghadam B. Reaction time and anticipatory skill of athletes in open and closed skill-dominated sport. *European Journal of Sport Science*. 2013;13:431-436.
94. Dawson D and McCulloch K. Managing fatigue: It's about sleep. *Sleep Medicine Reviews*. 2005;9:365-380.
95. Roach GD, Matthews R, Naweed A, Kontou TG, and Sargent C. Flat-out napping: The quantity and quality of sleep obtained in a seat during the daytime increase as the angle of recline of the seat increases. *Chronobiology International: Special Issue: 23rd International Symposium on Shiftwork and Working Time: Toward a Global Consensus*. 2018;35:872-883.
96. Roach GD, Sargent C, Darwent D, and Dawson D. Duty periods with early start times restrict the amount of sleep obtained by short-haul airline pilots. *Accident Analysis and Prevention*. 2012;45:22-26.
97. Carlos Mauricio Oliveira de A and Adriana M. Sleep, immunity and shift workers: A review. *Sleep Science* 2016;9:164-168.
98. Smith CD, Cooper AD, Merullo DJ, Cohen BS, Heaton KJ, Claro PJ, and Smith T. Sleep restriction and cognitive load affect performance on a simulated marksmanship task. *Journal of Sleep Research*. 2019;28.
99. Roach GR, KJ and Dawson D. The amount of sleep obtained by locomotive engineers: effects of break duration and time of break onset. . *Occupational and Environmental Medicine*. 2003;60.
100. Alhola P and Polo-Kantola P. Sleep deprivation: Impact on cognitive performance. *Neuropsychiatric Disease and Treatment*. 2007;3:553-567.
101. Skein JM, Duffield JR, Edge JJ, Short JM, and Mündel JT. Intermittent-Sprint Performance and Muscle Glycogen after 30 h of Sleep Deprivation. *Medicine & Science in Sports & Exercise*. 2011;43:1301-1311.

102. Skein M, Duffield R, Minett GM, Snape A, and Murphy A. The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery. *International Journal of Sports Physiology and Performance*. 2013;8:556.
103. Gleeson M. Immune function in sport and exercise. *Journal of Applied Physiology*. 2007;103:693.
104. Besedovsky L, Lange T, and Born J. Sleep and immune function. *Pflugers Arch, European Journal of Physiology*. 2012;463:121-137.
105. Walsh NP. Recommendations to maintain immune health in athletes. *European Journal of Sport Science*. 2018;18:820-831.
106. Aldabal L and Bahammam AS. Metabolic, endocrine, and immune consequences of sleep deprivation. *The Open Respiratory Medicine Journal*. 2011;5:31.
107. Lange T and Born J. The immune recovery function of sleep – Tracked by neutrophil counts. *Brain, Behavior, and Immunity*. 2011;25:14-15.
108. Faraut B, Boudjeltia KZ, Dyzma M, Rousseau A, David E, Stenuit P, Franck T, Antwerpen PV, Vanhaeverbeek M, and Kerkhofs M. Benefits of napping and an extended duration of recovery sleep on alertness and immune cells after acute sleep restriction. *Brain, Behavior, and Immunity*. 2011;25:16-24.
109. Fitzgerald D, Beckmans C, Joyce D, and Mills K. 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*. 2019;22:130.
110. Horgan BG, Drew MK, Halson SL, Piromalli LE, Drinkwater EJ, Chapman DW, and Haff GG. Impaired Recovery is Associated with Increased Injury and Illness: A Retrospective Study of 536 Female Netball Athletes. *Scandinavian Journal of Medicine & Science in Sports*. 2020.
111. Silva A, Narciso F, Soalheiro I, Viegas F, Freitas L, Lima A, Leite B, Aleixo H, Duffield R, and de Mello M. Poor Sleep Quality's Association With Soccer Injuries: Preliminary Data. *International Journal of Sports Physiology and Performance*. 2020;15:671-676.
112. Dennis J, Dawson B, Heasman J, Rogalski B, and Robey E. Sleep patterns and injury occurrence in elite Australian footballers. *Journal of Science and Medicine in Sport*. 2016;19:113-116.
113. Gao B, Cruz A, Dwivedi S, and Milewski M. Chronic Lack of Sleep is Associated with Increased Sports Injury in Adolescents: A Systematic Review and Meta-Analysis. *Pediatrics*. 2019;144:1.
114. Burke MT, Lisman JP, Maguire JK, Skeiky FL, Choynowski NJ, Capaldi JV, Wilder AJ, Brager AA, and Dobrosielski AD. Examination of Sleep and Injury Among College Football Athletes. *Journal of Strength and Conditioning Research*. 2020;34:609-616.
115. Guindon C. Do Collegiate Athletes' Sleep Habits Correspond to Injury Rate? *The Journal of Sports Medicine and Allied Health Sciences*. 2015;1.
116. Rosen P, Frohm A, Kottorp A, Fridén C, and Heijne A. Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. *Scandinavian Journal of Medicine & Science in Sports*. 2017;27:1364-1371.
117. Milewski MD, McCracken CM, Meehan B, and Stracciolini A. Increased Hours of Training per Week is Associated with Decreased Sleep in Pediatric & Adolescent Athletes. *Orthopaedic Journal of Sports Medicine*. 2019;7.
118. Lavallée L and Flint F. The relationship of stress, competitive anxiety, mood state, and social support to athletic injury. *Journal of Athletic Training*. 1996;31:296.

