GET SLEEP OR GET STUMPED

SLEEP BEHAVIOUR IN ELITE SOUTH AFRICAN CRICKET PLAYERS DURING COMPETITION

BY

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DECLARATION

I, Kayla McEwan, hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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ABSTRACT

Introduction: Good sleep behaviour is associated with achieving optimal athletic performance and reducing the risk of injury. Elite cricket players have unique physical and cognitive demands, and must accommodate for congested competition and travel schedules (all of which increase the risk of disruptive sleep). Further, the political pressures and socioeconomic barriers in South African cricket could affect the sleep of the country's elite players. Previous research in cricket has focussed on the impact that nutrition, equipment specifications, movement physiology and psychology could elicit on performance (where many professional teams hire support staff to supervise these disciplines); however, there is limited empirical application of sleep research in elite cricket players. Therefore, this study aimed to characterise the sleep behaviours of elite South African cricket players during periods of competition and investigate the relationship between pre-match sleep and cricket performance. **Methods:** A longitudinal field-based investigation was implemented to monitor the sleep behaviour of 26 elite South African cricket players (age: 28.6 ± 4.0 years; height: 1.8 ± 0.1 m; weight: 85.7 ± 10.8 kg; elite experience: 3.7 ± 4.0 years) during home and away competitive tours. The Morningness-Eveningness Questionnaire and Athlete Sleep Behaviour Questionnaire were administered to identify chronotype and poor sleep behaviours. Players completed an altered version of the Core Consensus Sleep Diary every morning post-travel, pre-match and post-match. Linear mixed model regression was used to compare differences in sleep variables between time-periods, match venues, player roles, match formats, sleep medication and racial groups. Spearman's correlation (r_s) was used to assess the relationship of substance use (alcohol and caffeine), age, elite experience and match performance with selected sleep indices. Statistical significance for all measures was accepted at $p < 0.05$. Hedge's (g) were used as the measure of effect size. **Results:** Light-emitting technology use, effects of travel, late evening alcohol consumption and muscle soreness were the main factors that impacted sleep. Post-match total sleep time (06:31 ± 01:09) was significantly ($p < 0.05$) shorter compared to post-travel (07:53 ± 01:07; g = 1.19 [0.81;1.57]) and pre-match (08:43 ± 01:03; g = 1.97 [1.55;2.39]) total sleep time. Post-travel sleep onset latency and sleep efficiency were significantly ($p < 0.05$) shorter (g = 0.74 [0.29;1.29]) and higher (g = 1.35 [0.76;1.94]) at home than away. Although not significant ($p > 0.05$), allrounders took longer to fall asleep (g = 0.90 [0.23;1.57]), obtained less total sleep (0.76 [0.29;1.42]) and had lower morning freshness scores (g = 1.10 [0.42;1.78]) the night before a match compared to batsmen. Wake after sleep onset and get up time were moderately longer (g = 0.61 [0.22;1.26]) and later (g = 0.62 [0.27;1.17]) before

Twenty20 matches compared to One-Day International matches respectively. Further, sleep duration significantly declined from pre-match to post-match during the multi-day Test format ($p = 0.04$, g= 0.75 [0.40;1.12]). Late alcohol consumption was significantly ($p < 0.05$) correlated with a decrease in total sleep time, regardless of match venue (home: $r_{s\,(49)} = -0.69$; away: $r_{s\,(27)} = -0.57$). During the away condition, an increase in age was significantly associated with longer wake after sleep onset durations ($r_{s\,(13)} = 0.52$, $p = 0.0003$), while greater elite experience was significantly associated with longer total sleep time ($r_{s\,(72)} = 0.36$, $p = 0.02$). The non-sleep medication group took significantly longer to fall asleep compared to the sleep medication group during the first week of the away condition ($p = 0.02$, g = 0.75 [0.25;1.26]) particularly on nights following transmeridian travel. Although not significant ($p > 0.05$), Asian/Indian players had moderately longer sleep onset latencies (g = 1.07 [0.66;1.47]), wake after sleep onset durations (g = 0.86 [0.42;1.29]), and lower subjective sleep quality (g = 0.86 [0.46;1.26]) and morning freshness scores (g = 0.89 [0.47;1.27]) compared to Whites. Similarly, Black Africans had moderately lower subjective sleep quality scores compared to Whites (g = 0.71 [0.43;0.97]). Longer sleep onset latencies and shorter total sleep times were significantly ($p < 0.05$) associated with poorer One-Day International ($r_{s\,(28)} = -0.57$) and Test ($r_{s\,(12)} = 0.59$) batting performances respectively. Higher subjective sleep quality scores were significantly associated with better Twenty20 bowling economies ($r_{s\,(8)} = -0.52$). **Discussion:** There was no evidence of poor pre-match sleep behaviour, irrespective of venue; however, the most apparent disruption to sleep occurred post-match (similar to that found in other team-sports). Most disparities in sleep between match venues existed post-travel, with better sleep behaviour observed during the home condition. The differences in sleep patterns found in all three match formats were expected given the variations in format scheduling and duration. Although sleep medication was shown to promote better sleep, its long-term effectiveness was limited. The results promote the implementation of practical strategies aimed to reduce bedtime light-emitting technology use, late evening alcohol consumption and muscle pain. Inter-individual sleep behaviour was found between player roles, age, experience level and race. Moderate associations existed between sleep and markers of batting performance, specifically for the longer, strategic formats of the game. **Conclusion:** The current study provided new insight of the sleep behaviour in elite South African cricket players during competition. Individualized sleep monitoring practices are encouraged, with specific supervision over older, less experienced players as well as the racial minorities and allrounders of the team. The poor post-match sleep behaviour, together with the sleep and performance correlations, provide

ideal opportunities for future interventions to focus on match recovery and the use sleep monitoring as a competitive advantage.

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THESIS RESEARCH OUTPUTS

Peer-reviewed publications

- McEwan, K.M., Davy, J.P., & Christie, C.J. Get sleep or get stumped: Sleep quantification of elite South African cricket players during competition. Journal of Sport Sciences. *Under revision.*

Conference publications

- McEwan, K.M., Davy, J.P., & Christie, C.J. Get sleep or get stumped: Sleep quantification of elite South African cricket players during competition. 6th World Congress of Science and Medicine in Cricket hosted at Loughborough, UK, 8-11 July 2019.

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GLOSSARY

- **Asian/Indian:** Individuals of Asian/Indian descent.
- **Batters:** Gender-neutral term used in the review of literature to identify both female and male batsmen.
- **Bedtime (hh:mm):** The time players indicated they got into bed.
- **Black African:** Individuals of indigenous African descent.
- **Coloured:** Individuals of mixed race or mixed ancestry.
- **Cricket series:** Refers to a collection of matches played within a cricket tour, which could range from two to six matches during a Test series, three to seven matches in an ODI series and one to three matches during a Twenty20 series.
- **Cricket tour:** When one nation travels to another for several weeks or months and plays multiple series of various match formats against the host nation.
- **Get-up time (hh:mm):** The time participants indicated they got out of bed for the day with no further attempt at sleeping.
- **Morning freshness score (1-5):** A rating indicated by the participants on how refreshed they felt when they woke up for the day.
- **Nap duration (hh:mm):** The total amount of time spent napping or dozing during the day.
- **Sleep efficiency (%):** The sleep duration expressed as a percentage of time asleep from bedtime to wake-up time.
- **Sleep onset (hh:mm):** The time participants indicated trying to go to sleep.
- **Sleep onset latency (hh:mm):** The total amount of time took to fall asleep.
- **Subjective sleep quality score (1-5):** A rating indicated by the participants of the quality of their sleep.
- **Time in bed (hh:mm):** The difference between bedtime and get-up time as indicated by the participant.
- **Total sleep time (hh:mm):** The actual time spent asleep determined from sleep start to wake-up time, minus any wake after sleep onset duration.
- **Wake after sleep onset (hh:mm):** Total time spent awake between sleep onset and final awakening.
- **Wake-up time (hh:mm):** The time which participants indicated they woke up in the morning/final awakening.
- **White:** Individuals of Caucasian or European descent.

CHAPTER I

1 INTRODUCTION

"...it is practice, with sleep, that ultimately leads to perfection" – Walker and Stickgold[1(p316)]

1.1 BACKGROUND TO THE STUDY

The notion that sleep is a prerequisite for optimal recovery and performance in elite athletes is well established.[2-8] Despite this, sleep is often deprioritised by athletes,[9] with widespread evidence of sleep impairment at the elite level, particularly during competition (see reviews by Gupta et al.[10], Nédélec et al.[11] and Roberts et al.[12]). Although all the functions of sleep are not clearly defined,[2] sleep plays a salient role in physiological and psychological restoration, learning processes, memory consolidation and metabolic function.[1,3,13] Inadequate sleep can impair critical physical and cognitive responses and disrupt the stress-recovery balance needed for optimal and consistent sports performance.[1,4,6,7,14] However, given the variations between individuals (e.g. chronotype, training status, age, sex, elite experience and race), sport modalities (individual vs team) and research methodologies (field vs laboratory-based) used in previous research, defining a set of sleep guidelines for athletes has been challenging.[7,11,12]

Elite athletes are frequently exposed to circadian rhythm desynchronization (e.g. jet lag during international competitions), changes in sleeping environments (e.g. hotel rooms), psychosocial stress and muscle soreness during congested competition, training and travelling schedules; increasing the risk of experiencing disrupted sleep in athletes.[3,10,15-17] Further, light-emitting technology use,[18-22] alcohol[23-25] and caffeine[26,27] before bedtime contribute to inadequate sleep. Post-match sleep disruptions in team sports are common after night matches,[28-29] possibly attributed to increased arousal from the match itself,[17,30,31] the biological effect of artificial floodlights on the sleep-wake cycle[19,28] and participation in post-match commitments (e.g. social events and press-conferences).[7,30,32] Athletes involved in sports, which are particularly exposed to these circumstances, should ensure they are obtaining enough sleep to prevent injury risk and reach their full potential.[6] One such sport is cricket.