119. Vgontzas NA, Zoumakis OE, Bixler ME, Lin PH, Follett PH, Kales PA, and Chrousos PG. Adverse Effects of Modest Sleep Restriction on Sleepiness, Performance, and Inflammatory Cytokines. *The Journal of Clinical Endocrinology & Metabolism*. 2004;89:2119-2126.
120. Spiegel K, Leproult R, and Van Cauter E. Impact of sleep debt on metabolic and endocrine function. *The Lancet (British edition)*. 1999;354:1435-1439.
121. Reilly T and Edwards B. Altered sleep-wake cycles and physical performance in athletes. *Physiology & Behavior*. 2007;90:274.
122. Dickinson RK and Hanrahan SJ. An Investigation of Subjective Sleep and Fatigue Measures for Use with Elite Athletes. *Journal of Clinical Sport Psychology*. 2009;3:244-266.
123. Roach Gregory DaSC. Interventions to Minimise Jet Lag After Westward and Eastward Flight. *Frontiers in Physiology*. 2019;31 July 2019.
124. Nutting AW and Price J. Time Zones, Game Start Times, and Team Performance: Evidence From the NBA. *Journal of Sports Economics*. 2017;18:471-478.
125. Kölling S, Treff G, Winkert K, Ferrauti A, Meyer T, Pfeiffer M, and Kellmann M. The effect of westward travel across five time zones on sleep and subjective jet-lag ratings in athletes before and during the 2015's World Rowing Junior Championships. *Journal of Sports Sciences*. 2017;35:2240-2248.
126. Chapman D, Bullock N, Ross A, Rosemond D, and Martin D. Detrimental effects of West to East transmeridian flight on jump performance. *European Journal of Applied Physiology*. 2012;112:1663-1669.
127. Lemmer B, Kern R-I, Nold G, and Lohrer H. Jet Lag In Athletes After Eastward and Westward Time-Zone Transition. *Chronobiology International*. 2002;19:743-764.
128. Fowler PM, McCall A, Jones M, and Duffield R. Effects of long-haul transmeridian travel on player preparedness: Case study of a national team at the 2014 FIFA World Cup. *Journal of Science and Medicine in Sport*. 2017;20:322-327.
129. Fowler P, Duffield R, and Vaile J. Effects of domestic air travel on technical and tactical performance and recovery in soccer. *International Journal of Sports Physiology and Performance*. 2014;9:378-386.
130. Roy J and Forest G. Greater circadian disadvantage during evening games for the National Basketball Association (NBA), National Hockey League (NHL) and National Football League (NFL) teams travelling westward. *Journal of Sleep Research*. 2018;27:86-89.
131. Waterhouse J, Reilly T, and Edwards B. The stress of travel. *Journal of Sports Sciences*. 2004;22:946-966.
132. Walsh NP, Halson SL, Sargent C, Roach GD, Nédélec M, Gupta L, Leeder J, Fullagar HH, Coutts AJ, Edwards BJ, Pullinger SA, Robertson CM, Burniston JG, Lastella M, Le Meur Y, Hausswirth C, Bender AM, Grandner MA, and Samuels CH. Sleep and the athlete: narrative review and 2021 expert consensus recommendations. *British Journal of Sports Medicine*. 2020:bjsports-2020-102025.
133. Spitzer RL, Terman M, Williams JBW, Terman JS, Malt UF, Singer F, and Lewy AJ. Jet Lag: Clinical Features, Validation of a New Syndrome-Specific Scale, and Lack of Response to Melatonin in a Randomized, Double-Blind Trial. *American Journal of Psychiatry*. 1999;156:1392-1396.
134. Fowler P, Duffield R, Waterson A, and Vaile J. Effects of Regular Away Travel on Training Loads, Recovery, and Injury Rates in Professional

Australian Soccer Players. *International Journal of Sports Physiology and Performance*. 2015;10:546-552.
135. Romyn G, Lastella M, Miller DJ, Versey NG, Roach GD, and Sargent C. Daytime naps can be used to supplement night-time sleep in athletes. *Chronobiology International: Special Issue: 23rd International Symposium on Shiftwork and Working Time: Toward a Global Consensus*. 2018;35:865-868.
136. Schwartz J and Simon RD. Sleep extension improves serving accuracy: A study with college varsity tennis players. *Physiology & Behavior*. 2015;151:541-544.
137. Roberts SSH, Teo W-P, Aisbett B, and Warmington SA. Extended Sleep Maintains Endurance Performance Better than Normal or Restricted Sleep. *Medicine and Science in Sports and Exercise*. 2019;51:2516.
138. Waterhouse J, Atkinson G, Edwards B, and Reilly T. 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*. 2007;25:1557-1566.
139. O'Donnell S, Beaven CM, and Driller M. The Influence of Match-Day Napping in Elite Female Netball Athletes. *International Journal of Sports Physiology and Performance*. 2018;13:1143.
140. Van Ryswyk E, Weeks R, Bandick L, O'Keefe M, Vakulin A, Catcheside P, Barger L, Potter A, Poulos N, Wallace J, and Antic NA. A novel sleep optimisation programme to improve athletes' well-being and performance. *European Journal of Sport Science*. 2017;17:144-151.
141. Swinbourne R, Miller J, Smart D, Dulson D, and Gill N. The Effects of Sleep Extension on Sleep, Performance, Immunity and Physical Stress in Rugby Players. *Sports* 2018;6:42.
142. Mastin D, Bryson J, and Corwyn R. Assessment of Sleep Hygiene Using the Sleep Hygiene Index. *Journal of Behavioral Medicine*. 2006;29:223-227.
143. O'Donnell S and Driller MW. Sleep-hygiene Education improves Sleep Indices in Elite Female Athletes. *International Journal of Exercise Science*. 2017;10:522.
144. Nishinoue N, Takano T, Kaku A, Eto R, Kato N, Ono Y, and Tanaka K. Effects of Sleep Hygiene Education and Behavioral Therapy on Sleep Quality of White-collar Workers: A Randomized Controlled Trial. *Industrial Health*. 2012;50:123-131.
145. Driller MW, Lastella M, and Sharp AP. Individualized sleep education improves subjective and objective sleep indices in elite cricket athletes: A pilot study. *Journal of Sports Sciences*. 2019;37:2021-2025.
146. O'Donnell S, Beaven C, and Driller M. From pillow to podium: a review on understanding sleep for elite athletes. *Nature and Science of Sleep*. 2018;10:243-253.
147. Davies DJ, Graham KS, and Chow CM. The effect of prior endurance training on nap sleep patterns. *International Journal of Sports Physiology and Performance*. 2010;5:87.
148. Lo JC, Leong RLF, Ng ASC, Jamaluddin SA, Ong JL, Ghorbani S, Lau T, Chee NIYN, Gooley JJ, and Chee MWL. Cognitive Effects of Split and Continuous Sleep Schedules in Adolescents Differ According to Total Sleep Opportunity. *Sleep*. 2020.
149. Hayashi M and Hori T. The effects of a 20-min nap before post-lunch dip. *Psychiatry and Clinical Neurosciences*. 1998;52:203-204.
150. Brooks A and Lack L. A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? *Sleep*. 2006;29:831.

151. Bartlett RM. The science and medicine of cricket: an overview and update. *Journal of Sports Sciences*. 2003;21:733-752.
152. Halson S and Jeukendrup A. Does Overtraining Exist? *Sports Medicine*. 2004;34:967-981.
153. Windt JGT. How do training and competition workloads relate to injury? The workload injury aetiology model. *Bristish Journal of Sports Medicine* 2017;51:428.
154. Cummins C, Orr R, O'Connor H, and West C. Global Positioning Systems (GPS) and Microtechnology Sensors in Team Sports: A Systematic Review. *Sports Medicine*. 2013;43:1025-1042.
155. Boyd LJ, Ball K, and Aughey RJ. Quantifying external load in Australian football matches and training using accelerometers. *International Journal of Sports Physiology and Performance*. 2013;8:44.
156. Lovell TWJ, Sirotic AC, Impellizzeri FM, and Coutts AJ. Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. *International Journal of Sports Physiology and Performance*. 2013;8:62.
157. Mauger AR, Huntley T, and Fletcher IM. RPE-Derived Work Rates Can Be Accurately Produced without External Feedback or Reference to the RPE Scale. *Perceptual and Motor Skills*. 2014;118:507-521.
158. Haddad M, Stylianides G, Djaoui L, Dellal A, and Chamari K. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Frontiers in Neuroscience*. 2017;11:612-612.
159. Saw AE, Kellmann M, Main LC, and Gastin PB. Athlete Self-Report Measures in Research and Practice: Considerations for the Discerning Reader and Fastidious Practitioner. *International Journal of Sports Physiology and Performance*. 2017;12:S2127.
160. Duignan C, Doherty C, Caulfield B, and Blake C. Single-Item Self-Report Measures of Team-Sport Athlete Wellbeing and Their Relationship With Training Load: A Systematic Review. *Journal of athletic training*. 2020;55:944.
161. Jeffries AC, Wallace L, Coutts AJ, McLaren SJ, McCall A, and Impellizzeri FM. Athlete-Reported Outcome Measures for Monitoring Training Responses: A Systematic Review of Risk of Bias and Measurement Property Quality According to the COSMIN Guidelines. *International Journal of Sports Physiology and Performance*. 2020:1.
162. Hooper S, Mackinnon LT. . Monitoring Overtraining in athletes. Recommendations. *Sports Medicine*. 1995;20:321-327.
163. Gastin BP, Meyer BD, and Robinson BD. Perceptions of Wellness to Monitor Adaptive Responses to Training and Competition in Elite Australian Football. *Journal of Strength and Conditioning Research*. 2013;27:2518-2526.
164. Gallo FT, Cormack JS, Gabbett JT, and Lorenzen HC. Self-Reported Wellness Profiles of Professional Australian Football Players During the Competition Phase of the Season. *Journal of Strength and Conditioning Research*. 2017;31:495-502.
165. Gallo FT, Cormack JS, Gabbett JT, and Lorenzen HC. Self-Reported Wellness Profiles Of Professional Australian Football Players During The Competition Phase Of The Season. *Journal of Strength and Conditioning Research*. 2016.
166. Selmi O, Gonçalves B, Ouergui I, Sampaio J, and Bouassida A. Influence of well-being variables and recovery state in physical enjoyment of professional soccer players during small-sided games. *Research in Sports Medicine*. 2018;26:199-210.