There has been an increase in the volume of cricket played across the annual season because of globalisation as well as the commercialisation of the sport.[33-36] Additionally, the growth in match format variations and financial incentives could impose greater physical and psychological strain on players who engage in ~100 matches per calendar year.[33,37] This evolvement has encouraged a more professional, structured approach to develop training programmes, game preparation, travelling arrangements and recovery monitoring practices using scientific opinions.[36] Consequently, more research attention is being given to understand the biomechanics of batting and bowling techniques,[38-40] psychophysiological stress and movement requirements,[41-47] predictive modelling of match outcomes[48-50] and injury prevention strategies.[51-54] Elite cricket players have distinctive physical and cognitive demands,[43,47] congested competition and training programs[33,36] and must accommodate for taxing travel schedules (all of which put them at high risk of experiencing disrupted sleep).[3,7,10] Cricket itself is a multifactorial sport with varied formats, specialist positions and performance demands, and unpredictable playing environments,[55] all of which could affect player sleep for unique reasons compared to other team-sports. In theory, proper sleep management would be a logical means of ensuring an adequate stress-recovery balance in this context.[2,54] This prospect is supported by a recent study which promoted the efficacy of sleep hygiene education in elite Australian cricket players during pre-season training.[56] Although not the primary aim, their results substantiated the importance of sleep research in elite cricket players, particularly investigations focused towards identifying factors (specific to cricket) which affect sleeping patterns.[56] Unlike other team-sports, such as rugby union,[27,30,57,58] elite soccer,[17,32,59] football,[28,60-64] basketball,[65,66] netball[29,31] and volleyball,[67,68] there is a void of published empirical evidence underpinning the sleep behaviours and effects of sleep loss in elite cricket during competition.

Since South Africa's political transformation in 1994, Cricket South Africa have made attempts to transform the game to be more representative of the "Rainbow Nation" ideology,[69,70] particularly through the quota system or ethnic "targets" (the term "targets" is preferred by Cricket South Africa).[71,72] By definition in the social sciences, 'race' alludes to physical characteristics and 'ethnicity' to cultural identity.[73] In South Africa, there are four accepted racial groups, which are maintained in this thesis, namely: 'White', 'Coloured', 'Asian/Indian' and 'Black African' (refer to glossary on page 11).[72] Unfortunately, racial and ethnic minority groups encounter structural (e.g. socioeconomic, educational, developmental) barriers.[74] Moreover, the politics around national team selection does not consider the tension it causes when players are chosen based on the colour of their skin.[72] Consequently, the barriers and political interference could potentially increase psychosocial anxiety through perceived racial, organisational and institutional discrimination, which can affect sleep duration and quality.[74,75]

There are physiological, emotional and psychological consequences of reduced sleep in athletes.[6,8,76,77] However, the applicability of existing laboratory-based research, which provide evidence of the noteworthy relationship between sports performance and sleep, is disputed because they do not account for the external factors (e.g. playing environment, policies, sociocultural and intrapersonal factors) which exist in the ecological sporting context.[6,11,19] The existing field-based studies, which have demonstrated a relationship between competitive success and optimal sleep behaviours (e.g. netball players[31] and Brazilian Olympians[78]), are only applicable to the homogenous group of elite athletes investigated.[11,79] This dilemma highlights the importance of undertaking context specific investigations.

1.2 STATEMENT OF THE PROBLEM

Despite the plethora of evidence supporting the positive affect sleep has on recovery and performance in sport, there is limited empirical application of sleep research on elite cricket players. Further, the political challenges and large diversity (e.g. in religions, age, socioeconomic background, ethnicity and race) of South African sports teams may contribute to a range of disparities in sleep behaviour between athletes which cannot be extrapolated from previous international studies. Therefore, the purpose of this study was to characterise the sleep behaviour of elite South African cricket players during competition and identify factors which influence their sleep. Additionally, this study aimed to assess the effect of sleep on match performance by employing a 'field-based design' using performance measures which are relevant to cricket.

1.3 STUDY OBJECTIVES

The four main objectives of this study were to:

1. Profile sleep patterns and behaviours among elite South African cricket players during home and away competitions.
2. Identify factors which impact sleep behaviours in elite South African cricket players.
3. Identify which inter-individual differences exist in sleep behaviours within an elite South African cricket team.
4. Explore the association between sleep and cricket match performance for all formats of the game.

1.4 RESEARCH QUESTIONS AND HYPOTHESES

The research questions based on the four main objectives of this study were:

- Research question 1: Is there evidence of sleep disruption among elite South African cricket players during competition?

  Hypothesis 1: There is evidence of sleep disruption among elite South African cricket players during competition, particularly when competing away.
- Research question 2: Which factors affect the sleep of elite South African cricket players?

  Hypothesis 2: The effects of travelling, pre-match anxiety, substance (alcohol and caffeine) use, sleep medication and light-emitting technology affect the sleep of elite South African cricket players.
- Research question 3: Which inter-individual differences exist in sleep behaviour within an elite South African cricket team?

  Hypothesis 3: Sleep behaviour differences exist within an elite South African cricket team depending on chronotype, age, experience level and race.
- Research question 4: Are there associations between pre-match sleep and cricket player match performance?

  Hypothesis 4: There are associations between pre-match sleep patterns and batting and bowling performance during a match for all formats.

CHAPTER II

2 REVIEW OF LITERATURE

This chapter aims to outline and inform the argument that there is a need to investigate the sleep behaviours and performance costs of inadequate sleep in elite cricket players. The chapter begins with theoretical introductions to cricket, performance and sleep, which serve as the foundation for the study. The next section reviews the empirical research, which has examined the sleep behaviours of elite athlete populations and scrutinises the main factors which affect sleep during team-sports competition. Following this is an overview of the methods used to measure sleep in athletes. Thereafter, the effects of sleep loss on physiological responses, cognitive athletic performance parameters (most relevant to cricket) and injury risk are highlighted. Lastly, a case is put forward, expressing why South African cricket players are a high-risk group to disrupted sleep.

2.1 THEORETICAL INTRODUCTION TO CRICKET, PERFORMANCE AND SLEEP

2.1.1 Cricket background

Cricket is a bat and ball game played between two teams on an oval-shaped grass field.[80,81] A team consists of 11 players made up of batters, bowlers (spin and fast), allrounders, fielders and a wicket-keeper.[80,81] An allrounder is a player who is efficient at both bowling and batting.[80] The International Cricket Council is the governing body of world cricket, which consists of 106 members (primarily Commonwealth countries).[36,81] There are three formats of the game, namely: Test cricket, One-Day International and Twenty20,[55,81-83] with each encompassing different variables and rules summarised in Table 1.

Table 1. Differences between Test, One-Day International and Twenty20 cricket match formats (Information obtained from Petersen et al.[43] and Ahmad et al.[81]).

	Test	One-Day International	Twenty20
Match Kit	All white	National colours	National colours
Ball colour	Red	White	Red or White
Duration	3-5 days	~ 8 hours	~ 3 hours
Number of overs	90	50	20
Sessions	4	2	2

The primary goal for the bowling team is to dismiss all ten batters as quickly as possible.[83] The following ways could dismiss a batter: caught out (ball caught on the fly), bowled out (the bowler strikes wicket), run out (the ball strikes wicket while batter is out of the crease), stumped out (batter steps out of the crease while striking and the wicket-keeper/fielder displaces the bail from the wicket with the ball), bowled leg-before-wicket (part of the batter's body stops a delivery from hitting the wickets) or the batter displaces the wicket themselves.[36,48,84] An 'over' consists of six balls being bowled at one wicket.[81,85] The main goal for the batting team is to score as many runs as possible with two batters in, one at each end of the pitch.[83] As the fielders attempt to get the ball back to the bowler or wicket-keeper, the two batters run between the wickets to score runs.[85] If the ball reaches or lands over the boundary line, four or six automatic runs are scored respectively.[36,48] The side which has scored the most runs at the end of the match is the winner.[36,48]

Cricket is played at different times of the day, depending on the match format.[55] A Test match is played during regular hours; however, One-Day International and Twenty20 schedules differ. During One-Day Internationals, there are two types of matches; day and day-night, where the difference lies in the times at which each start and end. In South Africa, a typical schedule for each One-Day International match type is as follows:

Day matches:

- 1st innings 10:00
- Innings change over 13:30-14:15
- 2nd innings 14:15-18:45

Day-night matches:

- 1st innings 14:30
- Innings change over 18:00-18:45
- 2nd innings 18:45-22:15

These times depend on the completion of the allotted 50 overs per side as a team may be bowled out before the innings is complete or a target is chased down with overs to spare.