167. Wellman DA, Coad CS, Flynn JP, Siam KT, and McLellan PC. Perceived Wellness Associated With Practice and Competition in National Collegiate Athletic Association Division I Football Players. *Journal of Strength and Conditioning Research*. 2019;33:112-124.
168. Govus A, Coutts A, Duffield R, Murray A, and Fullagar H. Relationship Between Pretraining Subjective Wellness Measures, Player Load, and Rating-of-Perceived-Exertion Training Load in American College Football. *International Journal of Sports Physiology and Performance*. 2018;13:95-101.
169. Cullen B, McCarren AL, Malone, S. Ecological validity of self-reported wellness measures to assess pre-training and pre-competition preparedness within elite Gaelic football. *Sport Sciences for Health* 2020.
170. Gallo T, Cormack S, Gabbett T, Williams M, and Lorenzen C. Characteristics impacting on session rating of perceived exertion training load in Australian footballers. *Journal of Sports Sciences*. 2015;33:467-475.
171. Bellinger PM, Ferguson C, Newans T, and Minahan CL. No Influence of Prematch Subjective Wellness Ratings on External Load During Elite Australian Football Match Play. *International Journal of Sports Physiology and Performance*. 2020;15:801.
172. Biggins M, Purtill H, Fowler P, Bender A, Sullivan K, Samuels C, and Cahalan R. Sleep in elite multi-sport athletes: Implications for athlete health and wellbeing. *Physical Therapy in Sport*. 2019;39:136-142.
173. Thornton HR, Duthie GM, Pitchford NW, Delaney JA, Benton DT, and Dascombe BJ. Effects of a 2-Week High-Intensity Training Camp on Sleep Activity of Professional Rugby League Athletes. *International Journal of Sports Physiology and Performance*. 2017;12:928.
174. Pitchford N, Robertson S, Sargent C, Cordy J, Bishop D, and Bartlett J. Sleep Quality but Not Quantity Altered With a Change in Training Environment in Elite Australian Rules Football Players. *International Journal of Sports Physiology and Performance*. 2017;12:75-80.
175. Schaal K, Le Meur Y, Louis J, Filliard J-R, Hellard P, Casazza G, and Hausswirth C. Whole-Body Cryostimulation Limits Overreaching in Elite Synchronized Swimmers. *Medicine and Science in Sports and Exercise*. 2015;47:1416-1425.
176. Lastella MR, G.D, Halson, S.L, MArtin D.T, West, N.P, Sargent, S. The impact of a simulated grand tour on sleep, mood, and well-being of competitive cyclists. *Journal of Sports Medicine and Physical Fitness* 2015;55:1555-1564.
177. Kölling S, Steinacker JM, Endler S, Ferrauti A, Meyer T, and Kellmann M. The longer the better: Sleep- wake patterns during preparation of the World Rowing Junior Championships. *Chronobiology International*. 2016;33:73-84.
178. Killer SC, Svendsen IS, Jeukendrup AE, and Gleeson M. 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*. 2015:1-9.
179. Hopkins WG. A scale of magnitudes for effect statistics. Accessed, 2002.
180. Scott TUM, Scott JT, and Kelly GV. The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *Journal of Strength and Conditioning Research*. 2016;30:1470-1490.
181. Saw AE, Gastin PB, and Main LC. Monitoring athletes through self-report: Factors influencing implementation. *Journal of Sports Science and Medicine*. 2014;14:137-146.

182. Sherry A and Henson RK. Conducting and Interpreting Canonical Correlation Analysis in Personality Research: A User-Friendly Primer. *Journal of Personality Assessment*. 2005;84:37-48.
183. Cohen J. Statistical Power Analysis for the Behavioural Sciences. . N. Hillsdale (Ed.): Lawrence Erlbaum, 1988.
184. Yeatts PE, Barton M, Henson RK, and Martin SB. The Use of Structure Coefficients to Address Multicollinearity in Sport and Exercise Science. *Measurement in Physical Education and Exercise Science*. 2017;21:83-91.
185. Team RC. R: A language and environment for statistical computing. . R. F. f. S. Computing (Ed.) Vienna, Austria., 2018.
186. Hadley Wickham RF, Lionel Henry and Kirill Müller In: *R package version 0.7.6*. d. A. G. o. D. Manipulation. (Ed.), 2018.
187. Wickham H. Reshaping Data with the reshape Package. *Journal of Statistical Software,*. 2007;21:1-20.
188. Déjean IGaS. CCA: Canonical correlation analysis. In: *R package version 1.2*, 2012.
189. Team RC. R: A language and environment for statistical computing. In: *R Foundation for Statistical Computing.*, 2020.
190. Müller K. here: A simpler way to find your files., 2017.
191. . In: *readxl: Read Excel files.* H. B. Wickham, J. (Ed.), 2019.
192. Wickham H. tidyr: Tidy messy data., 2020.
193. Wickham H. stringr: Simple, consistent wrappers for common string operations., 2019.
194. Firke S. janitor: Simple tools for examining and cleaning dirty data. In: *R package version 2.0.1.*, 2020.
195. Henry LW, H. . purrr: Functional programming tools. . In: *R package version 0.3.4.*, 2020.
196. Müller KW, H. . tibble: Simple data frames., 2020.
197. Grolemund GW, H. . Dates and times made easy with lubridate. *Journal of Statistical Software*. 2011;40:1-25.
198. James DH, K. chron: Chronological objects which can handle dates and times, 2020.
199. Wickham H. ggplot2: Elegant graphics for data analysis. S.-V. N. York (Ed.), 2016.
200. Pedersen TL. patchwork: The composer of plots., 2020.
201. Xie Y. knitr: A general-purpose package for dynamic report generation in R, 2020.
202. Zhu H. kableExtra: Construct complex table with 'kable' and pipe syntax. , 2020.
203. Noguchi K, Gel, Y.R., Brunner, E., & Konietschke, F. "nparLD: An R software package for the nonparametric analysis of longitudinal data in factorial experiments". *Journal of Statistical Software*. 2012;50:1-23.
204. Revelle W. psych: Procedures for personality and psychological research., 2020, pp. https://CRAN.R-project.org/package=psych.
205. Mooney GM, Cormack JS, O'brien MB, Morgan MW, and McGuigan MM. Impact of Neuromuscular Fatigue on Match Exercise Intensity and Performance in Elite Australian Football. *Journal of Strength and Conditioning Research*. 2013;27:166-173.
206. Fullagar HHK, Duffield R, Skorski S, Coutts AJ, Julian R, and Meyer T. Sleep and Recovery in Team Sport: Current Sleep-Related Issues Facing Professional Team-Sport Athletes. *International Journal of Sports Physiology and Performance*. 2015;10:950.