2.1.2 General cricket performance requirements

Cricket performance requires the optimisation of interrelated physical, tactical, technical and socio-psychological skills.[43,45,86-88] These requirements are dependent on the match format played, as shorter formats (One-Day Internationals and Twenty20), are more intensive per unit of time, but Test cricket has a higher overall physical and mental load because of its longer duration.[36,43,89] Nonetheless, cricket players sustain high load stressors through different speeds of movement along with rapid changes in direction during play (e.g. bowling run-ups, sprinting between wickets and while fielding). It is estimated that an elite batter scoring 100 runs (consisting of 50 singles, 20 twos, 10 threes and 20 fours), would cover a total of 3.2 km cumulatively in 8 minutes.[33] Additionally, during a One-Day International, fast bowlers could bowl 64 deliveries in 40 minutes running 1.9 km in 5.3 minutes.[33] The repeated eccentric muscle contractions during fast bowling as well as the repeated decelerations when turning during batting or fielding induce musculoskeletal stress.[33] Cricket is mistakenly known as a physically undemanding sport[33,43]; however, investigations using the BATEX protocol to measure heart rate responses have demonstrated otherwise.[44] Heart rate responses have ranged between 136 to 159 beats per minute (b.min^{-1}) during short-duration high-intensity work bouts,[41,90] 139 to 159 b.min^{-1} during One-Day International matches and 149 to 167 b.min^{-1} for Twenty20 matches.[43,46] Heart rate during fast bowling has been found to range between 73-77% maximum heart rate,[91] and peak between 180-190 b.min^{-1} during 12-over fast bowling spells.[92] Cricket also involves several psychological demands (e.g. decision-making, sustained attention and pacing strategies) which cause varying levels of mental fatigue.[87,93] For example, both wicket-keepers and batters need high levels of mental stamina as they are required to efficiently transition their attentional focus between deliveries to avoid mental exhaustion.[94,95] Cricket players are required to perform numerous technical actions such as different batting strokes, bowling styles, catching and throwing techniques. Batters, in particular, are under time constraints because of the ball speed, especially coming from a fast bowler.[87] A ball bowled takes about 600m.s^{-1} to reach the bat giving the batter 200m.s^{-1} to adjust and execute an appropriate stroke based on rapid visual information.[87] Players may also face psychosocial challenges caused by external sources (e.g. media scrutiny, public pressure, team cohesion and stress of team selection) that can affect the perception of workloads and the ability to perform them.[77,96]

Due to advances in technology, increased investments, media coverage as well as the introduction of the Twenty20 format, 21st century cricket is more competitive and profitable than ever before.[35,50,97-99] Most elite teams are expected to play ~100 matches per year,[33,37] which often involve three matches per week during a regular cricket series. The excessive exercise workloads, frequent travel and congested fixture schedules can result in performance decrements and injury occurrence if not properly managed.[4,7,10,17,100] With the growing rivalry and financial investment, cricketers are incentivised to train even harder to breakthrough professionally and produce consistent elite performances.[37] To achieve this entails an understanding of the intrinsic (which are predominantly genetically determined) and extrinsic (controllable external and environmental) factors, and their interaction,[101,102] as shown in Figure 1.

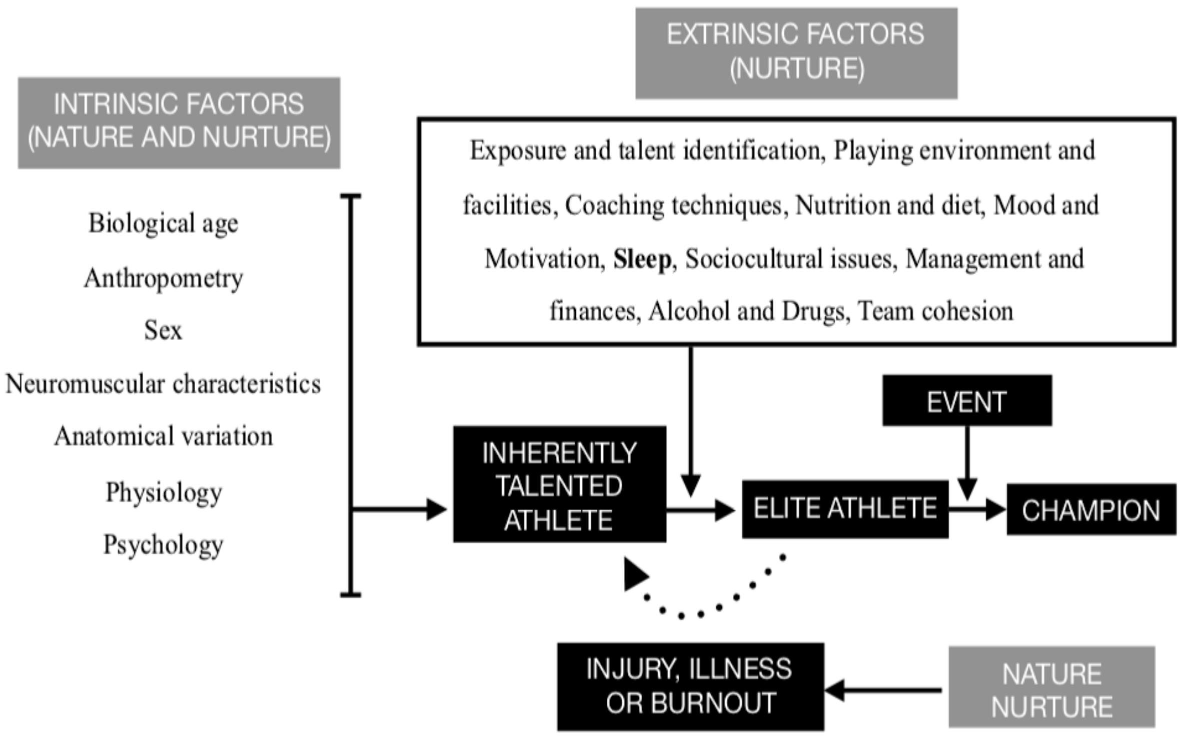

Figure 1. Breakdown of the complex relationship between intrinsic and extrinsic factors that influence athletic performance (Information consolidated from Tucker and Collins[101] and Dahl[102]).

Inherently talented athletes have greater maximum potentials because of favourable genetic variations, which could arise within any of the intrinsic factors presented in Figure 1. However, when these athletes reach the elite level, it is unlikely that merely genetics could propel them to ‘champion’ status. Consequently, the extrinsic factors that influence adaptation while simultaneously reducing risk of injury, illness and burnout, need to be optimised.[4,101] Elite sport often prioritises strategies based on proper nutrition, peak physical conditioning and emotional well-being.[103,104] However, despite empirical evidence which outlines the importance of sleep for athletes to reduce illness and injury rates,[32,105-107] as well as to optimise athletic performance,[6,76-79] sleep management in sport is often neglected.[9]

2.1.3 Understanding sleep

To comprehend the importance of sleep in elite athletes requires a broad understanding of the physiology of sleep and its role in the optimisation of cognitive and physiological functioning.

Generally, 7 to 9 hours of sleep per night is recommended for young (18-25 years) healthy adults,[108] however, between 8 to 10 hours of sleep is suggested for athletes to compensate for the additional demands of training and competition.[10,109,110] These recommendations only act as benchmarks since individuals have different innate sleep needs.[110] Several genetic, behavioural, medical and environmental factors influence these variations between individuals[110,111] There is no definition of “optimal sleep” [110]; accordingly, healthy sleep can be characterised as adequate sleep duration (depending on the individual), sleep quality, sleep consistency and in the absence of sleep disorders.[111,112] However, a U-shape relationship exists between sleep duration and negative health outcomes, whereby too little and too much sleep can have adverse effects on heath.[110,113]

2.1.3.1 The physiology of sleep

Sleep has been described as a reversible, complex combination of physiological and behavioural changes,[114] and is underpinned by several other related biological processes (known as circadian rhythms).[115,116] Circadian rhythms are assessed by measuring core temperature, blood pressure, immune function and numerous hormones[117] - the primary underlying mechanisms responsible for time-of-day fluctuations in human behaviour.[118,119]

A circadian rhythm follows a sinusoidal pattern and is regulated by an internal biological clock found in the suprachiasmatic nucleus in the hypothalamus of the brain.[76,120,121] The biological clock is somewhat flexible, and its regulation is subject to sensory cues called "zeitgebers".[76,122] Zeitgebers enable the built-in circadian rhythms to remain appropriately oriented to an individual's environment and desired daily routine through entrainment within a few minutes of the Earth's 24-hour rotation cycle.[76,122] Zeitgebers can be divided into two groups; photic and non-photic.[123] Photic zeitgebers are thought to be the most important and include natural and artificial light.[123] Blind people exemplify non-photic zeitgebers, which consist of social cues, physical activity, temperature and humidity.[122,123] As the suprachiasmatic nucleus obtains sensory inputs from the environment, it communicates with the endocrine system as well as other centres within the hypothalamus to stimulate and regulate behavioural and physiological processes (e.g. the sleep-wake cycle, physical activity, food consumption, body temperature, heart rate, muscle tone and hormone secretion).[120,122] Sleep-wake homeostasis is an internal system that generates sleep pressure and regulates sleep intensity.[121,122] Simply put, sleep pressure increases while awake and dissipates while sleeping.[118,119,121,122]

2.1.3.2 The sleep wake-cycle

The sleep-wake cycle is a two-process model (Figure 2) regulated by the circadian rhythm (C) and sleep-wake homeostasis (S).[122,124,125] While working in synchrony, these two systems have opposing effects.[122,125] The homeostatic sleep drive habitually increases throughout the day; however, is counteracted by the circadian drive for arousal, which maintains wakefulness.[118,126] During the evening, the circadian alerting system weakens, and melatonin (a sleep-promoting hormone) release begins.[116,118,121] When the distance between the homeostatic sleep drive and circadian drive for arousal is at its greatest, the "sleep gate" is opened and sleep commences.[116,121] While sleeping, the homeostatic sleep drive decreases exponentially, while the circadian-regulated melatonin production continues.[118] In the early morning (or the 'midpoint of sleep'), the circadian alerting system now starts to increase cortisol production (promoting wakefulness) and melatonin secretion begins to cease.[118,121] Eventually, the circadian drive for arousal overcomes the homeostatic sleep drive, causing full awakening, and the process repeats.[121] As such, the sleep-wake cycle acts as a blueprint for a recuperative refuelling process essential for optimal physical and cognitive performance.[127,128]

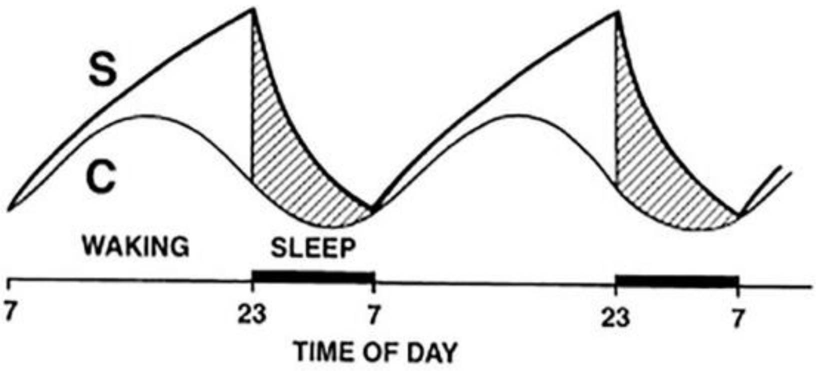

Figure 2. Representation of the sleep wake cycle as proposed by Borbely[124] (image taken from Carrier et al.[119]).

2.1.3.3 Sleep architecture

There are two primary sleep states based on physiological parameters known as rapid eye movement and non-rapid eye movement.[114,129,130] Non-rapid eye movement sleep consists of three stages at the beginning of sleep, namely: slow eye movement ('relaxed wakefulness'), no eye movement ('easily awakened') and slow wave sleep ('deep sleep').[114,130] Subsequently, rapid eye movement sleep is the 'fourth' stage of the sleep cycle, which occurs in alternating ~90 minute cycles.[114,129,130] Each sleep stage uniquely contributes to psychological and physiological functioning.[114] For athletes, deep sleep during the non-rapid eye movement state is considered an especially important sleep stage, as it is primarily involved in energy conservation and nervous system recuperation through the release of growth hormone, stimulation of protein synthesis and free fatty acid mobilisation.[131] This aids in facilitating quick rates of peripheral muscular repair and psychophysical recuperation after intense exercise.[13,132] Rapid eye movement sleep plays a critical role in the restorative benefits for cognition, specifically memory consolidation and the learning of motor skills.[1,5,77,133] Consequently, inadequate rapid eye movement sleep may adversely affect the learning process and short-changes the retention of new information and skill development in sport.[6,134]

2.1.3.4 Sleep deprivation (total vs partial)

Total sleep deprivation is the complete lack of sleep for 24 hours or longer[135,136] while partial sleep deprivation is when an individual gets significantly less sleep than usual per night and can occur in three ways.[135] The first occurs though sleep fragmentation, whereby sleep continuity is disrupted by multiple short awakenings throughout the night, reducing the time spent in consolidated physiological sleep.[135] The second type, referred to as selective sleep stage deprivation, is the least common type and involves the loss of specific physiological sleep stages.[135] The third type is sleep restriction, whereby total sleep duration is limited either by delaying bedtime or waking up prematurely.[6] Sleep debt is a result of cumulative partial sleep deprivation[137] and is acutely associated with cognition, memory and performance impediments, increased stress responsivity, reduced quality of life and emotional dysregulation.[137,138] Over time, chronic sleep debt is linked to poor health outcomes such as cardiometabolic disease risk factors,[139] obesity,[140] and psychological disorders,[141,142] which are concerns to both the general and athlete population.[20,138]

2.2 SLEEP BEHAVIOUR IN ELITE ATHLETES: AN OVERVIEW

A beneficial bilateral interaction occurs between exercise and sleep whereby moderate aerobic exercise training is suggested as a possible non-pharmacological treatment of sleep disorders.[143] Therefore, athletes (who take part in substantial amounts of exercise) should have better sleep than non-athletes; however, both anecdotal and empirical evidence suggests otherwise.[10-12] Olympic athletes have displayed comparable sleep durations, but poorer sleep quality, lower sleep efficiency and longer sleep onset latency than non-athletic sex and age-matched controls.[13] Further, there is a high prevalence of insomnia symptoms in athletes, such as longer sleep latencies, more fragmented sleep and excessive daytime sleepiness.[10] Based on Pittsburgh Sleep Quality Index results, 41% of Japanese Olympic athletes,[144] 50% of German ballet dancers,[145] 41% Dutch athletes,[146] and 28% elite Japanese athletes[113] reported global scores above the cut-off level (> 5.5) and were regarded as 'poor sleepers'. These outcomes suggest that elite athletes mainly experienced difficulties regarding quality compared to the quantity of sleep.[147]

When comparing seasonal sport periods (pre-season training vs in-season competition), athletes experience significantly less sleep, poorer sleep efficiency[58,148] and increased sleep onset latency[128,149,150] before competition compared to training. However, trivial differences between seasonal periods were found in Australian footballers,[64] and Rugby league players.[30] A summary of existing, relevant research which has investigated the sleep behaviour in elite athletes during periods of both training and competition is found in Appendix A.

2.2.1 Sleep behaviour during training

Even though this thesis is primarily focussed on sleep-wake behaviour within a team-sport during periods of competition, it is essential to acknowledge that sleep disruption is also regularly found during training. Studies which have investigated the impact of training on sleep in elite athletes have mainly compared training days to rest days, or increased training workloads to regular training programmes. It is proposed that higher daily training volume and intensity negatively affect sleep duration and quality.[151-154] Further, studies which compared training and rest days, mostly reported significantly earlier wake-up times and reduced sleep duration on training days.[128,150,155-158] This finding is common among individual sports athletes, as early morning training times is associated with less total sleep, higher daytime sleepiness and reduced sleep quality.[150,155,158-160] With regards to sleep obtained by team sport athletes, sleep duration typically ranges between 6.7-7.7 hours in Australian Rules football[161], elite rugby players,[153,154,161] and cricket players[56] during training periods. Australian Rules football players experience more sleep disturbances (compared to rugby union players and soccer players) as a possible result of the combination of high aerobic demand and high physical contact leading to residual pain during sleep.[161]

2.2.2 Sleep behaviour during competition

Subjective reports have found that 62% of elite German[149] and 64% of elite Australian[128] athletes indicate poorer quality of sleep than usual preceding an important competition. Conversely, wrist actigraphy in collision-based team-sport athletes either found no change in pre-match sleep duration,[57] or higher sleep duration relative to baseline nights.[27,58,62,63] The contradictory findings may be because of the different methods used to collect sleep data (i.e. subjective and objective) or the growing awareness of the consequences of sleep loss, which athletes respond to by deliberately going to bed earlier. In several team sports, average pre-competition sleep duration is between 7.5 - 8 hours for rugby union players,[57,58] 6.7 - 7.9 hours for male collegiate basketball players,[65,66] and 6.9- 7.8 hours for elite footballers.[17,61]

Many team-sport competitions take place in the evening during television 'prime time' to maximise audiences and profits.[28,32] There is evidence of significant reductions in post-match total sleep time compared to baseline and pre-match sleep in Australian Rule Footballers,[62] elite soccer[17,162] and rugby players[57,163] (mainly found after late night matches). However, there is opposing evidence on the effect of competing at night on sleep, which is likely attributable to differences in age. For example, sleep duration and quality were reduced after a night match in elite adult football players[28,32,59,60]; however, no effect on sleep was found after night matches,[164] and early evening high-intensity training[165] in elite youth football players.

In the context of cricket, Twenty20 and day-night One-Day International matches are commonly played into the evening when the drive for sleep is increasing; therefore, through the examples from previous research, a cricket player's sleep could be compromised by the increased arousal (e.g. body temperature, cortisol levels) following exercise,[17,19,30,31] the biological effect of artificial floodlights on the sleep-wake cycle,[19,28,166] participation in post-match commitments,[7,30,32] as well as the earlier wake-up times caused by travel provisions (often a necessity the day after a match).[167] Further, the cumulative effect of sleep loss has the potential to negatively influence athletic performance,[6,168] preparation and recovery.[3,7,32,166] This consequence could be explicitly applicable during Test matches, as even though they are played during daytime hours, the match lasts over 3-5 consecutive days,[43,81] which increases the risk of accumulating sleep debt. Because of the discrepancies in start and end times of cricket matches, cricket players may experience different sleeping patterns depending on the format they play.

The influence of match location on team-sport athletes appears to affect variables associated with sleep quality more than that of sleep quantity. For example, the sleep duration in elite team-sports athletes on the night before home and away games were significantly more than baseline, but not between home and away games themselves.[59,63,66] However, lower sleep quality and longer sleep onset latencies have commonly occurred before away games compared to home games.[63,66,68,169] Competing away involves sleeping in different surroundings, and the tediousness of travelling itself may influence sleep.[26,170-172] A reduction in sleep quality may be explained by a concept known as the "first night effect", where an individual lacks adaptation and comfort in an unfamiliar environment.[68,173]

2.3 FACTORS CONTRIBUTING TO VARIABILITY OF SLEEP BEHAVIOUR IN ATHLETES

It is clear from section 2.2 that athletes suffer from sleep disruption, particularly during competition. Moving forward, this section engages with the main factors which affect and cause variability of sleep behaviour during this time-period.