207. Ohayon MM, Carskadon MA, Guilleminault C, and Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*. 2004;27:1255.
208. Thomee S, Harenstam A, and Hagberg M. Mobile phone use and stress, sleep disturbances, and symptoms of depression among young adults - a prospective cohort study. *BMC Public Health*. 2011;11:66.
209. Thomée S, Eklöf M, Gustafsson E, Nilsson R, and Hagberg M. Prevalence of perceived stress, symptoms of depression and sleep disturbances in relation to information and communication technology (ICT) use among young adults – an explorative prospective study. *Computers in Human Behavior*. 2007;23:1300-1321.
210. Stepanski EJ and Wyatt JK. Use of sleep hygiene in the treatment of insomnia. *Sleep Medicine Reviews*. 2003;7:215-225.
211. Roach GD, Schmidt WF, Aughey RJ, Bourdon PC, Soria R, Claros JCJ, Garvican-Lewis LA, Buchheit M, Simpson BM, Hammond K, Kley M, Wachsmuth N, Gore CJ, and Sargent C. 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*. 2013;47:i114.
212. Chokroverty S. *Sleep disorders medicine: Basic science, technical considerations, and clinical aspects*. Boston: Butterworth-Heinemann, 2013
213. Romyn G, Robey E, Dimmock JA, Halson SL, and Peeling P. Sleep, anxiety and electronic device use by athletes in the training and competition environments. *European Journal of Sport Science*. 2016;16:301-308.
214. Sadeh A, Hauri P, Kripke D, and Lavie P. The role of actigraphy in the evaluation of sleep disorders, 1995, pp. 288-302.
215. Lalor BJ, Halson SL, Tran J, Kemp JG, and Cormack SJ. No Compromise of Competition Sleep Compared With Habitual Sleep in Elite Australian Footballers. *Int J Sports Physiol Perform*. 2018;13:29-36.
216. Sadeh A. The role and validity of actigraphy in sleep medicine: An update. *Sleep Medicine Reviews*. 2011;15:259-267.
217. Mark R. Wilson VWaBP (Ed.). *Progress in Brain Research*. Amsterdam: Academic Press, 2017.
218. Dupuy O, Douzi W, Theurot D, Bosquet L, and Dugue B. 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*. 2018;9.
219. Fang Z and Rao H. Imaging homeostatic sleep pressure and circadian rhythm in the human brain. *Journal of Thoracic Disease*. 2017;9:E495-E498.
220. Sargent C, Darwent D, Ferguson SA, Kennaway DJ, and Roach GD. Sleep Restriction Masks the Influence of the Circadian Process on Sleep Propensity. *Chronobiology International*. 2012;29:565-571.
221. Lee A and Galvez JC. Jet Lag in Athletes. *Sports Health: A Multidisciplinary Approach*. 2012;4:211-216.
222. Bonnet MH. Hyperarousal and insomnia. *Sleep Medicine Reviews*. 2010;14:33-33.
223. De Zambotti MM, Cellini CN, Goldstone CA, Colrain CI, and Baker CF. Wearable Sleep Technology in Clinical and Research Settings. *Medicine & Science in Sports & Exercise*. 2019;51:1538-1557.
224. Green PaM, C.J. . SIMR: an R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*. 2016;7:493-498.

225. Miller B, O'Connor H, Orr R, Ruell P, Cheng H, and Chow C. Combined caffeine and carbohydrate ingestion: effects on nocturnal sleep and exercise performance in athletes. *European Journal of Applied Physiology*. 2014;114:2529-2537.
226. Woosley JA and Lichstein KL. Dysmenorrhea, the Menstrual Cycle, and Sleep. *Behavioral Medicine*. 2014;40:14-21.

Appendix 1 - Research Portfolio

Publications

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. No compromise of competition sleep compared with habitual sleep in elite Australian footballers. *International Journal of Sports Physiology and Performance.* 2018;13(1):29-36.

Contribution statement BL was primarily responsible for the study design, gaining ethics approval, data collection, interpreting the results and drafting the manuscript. BL and JT were responsible for the data analysis. All authors were involved in the development of the study design, interpretation of the results and the preparation of the manuscript.

The approximate percentage contributions are as follows – B.Lalor 73%, J Tran 10% J Kemp 2% S. Halson 5% and S. Cormack 10%

I acknowledge that my contribution to the above publication is 73%

[redacted]

Benita Lalor Date: 22/01/21

As principle supervisor, I certify that the above contributions are true and correct:

[redacted]

Stuart Cormack Date: 22/01/21

Co-author signatures:

[redacted]

Shona Halson Date: 22/01/21

[redacted]

Justin Kemp Date: 22/01/21

[redacted]

Jacqueline Tran Date: 22/01/21

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. A Complex Relationship: Sleep, External Training Load, and Well-Being in Elite Australian Footballers. *International Journal of Sports Physiology and Performance*. 2020-02-04, Vol.15(6):777-787.

Contribution statement BL was primarily responsible for the study design, gaining ethics approval, data collection, interpreting the results and drafting the manuscript. BL and JT were responsible for the data analysis. All authors were involved in the development of the study design, interpretation of the results and the preparation of the manuscript.

The approximate percentage contributions are as follows – B.Lalor 73%, J Tran 10% J Kemp 2% S. Halson 5% and S. Cormack 10%

I acknowledge that my contribution to the above publication is 75%

[redacted]

Benita Lalor Date: 22/01/21

As principle supervisor, I certify that the above contributions are true and correct:

[redacted]

Stuart Cormack Date: 22/01/21

Co-author signatures:

[redacted]

Shona Halson Date: 22/01/21

[redacted]

Justin Kemp Date: 22/01/21

[redacted]

Jacqueline Tran Date: 22/01/21

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. Business Class Travel Preserves Sleep Quality & Quantity and Minimises Jet-Lag During The Women's World T20 Cricket Tournament. *International Journal of Sports Physiology and Performance.* **Accepted for publication**

Contribution statement BL was primarily responsible for the study design, gaining ethics approval, data collection, interpreting the results and drafting the manuscript. BL and JT were responsible for the data analysis. All authors were involved in the development of the study design, interpretation of the results and the preparation and proof reading of the manuscript.