2.3.1 Inter-individual sleep differences

There is high inter-individual variability in athletes' sleep characteristics.[11,28,150,174,175] For example, as a squad, male elite football players experienced reduced sleep quantity after late-evening league matches; however, within-squad comparisons revealed wide individual variations in the degree of resultant sleep loss experienced.[28] In this regard, sleep studies need to incorporate individual responses, in addition to group averages.[11,28] Significant sources of inter-individual variation in sleeping patterns include, but are not limited to, chronotype, age, sex, religion and race.[11,28]

Chronotype, which was first investigated by Kleitman[176], can be explained as the behavioural change in preference to do certain activities at different times of the day.[177,178] People will either be morning, evening or intermediate type.[175,177,179] An individual's chronotype is usually identified using a score obtained from one of many versions of an instrument called the Morningness-Eveningness Questionnaire.[180] The Morningness-Eveningness Questionnaire contains 19 questions aimed at determining when, during the day, the participants highest propensity to be active lies.[180] Questions are preferential (i.e. participants are asked when they would prefer to wake up or start sleeping rather than when they do) and multiple choice based, with each answer being assigned a numerical score.[181] Morning types have an advanced circadian rhythm and demonstrate clear preference in waking up and performing activities in the early morning and find it difficult to remain awake and perform well past usual bedtime.[174,175,182] In contrast, evening types are phase delayed such that they prefer going to bed later and find it difficult to wake up and perform early in the morning.[174,175,182] Differences between individual chronotype can affect how well one adjusts to jet-lag.[15,176,183] Theoretically, morning types should manage more easily with eastward travel (a phase advance), whereas evening types have an advantage during westward travel (which requires a phase delay).[177,183] Some studies exploring chronotype in individual sports athletes indicate that there is an overrepresentation of morning-types.[174,178,184] Conversely, team-sport athletes are observed to be predominantly intermediate types (73% cricket, 63% hockey, 84% soccer, 59% cycling).[184] Athletes often choose sports where training schedules align with their chronotype, as it may increase their chances of success in that sport.[147] Accordingly, athletes involved in sports which occur in the mornings are mostly morning types; similarly, athletes who participate in evening sports are more likely to be evening types.[178,184]

As one *ages*, sleep patterns undergo significant quantitative and qualitative changes.[110,185] Adolescents have sleep characteristics typical of evening chronotypes mostly attributable to pubertal hormonal phases.[186] Older adults experience circadian shifts (earlier phase peak in core body temperature, melatonin and cortisol secretion) that results in earlier bedtime and wake-up times compared to the younger population.[110,179,187,188] Ageing is associated with impairments in sleep,[189,190] longer sleep onset latencies,[185] less sleep quantity and more frequent awakenings of longer duration.[191] However, while travelling, older athletes less prone to symptoms of jet-lag,[190] likely because they are more experienced and may have competed internationally many times.[169]

Sex differences exist in sleep quality, duration, latency and prevalence of sleep disorders of the general and athletic populations.[192,193] There are higher rates of insomnia and sleep disruption in female athletes,[194] particularly before competition,[129] with reports of disturbing dreams and nervousness identified as the main reasons for sleeping problems.[128] However, one study reported lower sleep efficiency in male compared to female athletes.[13] Nonetheless, it is well established that sleep disorders such as restless legs syndrome, obstructive sleep apnoea and insomnia are more prevalent in women because of naturally occurring hormonal changes during menstruation, pregnancy and menopause.[66,192]

Some athlete's *religions* may also cause sleep challenges, for example the prayer demands during Ramadan interact with training loads and may negatively influence sleep.[195-197] Ramadan fasting reduces sleep duration by approximately 1.1 hours when compared to non-fasting.[196] Ramadan fasting has also been shown to double night awakenings, increase light sleep, reduce deep and rapid eye movement sleep compared to baseline control values within trained cyclists.[197]

There are conflicting inferences of how sleep varies according to *race.* For example, there is evidence of no significant difference regarding insomnia between races (Whites and non-Whites)[198] while more recent research has found lower total sleep duration, lower sleep efficiency and higher sleep onset latency in Black compared to White Americans.[199] However, in South Africa, White, Asian/Indian and Coloureds have short sleep durations, while longer durations are most prevalent in Black Africans.[200] The reasons behind these discrepancies are unclear but race is commonly amalgamated with socioeconomic status[201] whereby low socioeconomic status is linked with higher rates of overall sleep disturbance,[202] insomnia[203] and low sleep quality.[204] However, the degree to which both race and socioeconomic status mutually affect sleep remains uncertain.[205]

2.3.2 Travel fatigue and jet lag

International and national tournaments are an integral facet of an elite athlete's career,[206] varying from regular short-haul (< 5 hours) domestic (and international) to long-haul (> 20 hours) international travel.[59,169] Often the demands of travelling such as uncomfortable seating conditions, baggage-handling, security stresses, unanticipated schedule delays, and the combination of noisy surroundings, high altitudes and dry air, timing of meals and layovers can exacerbate travel fatigue.[59,169,171,207,208]

Jet lag is a misalignment between circadian rhythms and the external destination time which occurs after rapidly fording multiple time zones.[79,207,209] As the number of time zones crossed increases, the amount of time required for re-entrainment lengthens by approximately half a day per hour of the time difference westwards, or one day per hour of the time difference eastwards.[206,207,210] Sleep disturbances associated with travel are also attributed to the impingement of travel schedules (late and early departure times) on sleep.[17,21,169]

Short-haul flights rarely have a significant effect on sleep onset latency, sleep efficiency and total sleep time in athletes.[21,59,62,63] However, findings from long-haul flights are less conclusive. Several studies have reported a significant decrease in sleep quantity after eastward international air travel[17,190,211] and an increase in total sleep time after westward flights[21,212]; whereas others found negligible effects of northbound[169] and westward[213] long-haul air travel on sleep in athletes. These discrepancies could be associated with the direction of travel, as greater detrimental effects on sleep, subjective jet-lag, fatigue and motivation occurs after eastward travel compared to westward travel.[211] This result occurs because the body's circadian rhythm is naturally longer than the 24-hour light-dark cycle (24.2-hours on average),[214] and as such, it is easier for the body to adapt to a phase delay after westward travel than a phase advance after eastward travel.[207]

Although elite teams normally travel earlier to allow for enough days in a new time-zone for the body clock to fully adjust before competition,[166] sleep medication (e.g. benzodiazepines and Ambien) is commonly used to help improve sleep quantity, quality and accelerate chronobiological re-alignment.[215-217] These effects were reported in a double-blind, placebo-controlled study, consisting of an 8-hour phase-delay of the sleep-wake and dark-light cycles to simulate westward air travel.[215] Additionally, a significant increase in sleep duration, reduction in the number of awakenings and improved sleep quality was found in individuals who were administered 10 mg Ambien, compared to a placebo, after eastward travel across > 5 time zones.[216] Conversely, 10 mg of short-acting benzodiazepine administered immediately before bed for three days after westward travel across five time-zones did not significantly affect subjective jet lag and sleep quality compared to a placebo.[217] It could be deduced from these conflicting studies that the direction of travel (similar to the sleep discrepancies between short- and long-haul flights) may be a contributing factor defining the usefulness of sleep medication; however more empirical research is needed to support this opinion. In addition, chronic sleep medication could have adverse health consequences such as respiratory disease exacerbation, infections, dementia, pancreatitis, cancer and have negative residual effects on sleep timing and alertness; therefore, the appropriate timing and dose of administration is crucial.[207,217]

2.3.3 Anxiety and stress

Anxiety is a primary contributor to sleep problems in athletes, especially before competition,[128,148,218,219] mainly because of "thoughts about the competition".[128] However, there are several other sources of stress such as coping with injury, contesting for team selection, public scrutiny and managing training schedules along with other life stressors unrelated to a sport.[77,96] There are nine models of insomnia,[220] one of which is the cognitive model of insomnia,[221] which could be used to explain the bidirectional relationship between sleep and anxiety. Even though this model was initially developed to describe a cognitive mechanism related to insomnia, it could be equally applicable to elite athletes experiencing anxiety during the build-up to a competition or before team selection. The model assumes the plausibility that a reduction of, or disturbance to, sleep could cause anxiety itself, whereas elevated levels of anxiety could interfere with sleeping patterns.[221,222]

The differences in sleep behaviour depending on the type of sport played can be explained by varying levels of anxiety.[11,159] For example, individual sports athletes have been found to obtain significantly less sleep,[149,159,223] and have poorer sleep efficiency than team sports athletes,[159] possibly because individual athletes experience greater pressure as they are solely accountable for the result of the event.[149] However, this discrepancy is not always found between sport modalities.[78,128] Nonetheless, in cricket, the sleeping patterns of each player should be individually investigated as, even though cricket is considered a team sport, it is also an individual sport in that each player role (i.e. batters, bowlers, wicket-keepers and fielders) carry out independent actions and incur different psychophysiological demands.[45,55,82]

2.3.4 Light

Light alters an individual's circadian rhythm which directly affects sleep,[123,224-226]; however, the effects are dependent on the type (natural and artificial), timing and intensity of light exposure. For example, research using subjective methodology have found reduced sleep quality when exposed to low light exposure during the day.[227] Conversely, an objective analysis found an increase in night-time awakenings following late light exposure.[228] Unfortunately, objective results discerning the association of everyday light exposure with subsequent sleep scheduling and duration is lacking.[228]

A light-emitting diode is a source of short-wave artificial light in which can suppress melatonin production.[225] This effect could occur post-day-night One-Day International and Twenty20 matches because they play into the evening under floodlights.[19,28,166] However, the effect of light-emitting diode technology use before bedtime remains a controversial topic. Some suggest that technology use before bedtime delays sleep onset,[229] and can be detrimental to overall sleep in adolescents[226] and adults.[230] Further, restricting short wavelength light in the evening has resulted in shorter subjective sleep onset latency, improved subjective sleep quality and higher subjective alertness in athletes.[18] Opposingly, some studies have shown no effect of using[148] or removing[231,232] electronic devices in the evening on sleep in athletes. However, artificial light from technology is not the only factor associated with sleep problems. Receiving messages or calls may cause awakenings,[233] and disrupt relaxation,[20] with athletes using social media before bed reporting almost one hour less sleep per night.[19,28]

2.3.5 Heat and humidity

Sleep loss affects the ability to use energy to maintain normal body temperature,[234] a consequence applicable to cricket players, who are required to compete in hot and humid environments.[235] Performing in these conditions could accelerate sweat rate and increase the risk of dehydration,[236,237] which has been shown to impair fast bowing accuracy.[236] On the other hand, an increase in body core temperature, through both exercise itself and the physical transfer of heat from the environment,[238] reduces sleep quantity and quality.[19]

2.3.6 Substance use (alcohol, nicotine and caffeine)

Alcohol is the most consumed drug among the athletic community[23,239] and usually associated with the celebratory activities after a match.[24,25] With that commonality, it is essential to understand the effects that alcohol has on sleep in this population. Alcohol consumption before bedtime initially acts as a sedative by increasing adenosine (a sleep-promoting hormone) production, which shortens sleep onset latency.[240,241] However, there is an increase in non-rapid eye movement sleep and reduction in rapid eye movement sleep (which is essential for restoration) as the alcohol metabolises, resulting in shallower sleep and multiple awakenings.[240,241] Ultimately, alcohol may be useful in sleep induction, but it impairs sleep during the second half of the night and can lead to a reduction in overall sleep time and quality.[240,241]