The approximate percentage contributions are as follows – B.Lalor 73%, J Tran 10% J Kemp 2% S. Halson 5% and S. Cormack 10%

I acknowledge that my contribution to the above publication is 75%

[redacted]

Benita Lalor Date: 22/01/21

As principle supervisor, I certify that the above contributions are true and correct:

[redacted]

Stuart Cormack Date: 22/01/21

Co-author signatures:

[redacted]

Shona Halson Date: 22/01/21

[redacted]

Justin Kemp Date: 22/01/21

[redacted]

Jacqueline Tran Date: 22/01/21

Appendix II –Published Paper Which Forms the Basis of Chapter 4

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. No compromise of competition sleep compared with habitual sleep in elite Australian footballers. Int J Sports Physiol Perform. 2018;13(1):29-36.

Please view the published version online at:

https://journals.humankinetics.com/view/journals/ijspp/13/1/article-p29.xml?rskey=CaOKQv&result=2

Appendix III – Published Paper Which Forms the Basis of Chapter 5

Lalor BJ, Halson SL, Tran J, Kemp JG, Cormack SJ. A Complex Relationship: Sleep, External Training Load, and Well-Being in Elite Australian Footballers. Int J Sports Physiol Perform. 2020, Vol.15(6), pp.777-787

Please view the published version online at:

https://journals.humankinetics.com/view/journals/ijspp/15/6/article-p777.xml

Appendix IV – Ethics Approvals, Letters to Participants, Consent Form, Gatekeeper Letter and Sleep Diary

Study 1 and 2: Letter to Participants, Consent Form, Gatekeeper Letter and Sleep Diary

ACU Human Ethics Committee Approval Number 2014 226VR

PARTICIPANT INFORMATION LETTER

PROJECT TITLE: "Assessment of Sleep Patterns and the Relationship between fatigue and match day performance in AFL players".
INVESTIGATOR 1: Dr Stuart Cormack
INVESTIGATOR 2: Prof Justin Kemp
STUDENT RESEARCHER: Ms Benita Lalor
STUDENT'S DEGREE: Enrolled in PhD, Exercise Science

Dear Participant,

You are invited to participate in the research project titled Assessment of Sleep Patterns and the Relationship between fatigue and match day performance in AFL players". being conducted by Dr Stuart Cormack, Prof Justin Kemp and Ms Benita Lalor (PhD student).

What is the project about?

The project aims to examine the sleep patterns of elite AFL players using wrist worn activity monitor. The project also aims to identify any links between training load, perceptions of well-being, sleep and performance during the preparation and competition phases of the Australian Football season.

What will I be asked to do?

You will be required to attend an initial information session where you will complete the medical history questionnaire, informed consent and be provided with written and verbal information about the project. This initial session will also include familiarisation with the use of the wrist worn watches and sleep diary that will be used to monitor your sleep during the assessment period. This session will take approximately thirty (30) minutes of your time.

During the project times (outlined below) you will be required to wear a wrist worn activity monitor at all times during these monitoring blocks, except where the monitors may get wet or damaged, or in high contact training sessions and games. During this monitoring time you will also be required to complete a sleep diary. For each sleep period (including naps) you will be required to record the date, sleep onset/offset times, sleep quality and pre/post sleep fatigue levels. You will also be required to continue to complete your wellness questions on the Gold Coast Football Club Monitoring System (Smartabase) as per existing Gold Coast Suns monitoring protocol.

Are there any risks associated with participating in this project?

The risks to you are minimal. Steps have been taken to ensure your safety at all times and you may be required to remove your watch during training sessions and matches.

How much time will the project take?

The assessment of your sleep will be undertaken in five (5) data collection periods during the 2013 preseason and 2013 and 2014 AFL season. There will be a total of 35 days of sleep data collected during this time. These collection periods are outlined below.

Assessment Period 1

Preseason Feb 12 – 26 2013

Assessment Period 2

Round 6 May 29 – 10 2013

Assessment Period 3

Round 12 June 10 - 17 2013

Assessment Period 4

Round 2014

Assessment Period 5

Round 2014

During these times you will be required to wear activity monitors at all times during these monitoring blocks, except where the monitors may get wet or damaged, in high contact training sessions and in games. During this monitoring time you will also be required to complete a sleep diary. For each sleep period (including naps) you will be required to record the date, sleep onset/offset times, sleep quality and pre/post sleep fatigue levels. You will also be required to continue to complete your wellness questions as per existing Gold Coast Football Club monitoring protocol.

What are the benefits of the research project?
The benefits to you as a participant are the assessment of your sleep characteristics, both during the preseason and during competition. This may provide you with valuable information to allow you to further improve your recovery and subsequent performance. In the long-term, the research will inform high performance staff and coaches, as well as team-sport athletes in understanding the effects of sleep characteristics and performance. This in turn will provide guidance as to the best management of athletes training and scheduling in preparation for international competition.

Can I withdraw from the study?
Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?
Your personal information and any data collected during this study will be kept confidential. The only people who will have access to this information are the researchers (Stuart Cormack, Justin Kemp and Benita Lalor) and Cricket Australia High Performance staff. After all data have been collected and analysed, average scores for the group as a whole will also be used in sports science presentations and publications; however, no individually identifiable data will be apparent in such presentations/publications

Will I be able to find out the results of the project?
Once you have completed your participation in the project, the researchers will provide you with a summary of your individual results from the assessment periods.

Who do I contact if I have questions about the project?
If you have any questions or queries about the project please do not hesitate to contact Stuart Cormack.
E-mail address: Stuart.Cormack@acu.edu.au
Contact phone number: [redacted]

CONSENT FORM

Copy for Researcher

TITLE OF PROJECT: ASSESSMENT OF SLEEP PATTERNS AND THE RELATIONSHIP BETWEEN FATIGUE AND MATCH DAY PERFORMANCE IN AFL PLAYERS.

PRINCIPAL INVESTIGATOR: Dr Stuart Cormack
CO-SUPERVISOR: Professor Justin Kemp
STUDENT RESEARCHER (if applicable): Ms Benita Lalor

I .... *(the participant)* have read and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this research project over a 35 day period. I am aware and agree to participate in five blocks of sleep assessment, and completion of routine wellness and monitoring on the Gold Coast Suns Football Club Monitoring System (Smartabase), realising that I can withdraw my consent at any time, without adverse consequences. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): ....

DATE:………………………..

SIGNATURE OF STUDENT RESEARCHER: ....

DATE:.....................………

CONSENT FORM

Copy for Participant to Keep

TITLE OF PROJECT: IMPACT ON INTERNATIONAL TRAVEL ON HABITUAL SLEEP CHARACTERISTICS AND PERFORMANCE OF ELITE AUSTRALIAN CRICKET PLAYERS

PRINCIPAL INVESTIGATOR: Dr Stuart Cormack
CO-SUPERVISOR: Professor Justin Kemp
STUDENT RESEARCHER (if applicable): Ms Benita Lalor

I .... *(the participant)* have read and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this research project over a 35 day period. I am aware and agree to participate in five blocks of sleep assessment, and completion of routine wellness and monitoring on the Gold Coast Suns Football Club Monitoring System (Smartabase), realising that I can withdraw my consent at any time, without adverse consequences. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): ....

DATE:………………………..

SIGNATURE OF STUDENT RESEARCHER: ....

DATE:.......................………

What if I have a complaint or any concerns?
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (approval number 2013 xxxx). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph: 02 9739 2519
Fax: 02 9739 2870
Email: res.ethics@acu.edu.au..

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?
Two consent forms have been sent to you along with this information letter. Please fill out the details and sign both consent forms and give them to Benita Lalor.

Email: [redacted]
Postal Address: [redacted]

Yours sincerely,

Add signatures

Dr Stuart Cormack, Prof Justin Kemp, and Ms Benita Lalor

Sleep Diary

Name:

Date:

Study ID:

Monitor ID:

Study Contacts:

Benita Lalor

Performance Dietitian
Mob: [redacted]
Email: [redacted]

Personal Details

Age: _________ yr DOB: ___________ Gender: ☐ male

Height: ________ cm Weight: _________ kg ☐ female

Sport Details

How long have you been involved in sport at a professional level? __ yrs __ mths

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 _____________

Player Instructions

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

(i) wear an activity monitor

(ii) keep a sleep diary

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** – so please remove it when showering or swimming. The Activity Monitor can be worn in the rain.
- It is important that you always wear the Activity Monitor on the **same wrist**.
- When training or competing, do not wear the activity monitor if there is a chance that it could be damaged or cause injury to yourself or others.
- Please take care of your Activity Monitor – **replacement value = $3,000**

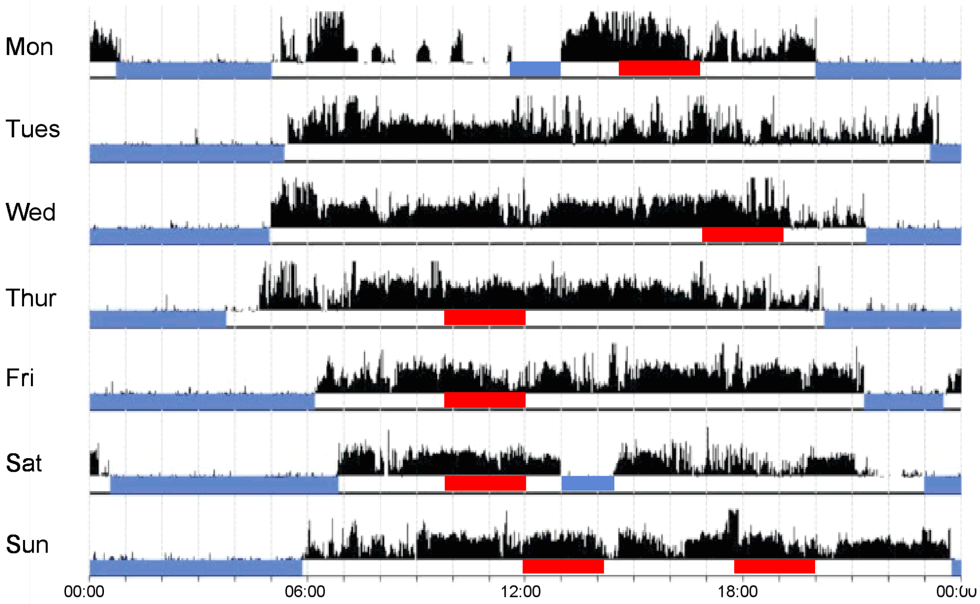
Keeping a Sleep Diary

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

- Complete a single line of the sleep diary for every sleep period (main sleeps and naps).
- 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.
- Date - the date that you go to bed
- Sleep Location - the city where the sleep occurs
- How many cups of caffeine did you have today? – record the number of cups of caffeine (e.g., 0, 1, 2, 3) that you consumed during the day (coffee, red bull, coke, tea etc).
- When was you last cup of caffeine? – record the time of your last cup of caffeine.
- Electronic Device Use - the time you're were using an electronic device before attempting to go asleep.
- Bed Time - the time that you start attempting to sleep. Don't include time spent reading, watching TV, etc
- Get Up Time - the time that you stop attempting to sleep. Don't include time spent reading, watching TV, etc.
- Did you watch TV in bed before sleep? – number of minutes you spent watching TV in bed before lights out.
- Sleep Quality - the quality of your sleep compared to a 'normal' sleep period - see the bottom of your sleep diary for scale.