Sleep architecture, maintenance and quality is affected by cigarette smoking,[242,243] either by the release of neurotransmitters which regulate the sleep-wake cycle[244] stimulated by nicotine, or through acute withdrawal symptoms which is often experienced during sleep by habitual smokers.[245]

Caffeine is also widely consumed by athletes during match play as an ergogenic aid.[27,57,246] Although previous findings suggest that caffeine reduces daytime sleepiness[26,247] and temporarily alleviate fatigue,[207,247] there are objective and subjective reports of adverse side effects on sleep patterns, including a reduction in total sleep times, increased sleep onset latency and earlier wake-up times in athletes.[26,27,248] Caffeine consumption reduces the concentration of 6-sulphoxymelatonin secretion (the main metabolite of melatonin) which has been directly linked with reduced sleep quantity and quality.[249] Further, a dose-response relationship is seen with increasing units of caffeine administered six hours before bedtime associated with significant sleep disturbance resulting in lower sleep quality and total sleep.[248,250] Therefore, late-afternoon ingestion of caffeine may interfere with sleep induction.[26,248,249]

2.4 MEASURING SLEEP IN ATHLETES

There are several ways to measure sleep, namely: polysomnography, wrist actigraphy, sleep diaries and retrospective self-report questionnaires.[251,252] Polysomnography provides information on sleep staging and is considered the "gold standard" for assessing sleep quality and quantity.[127,253] Unfortunately, polysomnography is labour intensive, expensive, time-consuming and is a laboratory-specific measure.[127,251] Further, a high degree of expertise is required to operate it and analyse the data collected. For these reasons, this method is often used to assess clinical disorders related to sleep[127] and limits its use in field-based environments and studies involving elite sporting populations.[14,252,254]

Actigraphy is an alternative method of obtaining objective sleep information in ecologically valid field settings and offers an opportunity to monitor athletes without disturbing sleep patterns.[14,251,252,254] Sleep disorder research, in both general[199] and athletic populations,[13,66,148,155,156,159,252,254] commonly uses actigraphy because it is non-invasive and comparable to polysomnography in terms of validity and reliability (91% - 93%).[255] Typical parameters such as total sleep time, sleep efficiency, sleep onset latency, and wake after sleep onset can be deduced through these activity monitors based on the principle of multidirectional accelerometry.[256] Actigraphy is often used in a clinical setting to diagnose and treat patients with sleep disorders such as insomnia.[257] However, in an athletic environment, issues related to player comfort and competition regulations need to be considered.[252]

Subjective sleep assessment tools are regarded as being the cheapest and most practical way to provide useful information about an individual's habits and perception of sleep in large or otherwise 'challenging' population samples.[258] Athlete sleep quantification research often use sleep diaries,[155,156,159,259,260] specifically the standardised Consensus Sleep Diary[258] and Pittsburgh Sleep diary.[261] Most sleep diaries are completed by hand and include items based on sleep/wake duration, subjective sleep quality ratings and experiences of the previous night.[258] There have been advancements to this method, whereby sleep diaries are customised and used in a mobile setting (e.g. Sleep Diary Pro, Healthy Sleep Diary, Sleep Diary Lite).[262] The two methods (paper and electronic sleep diaries) are found to be similar regarding their analytical power.[263]

There are several discrepancies detected when comparing subjective parameters with objective measures as individuals tend to perceive longer sleep onset latency and recall fewer night-time awakenings.[256,264] Further, there are conflicting results regarding the estimation of total sleep time through reports of shorter,[265] longer[199] and congruent[266] total sleep time from sleep diaries compared to actigraphy by clinical populations or non-athletic contexts. However, generalities to athletic populations are unsuitable because of the disparities in sleep behaviour between athletes and non-athletes.[13,128,148,159] There are inconsistencies regarding the subjective rating of sleep duration compared to actigraphy in athletes, both during an intervention-free baseline assessment and sleep extension programmes.[65] In contrast, a strong agreement between self-perceived and actigraphy-derived sleep duration in professional rugby league athletes has been found, while the relationship between self-perceived sleep quality and sleep efficiency estimated were limited.[260] This agrees with reports, where athletes subjectively perceived good sleep quality, however, objective measures indicated otherwise.[62,145,149,267,268] As such, sleep diaries should, where possible, be kept by participants to inform actigraphy analysis.[128,155,159,255]

Most retrospective self-reported sleep behaviour assessments such as the Pittsburgh Sleep Quality Index[269] and the Sleep Hygiene Index[270] are quite broad and are inadequate for subjective sleep screening of an elite athlete population.[271,272] Athletes have different sleep requirements than the general population,[271,272] which has led to the recent development of the Athlete Sleep Screening Questionnaire[271] and Athlete Sleep Behaviour Questionnaire.[272] Even though initial reports of the Athlete Sleep Screening Questionnaire are suggested to be acceptable in screening athletes, the Athlete Sleep Behaviour Questionnaire is seen as more of a practical tool for coaches and practitioners to acquire information on maladaptive sleep hygiene behaviours rather than sleep disorders; moreover, allowing for individualised feedback and behavioural modifications.[14,56,272]

2.5 CRICKET PERFORMANCE AND SLEEP LOSS

This section aims to contextualise the role that sleep loss would play in elite cricket performance. As discussed at the beginning of the chapter, cricket players must possess a blend of tremendous physical skill and mental ability to enable them to fulfil specific roles in the team.[45,82,86,87] No study has specifically investigated sleep behaviours in elite cricket during competition; therefore, the effect of sleep loss on cricket performance can only be hypothesised using evidence from laboratory and field-based studies in other sports. However, caution must be taken as experimental results found in laboratory-based studies do not account for the external factors which exist in the 'real world'.[11] Further, field-based results are only applicable to the specific group of athletes which were investigated. This issue highlights the importance of assessing the effect of sleep on match performance in elite cricket players, employing a 'field-based design', while using performance measures which are applicable to cricket.

2.5.1 Measuring cricket performance

The game result (win or loss) has been used to determine the success of competition in team-sports.[63,120] However, measuring individual player performance within a team sport is more complex, especially in cricket, where tactical approaches and responsibilities differ between match formats and player positions, respectively.[37,43,88] Moreover, external factors (e.g. weather, pitch type and opposition strength) can considerably change the nature of a match.[273] Despite these complexities, specific performance measures have been developed in cricket dependent on player role. For example, batting ability is typically measured using a batting average (the sum of all scores divided by the number of innings the batter was out), batting consistency (standard deviation from average) and strike rate (average number of runs scored per hundred balls faced).[274,275] Similarly, a bowler's average (runs conceded per wicket), economy rate (total number of runs conceded by the bowler divided by the number of overs bowled) and strike rate (total number of balls bowled divided by the number of wickets taken) are the criteria used to determine bowling performance.[80,276] In the context for each match format, batting strike rate and bowling economy are identified as primary measures of performance during limited-overs formats, while batting and bowling averages are considered important in the longer format of the cricket (i.e. Test matches).[277] For wicketkeeping, a measure combining the dismissal rate (catches and stumpings divided by matches played) and batting performance has been proposed.[278] There is no standard measure for quantifying fielding performance, however, the number of catches and run-outs are accessible fielding measures on match scorecards.[279]

2.5.2 Relationship between sleep and performance

Although sleep deprivation studies reveal important performance implications, the findings are not always relevant to an elite athletic population, given it would be unlikely for an athlete to lose sleep in this manner.[6,218,280] Consequently, to minimise potential confusion, this section primarily considers former sleep restriction research (involving later sleep onset or earlier wake times which disrupt the normal sleep-wake cycle).[6] A summary of several studies which investigated the effects of sleep restriction on various performance outcomes is found in Appendix B; however, a detailed review of the studies effects is beyond the scope of this thesis.

2.5.2.1 Sports performance and sleep loss: Field-based studies

There are conflicting findings between the few existing published data which explored potential relationships between sleep and match play. For example, results from elite Australian Rules football[63] and elite female basketball[66] players found no significant association between sleep patterns and average match performance. Although these studies presented small correlations at a team level, substantial variability in the strength of correlations between specific players demonstrated that the relationship between sleep and performance is highly individualised.[63,66] Similarly, sleep duration and quality during competition did not influence overall performance ranking in cyclists.[223] However, several investigations have demonstrated that competitive success is related to optimal sleep behaviours.[31,78,79] In a study of netball athletes, the higher ranked teams in the tournament had significantly greater sleep quantity and subjective ratings of sleep quality compared with the lesser ranked teams.[31] Further, a strong inverse correlation was identified between sleep duration during the competition and final tournament position.[31] Similarly, poor sleep quality was an independent predictor of lost competition in elite male and female Brazilian athletes immediately before a national or international competition.[78]

2.5.2.2 Exercise performance and sleep loss: Laboratory-based studies

The effects of sleep loss are greater for short-duration anaerobic exercises and single exercise bouts (e.g. sprints, peak power output)[281-284] than for sustained efforts (endurance > 30 minutes) and repeated exercise bouts.[6,285-287] Further, there are reductions in pacing strategies and intermittent-sprint performance after sleep loss,[136] with improvements in these factors exhibited after sleep extension interventions.[65] These adverse effects are relatable to cricket performance which involves short bursts of high-intensity effort that requires a contribution from the anaerobic energy system, whether it be during batting,[41] bowling[39] or fielding.[45] Furthermore, effective pacing strategies are particularity necessary for batters to conserve energy while sprinting between wickets.[288] Upper body strength and peak power are essential during the overthrow bowling[289] and bat-ball contact during batting.[290] Reactive leg power is required from wicket-keepers who hold a crouch position over prolonged periods and aid in dismissals by catches quickly coming off the bat.[95]

2.5.2.3 *Physiological responses to sleep loss*

Unfortunately, the effects of sleep restriction on physiological responses are unclear. Some studies have found a decrease in heart rate, minute ventilation and oxygen uptake (VO_2) peak during submaximal and maximal exercise after restricted sleep.[287,291] However, others did not find any significant effect in those same responses,[292-294] as well lung function and power.[285,286] The differences found across studies could be attributed to the exercise mode and protocol each study administered.[280] The cited research is out-dated and newer research is required to assess the impact of sleep loss on physiological responses to exercise in elite athletes.

2.5.2.4 *Cognitive and perceptual responses to sleep loss*

The detrimental effect of sleep loss on most aspects of cognitive function is undisputable,[295-297] with a dose-response relationship previously identified whereby a shorter sleep durations were associated with impaired cognition.[133,296,297] The fundamental mental requirements in cricket, irrespective of the position played, are quick reaction times, accuracy, executive function,[87] positive mood states[298,299] and extraordinary ability to focus for sustained periods.[45,86] The effects of sleep restriction found on cognitive and perceptual performance include an increase in perceived exertion,[286,292,300,301] slower reaction time,[302-305] a decline in working memory,[306] earlier fatigue onset,[286,306] reduced attention,[306-309] poorer accuracy,[296,308,310,311] and lapses in speed during a psychomotor vigilance task.[296,312,313] Additionally, a reduction in mood and vigour occurs after restricted sleep.[300,302,306,312] These adverse effects after sleep loss augment the need for cricketers, who have a high reliance on these cognitive components, as well as critical decision making,[93] to obtain optimal sleep.

2.6 SLEEP LOSS AND INJURY RISK

There is considerable evidence supporting the recuperative nature of sleep, as disturbances to either the quality or duration of sleep can interfere with psychological and physical recovery after exercise.[2,313,314] This recuperation would seem particularly crucial for field-based team sports,[7] such as cricket, which is typically exposed to prolonged bouts of intermittent-sprint activity[39,41,288] and attentional demands[45,86] during competition. Consequently, the overload of physical and cognitive pressure will increase the need for recovery resulting in a greater overall requirement for sleep.[159]

Sleep's role in hormonal regulation is mainly responsible for physiological recovery.[314] For example, melatonin production during sleep modulates immune functioning and activates pro-inflammatory enzymes, which neutralise oxidative radicals and reduces tissue inflammation.[315] Similarly, growth hormone secretion is responsible for repairing muscle and building bone tissue.[77,131] Sleep loss, however, increases levels of cortisol (which breaks down muscle tissue) and reduces levels of testosterone (which builds up muscle tissue) consequently compromising muscle growth, injury repair and tissue recovery.[314] Sleep loss also harms metabolic functioning; such as glucose metabolism and removal.[136,316] Glucose metabolism serves as a vital component in fuelling endurance activities, and if glycogen stores are low, it will deplete more rapidly during exercise and cause early fatigue onset.[136] On the other hand, excessive glucose causes chronic inflammation, which could increase the likelihood of injury.[316,317]

There is no significant effect of sleep quantity and quality on injury incidence in elite Australian footballers tracked across one season.[61] Further, although adolescent athletes who obtain more than 8 hours of sleep per night were 68% less likely to injure themselves,[318] a slight inverted-U relationship was apparent, whereby those who obtained 5 hours of sleep were also associated with a decreased risk of injury. On the contrary, sleep loss over consecutive days has been linked to increased incidence of an upper respiratory tract infection among elite athletes,[268,319] which concurs with the inverse relationship between sleep quantity and incidence of illness in nationally competitive Australian football athletes[320] and adolescent cricket players.[54] Despite inconsistencies, there is more supporting evidence to suggest that sleep loss can decrease career longevity, as getting adequate sleep at night may act as a buffer against injuries and illness.[318,321]

2.7 SLEEP IMPROVING STRATEGIES

Sleep hygiene is described as practising behaviours that promote continuous and adequate sleep, centralised around several principles: proper exercise timing, healthy diet, stress management, noise reduction, regular sleep schedules and avoidance of caffeine and alcohol.[9,127] Findings from sleep extension studies support the potential for athletes to enhance sporting performance through sleep optimisation. For example, increasing total sleep time by

~ 2 hours per night over several weeks was shown to improve shooting accuracy, reaction time and psychological well-being in basketball players during training.[65]

There have been mixed reports regarding the effectiveness of daytime napping to alleviate the consequences of inadequate sleep. Several studies favour napping as a useful recovery tool and strategy to extend sleep[11,154,159,322]; whereas, South African team athletes from field hockey, netball, rugby union and soccer did not regard napping as an essential recovery modality.[323] There were no differences in nap frequency during training and rest days in elite swimmers[156]; conversely, more elite rowers napped on training days than rest days.[324] Nonetheless, the timing and duration of daytime napping is deemed essential, as such, naps should be kept relatively brief (~30 minutes) to prevent sleep inertia and avoided late in the day (preferably between 14:00-16:00) to prevent any disruption of night-time sleep.[3,322]

The first study to provide information on the strategies implemented by athletes to sleep better before competitions found that 56.6% had no specific strategy, 34% watched TV, 16.6% read something before bed, 9.2% used relaxation methods and 1.3% claimed to take sleeping pills.[149] Additionally, a higher percentage of team-sports athletes reported having no strategy to obtain better sleep the night before competition compared with individual athletes.[128] There is a positive relationship with sleep indices and the use of sleep hygiene intervention and education sessions seen in several sports.[9,56,325,326] A recent study in elite Australian cricket players indicated that on average, before the sleep hygiene education intervention, they obtained 7 hours 40 minutes total sleep time, 80% sleep efficiency, 1 hour two minutes sleep onset latency and 34 minutes wake after sleep onset durations during three weeks of pre-season training.[56] Although this cohort obtained the recommended > 7 hours of sleep duration for healthy adults, the sleep onset latency and sleep efficiency scores exceeded population norms of ~ 11 minutes[327] and ~ 90%,[108,328,329] respectively. However, after specifically providing corrective information on consistent sleep routines, optimal sleeping environments (quiet, cool and dark), avoiding substance and light-emitting technology use before bed and relaxation strategies, large to very large improvements in sleep onset latency and sleep efficiency were achieved.[56] Further, a decrease in the Athlete Sleep Behaviour Questionnaire global score from 47 ± 5 to 44 ± 7 was associated with a small improvement in sleep behaviour post-intervention.[56] These findings emphasise that both individual and team sports athletes do not have appropriate methods for managing their sleep and would benefit from sleep hygiene education.[128,149,271] However, sport-specific sleep monitoring must first be conducted to identify circumstantial problem areas to appropriately implement sleep hygiene interventions.[271]

2.8 CHALLENGES IN SPORT MONITORING PRACTICES

Unfortunately, substantial challenges exist for sport science practitioners in implementing monitoring strategies within an elite team sport environment.[330-332] For example, despite the convincing evidence linking effective monitoring to enhancing aspects of team performance, coaches and management staff often perceive these strategies with uncertainty.[330] This scepticism may be primarily attributed to the inability of sport scientists to effectively communicate the importance of their findings so that it is easily understandable by coaches,[333-335] a particular issue reported by South African coaches.[331,332] Furthermore, player compliance can often be unreliable because of the inconvenience involved, especially if several other monitoring practises are already in progress.[330] Additionally, some monitoring plans require professional staffing and added technological costs, which are not always practical in elite team sports.[330,335]

2.9 THE SOUTH AFRICAN CONTEXT

This section will engage with risk factors unique to the South African population through acknowledgement of the country's socioeconomic status, anxiety levels and oppressive history which consequently position South African cricket players as a necessary cohort to monitor sleep.

Previous researchers have reported poor sleeping behaviours in South African athletes,[5] youths[336] and elders.[337] For example, evidence from a survey-based study of 890 elite South African athletes revealed that three-quarters of athletes reported an average total sleep time of between 6-8 hours per night and 11% reported sleeping less than six hours during weekend nights.[5] Further, based on findings using the Epworth Sleepiness Scale, 44% of South African students had a high propensity for daytime sleepiness, which was associated with not getting enough sleep, consuming caffeine, daytime napping and having minimal energy.[336] A large multi-country study from Asia and Africa focusing on adults (≥ 50 years old) reported the prevalence of extreme sleep problems to be as high as 25%.[337] These researchers suggested that there is a strong link between sleep problems and poorer general well-being and quality of life in low-income countries (such as South Africa).[337] Accordingly, the link could be attributed to socioeconomic status and various causes of anxiety which, as previously identified in section 2.3.3, are significant contributors of sleep disturbances. This relationship is plausible in this context, as South Africa was ranked 9th out of all countries participating in the World Mental Health Survey Initiative, with high occurrences of anxiety disorders.[338] Further, South Africa has been ranked the 16th most dangerous country on the Safety, and Security list in the World Economic Forum's Travel and Tourism Competitiveness report 2016/2017,[339] and ranked the world's 9th most violent country according to a 2016 report by the World Health Organization.[340] Despite no definitive links between anxiety and the country's societal turbulence, the general population does experience high levels of anxiety.