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 day/mth	**How many cups of caffeine have you had today?** **What time was your last cup?**	**Bed Time** hh:mm	**Get-up Time** hh:mm	**Did you watch TV in bed before sleep?** **If yes, for how long?**	**Did you use an electronic device before sleep?** **If yes, for how long?**	**Sleep Quality** *please circle*
26/1	2 x coffee 16:00	22:30	06:30	Y – 60 min	Y – 60 min	very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor
						very good | good | average | poor | very poor

Instructions

1. Complete a single line of the sleep diary for every sleep period (**i.e. major sleeps and naps**).
2. Date – the date that you go to bed.
3. How many cups of caffeine did you have today? – record the number of cups of caffeine you consumed during the day (coffee, red bull, coke, tea etc).
4. When was you last cup of caffeine? – record the time of your last cup of caffeine.
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. Did you watch TV in bed before sleep? – number of minutes you spent watching TV in bed before lights out.
8. Did you use an electronic device before sleep? – number of minutes you spent using before attempting to sleep.
9. Sleep Quality – the quality of your sleep compared to a 'normal' sleep period.

NB – 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.

Study 3: AIS Ethics Letters, Cricket Australia Gatekeeper Letter and Confirmation Accepted for Publication.

ACU Human Ethics Committee Approval Number 2014 225VR

Australian Institute of Sport

MINUTE

TO:	Dr Nathan Versey	CC: Dr Shona Halson
FROM:	Ms Helene Rushby	
SUBJECT:	Approval from AIS Ethics Committee	DATE: 11th September 2014

On the 2nd of September 2014, the AIS Ethics Committee Secretary approved the request of the Project Lead to amend the list of researchers on the project titled "Monitoring athlete' sleep habits, quality and quantity via actual activity monitors" to include the following names:

- Ms Benita Lalor (PhD Student- Australian Catholic University)
- Dr Stuart Cormack (Lecturer/PhD Supervisor- Australian Catholic University)
- Mr Ian Dunican (PhD Student- University of Western Australia)
- Prof Peter Eastwood (Lecturer/PhD Supervisor- University of Western Australia).

The approval number for this project remains as: 20130406

It is a requirement of the AIS Ethics Committee that the Principal Researcher (you) advise all researchers involved in the study of Ethics Committee approval and any conditions of that approval. You are also required to advise the Ethics Committee immediately (via the Secretary) of:

Any proposed changes to the research design,
Any adverse events that may occur,

Researchers are required to submit **annual status reports** and **final reports** to the secretary of the AIS Ethics Committee. Details of status report requirements are contained in the "Guidelines" for ethics submissions.

Please note the approval for this submission expires on the 31st March 2017 after which time an extension will need to be sought.

If you have any questions regarding this matter, please don't hesitate to contact me on (02) [redacted]

Helene Rushby
Secretary, AIS EC

AIS RESEARCH

REQUEST FOR

'EXTENSION OF TIME'

If a project cannot be completed within the date indicated on the approved Ethics Submission, then the researcher must make a request to the Research Office for an 'Extension of Time' to complete the project. **Please note** that a project's ***Completion Date*** is the date on which the ***Final Report*** is provided to the AIS Research Office.

TO: AIS Research Coordinator Tel: 02 6214 1791
Email: Tim.Kelly@ausport.gov.au

FROM: Benita Lalor

DATE: 19.03.20

I hereby request an 'Extension of Time' to complete my research project "Monitoring athlete sleep habits, quality and quantity via actual activity monitors" [20130406]

The original ***Completion Date*** indicated in my application for research funding was 31/07/17

An extension was granted on 13/04/18 to a revised Completion Date to be 30/02/19

I now anticipate the Completion Date to be __31_/_12__/__2020_.

Reason(s) for the delay are as follows: Maternity Leave

Signed: [redacted] 19/03/2020
Principal Researcher

Endorsed: ..[redacted]........20/03/20 Tim KELLY.............20/03/20
Acting Secretary AIS Ethics Committee

Approval is/is not given to extend the completion date to 31/12/20.

CRICKET AUSTRALIA

MEMO

To: Whom it may concern

Date: 5th March 2016

Subject: Sleep Research for Australian Female Cricket players (RO1629)

Cricket Australia acknowledges that Benita Lalor is undertaking a research project (RO 1629) investigating the analysis of sleep patterns in elite athletes, and authorise her to include Australian Cricket Players in the study.

Cricket Australia will assist Ms Lalor to recruit the volunteers required for the project.

Kind Regards,

[redacted]

Alex Kountouris

Sports Science and Sports Medicine Manager

Cricket Australia

Confirmation of the Acceptance for Publication

International Journal of Sports Physiology and Performance <o… Mon, Nov 16, 8:21 AM
to benita.lalor, me

15-Nov-2020

Dear Ms Lalor,

It is a pleasure to accept your manuscript entitled "Business Class Travel Preserves Sleep Quality & Quantity and Minimises Jet-Lag During The Women's World T20 Cricket Tournament" in its current form for publication in the International Journal of Sports Physiology and Performance. The comments of the reviewer(s) who reviewed your manuscript are included at the foot of this letter.

We anticipate that your paper will be published in print in approximately eight to ten months. The In Press and MedLine listings should be available well before that.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Dr Øyvind Sandbakk
Associate Editor, International Journal of Sports Physiology and Performance
oyvind.sandbakk@ntnu.no