Cricket arrived in South Africa during the 19th century and has a history of racial compartmentalisation.[71,341] During the apartheid era, South Africa's failure to separate sport from politics caused 21 years of segregation from international competition.[342] However, since South Africa's readmission to compete internationally in 1992, cricket has grown into one of the country's most beloved and popular sports watched by all race and class groups.[343] Further, South Africa has been a preferred destination for global cricket events such as the 2003 International Cricket Council Cricket World Cup, 2007 World Twenty20 Championships and 2009 International Cricket Council Champions trophy.[344] Therefore, the economy has reaped the benefits of substantial investment through the success of hosting these events, building touristic infrastructure and growing its reputation as an international holiday destination.[344] Cricket South Africa (in the post-Apartheid setting) positioned itself as a driver which would unite players regardless of age, gender, ethnicity, religion or socioeconomic status using a “bottom-up” transformation model.[69,70] As such, Africanisation (the increased inclusion of indigenous Black Africans and other racial minorities) in cricket has become a key focus of transformation, which involves several development initiatives including a variety of quotas to be met.[69-71,345] However, despite these interventions, Black South African cricket players encounter greater emotional instability due to socioeconomic barriers, toxic team-environments, the added pressure to be identified professionally and once identified, retain their position in the team.[71] Further research is required to explore the effects of discrimination on sleep behaviour, however, there is existing evidence to suggest that psychosocial anxiety, partially mediated by perceived racial discrimination,[74] could place racial minorities at greater risk of poorer sleep behaviour compared to their White counterparts.[73]

2.10 SUMMARY

Existing literature has highlighted that adequate sleep quantity and quality is necessary to optimise health and performance by reducing the risk of both injury and illness, increasing career longevity[318,321] and ensuring optimal physical and mental state in elite athletes.[7,10,12] Factors such as frequent travel,[17,190,211] sleeping in foreign environments,[68,173] increase in arousal after exercise,[19,143] psychophysiological stress,[7,9,128] muscle pain and fatigue,[127] disruption from light, heat and noise,[148,323] and substance use (alcohol,[25] nicotine[242] and caffeine[27]) have been held accountable for compromised sleep quantity and quality.

Across the handful of publications examining sleep in various elite team-sports, athletes average between 6-8 hours of sleep per night,[17,30,61,66,162,163] with poorer sleep behaviour specifically found after travel,[17,166,171,190,211] and night matches.[28,59,60,162] Previous field- and laboratory-based studies provide provisional grounds to support the assumption that sleep is directly related to sport performance, specifically cognitive adaptation, memory recall, attention, aerobic fitness and executive functioning.[6,8,11,76] As elite cricket players are required to frequently travel to compete (both nationally and internationally), play long tiresome matches (in hot environments,[235] which often carry into the evening[55,81]) and are exposed to great social, physical[44,47] and cognitive pressures,[55,82,86,90] place them at a high-risk of performance decrements and injury though sleep disruptions. It is possible that because of the complexity of studying sleep,[2] limited access to elite athletes to participate in sleep-related research,[7,11] and scepticism from coaches,[330] there is no supporting evidence underpinning the sleep behaviours and effects of sleep loss in elite cricket during competition.

Despite Cricket South Africa's attempts to implement strict policies to maintain ethnic-, gender-, and religion- based diversity within all cricket teams, minority groups are still exposed to potential structural barriers as by-products of the country's oppressive history[71] which may contribute to adverse changes in sleep behaviour.[75] Further, with professional cricket increasing profitability and significant monetary contribution to the South African economy,[344] the concern of how sleep impacts cricket performance carries considerable scientific, as well as financial importance. These reasons further warrant the need for appropriate sleep monitoring practices in elite South African cricket teams.

CHAPTER III

3 RESEARCH METHODS

This chapter outlines the ethical considerations, recruitment process, participant characteristics, research design, data-collecting and processing practices and statistical analysis.

3.1 RESEARCH DESIGN

The study was designed as a longitudinal field-based investigation where sleep behaviours and match performance measures of elite South African male cricket players were monitored during competitive cricket tours in preparation for the 2019 Cricket World Cup. There were three conditions characterized based on the venue (home and away) and match format series (One-Day International, Twenty20 and Test):

- **Condition A:** Home tour against Zimbabwe (27 September 2018 - 17 October 2018). The tour consisted of three completed One-Day International matches and two completed Twenty20 matches.
- **Condition B:** Away tour against Australia (24 October 2018 - 16 November 2018). The tour consisted of three completed One-Day International matches and one completed Twenty20 match.
- **Condition C:** Home tour against Sri Lanka (10 February 2019 - 22 February 2019). The Test series consisted of two completed Test matches.

The division of conditions allowed for comparisons in sleep behaviour between match venues and formats. Player demographics (age (years), weight (kg), height (m), elite experience (years) and race), travel information (mode of transport, time zones crossed, travel direction and duration) and match information (start and end times) were provided by the strength and conditioning coach and recorded by the researcher throughout the study. Unfortunately, the inclusion of religion was not approved because of the sensitive nature of this variable. Further, travel information regarding departure and arrival times were not provided.

Table 2 displays a summary of the travel information for condition A and condition B. Condition A travel periods consisted of a combination of six short-haul domestic economy class flights and bus trips. During condition B, participants arrived in Australia ten days before the first match. The long-haul transmeridian flight from South Africa to Australia (23 October) was excluded from this study; therefore, travel periods during condition B only consisted of five short-haul transmeridian economy class flights (four eastwards, one westward). No travel information was necessary for condition C.

Table 2. Travel information for condition A (home) and condition B (away).

Travel dates	From	To	Travel mode	Total travel time	Time zones	Travel direction
Condition A						
27 September	Johannesburg	Kimberly	Short-haul flight	±1h 10 min	0	South West
1 October	Kimberly	Bloemfontein	Bus	±1h 50 min	0	East
4 October	Bloemfontein	Paarl	Short-haul flight; Bus	±2h 25 min	0	South West
7 October	Paarl	East London	Bus; Short-haul flight	±2h 20 min	0	East
10 October	East London	Potchefstroom	Short-haul flight; Bus	±3h 10 min	0	North
13 October	Potchefstroom	Johannesburg	Bus	±1h 40 min	0	North East
Condition B						
*23 October	Johannesburg	Perth	Long-haul flight	±19 hours (layover in Singapore)	6	East
29 October	Perth	Canberra	Short-haul flight	±3h 50 min	3	East
31 October	Canberra	Perth	Short-haul flight	±3h 50 min (layover in Melbourne)	3	West
5 November	Perth	Adelaide	Short-haul flight	±2h 50 min	2.5	East
10 November	Adelaide	Hobart	Short-haul flight	±1h 50 min	0.5	East
12 November	Hobart	Brisbane	Short-haul flight	±2h 40min	1	East

*Sleep data from this flight was not recorded.

3.2 ETHICAL CONSIDERATIONS

The study was approved by the Rhodes University Ethical Standards Committee and the Department of Human Kinetics and Ergonomics Ethics Committee (reference number HKE-2018-06; Appendix C). During the informed consent process, an information letter was provided which explained the study's purpose, protocol and affirmed that all data will be collected for research purposes which would be kept strictly confidential with anonymity being ensured (Appendix D). Participants, coaches and management support staff were made aware that they could withdraw from the study at any time without prejudice. Permission to test the players was obtained from Cricket South Africa and all players gave their written, informed consent prior to participation.

3.3 RECRUITMENT AND PARTICIPANTS

Thirty elite South African male cricket players were purposively recruited. Participants were classified as elite cricket players, as they were contracted to the National South African cricket squad during the 2018 and 2019 seasons. Males were used as a sample of convenience because of the accessibility and limited number of scheduled elite female cricket matches during the intended data collection period.

The additional inclusion criteria were as follows:

- Players over the age of 18 years old.
- Players who were healthy during the time of data collection.
- Players who were free of any sleep disorders (insomnia, sleep apnoea, restless leg syndrome).
- Non-smokers

3.4 BEHAVIOURAL QUESTIONNAIRES

Behavioural questionnaires were administered in both hard-copy and was available online depending on player access during each condition.

3.4.1 Morningness-Eveningness Questionnaire

The Morningness-Eveningness Questionnaire[180] determine chronotype (link: https://forms.gle/trXA3QjzSbyYrRfe9). This questionnaire has been validated and used previously in sport-related sleep research.[178,184] The questionnaire consists of 19 multiple choice questions with answers given points ranging from 0-4 to 0-6. Each player was given a score between 16 and 86 which determined their chronotype based on distinct thresholds: ≤30 = definite evening, 31-41 = moderate evening, 42-58 = intermediate, 59-69 = moderate morning and ≥70 = definite evening.[180]

3.4.2 The Athlete Sleep Behaviour Questionnaire

The Athlete Sleep Behaviour Questionnaire[272] consists of 18 questions about sleeping behaviour and habits (link: https://forms.gle/fhaTSVmhg2GJSxci7). It is a practical way to identify causes of sleep loss and areas where improvements in sleep behaviour could be made. Further, it is a reliable tool validated by Driller et al.[272] and used previously in similar research.[56,163]The questionnaire asked players how frequently they engage in specific behaviours with weightings for each response (1 = never, 2 = rarely, 3 = sometimes, 4 = frequently, 5 = always), which was then added together to provide a global score. The current recommended global score cut-offs were used to characterise sleep behaviour: ≤ 36 = good; 37-41 = average and ≥ 42 = poor.[272] Questions which obtained an average score of > 3 were identified as focus improvement areas.[56]

3.5 ASSESSMENT OF SLEEP PATTERNS

3.5.1 Subjective sleep measures - Core Consensus Sleep Diary

An altered version of the Core Consensus Sleep Diary (Appendix E), including instructions as described by Carney et al.[258], was used to obtain subjective sleep data. It has been validated and used previously in clinical research[346] and in student-athletes.[347] The questions, "After your final awakening, how long did you spend in bed trying to sleep?", "Did you wake up earlier than you planned?", "If yes, how much earlier?" and "In total, how long did you sleep?" were deemed unnecessary and excluded from the original Core Consensus Sleep Diary. The decision to remove these questions was made between the researcher and the strength and conditioning coach of the team to reduce the time and effort required to complete the sleep diary in order to improve compliance.

The responses from the sleep diary questions (Appendix E) were used to determine the following sleep-related variables: bedtime (question 1; hh:mm), sleep onset time (question 2; hh:mm), sleep onset latency (question 3; hh:mm), wake after sleep onset (question 4; hh:mm), wake-up time (question 5; hh:mm AM), get-up time (question 6; hh:mm AM), time in bed (question 6 minus question 5; hh:mm), total sleep time (hh:mm), sleep efficiency (%), subjective sleep quality (question 7; 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good), morning freshness score (question 8; 1 = not at all rested; 2 = slightly rested; 3 = somewhat rested; 4 = well-rested; 5 = very well rested) and nap duration (question 9; hh:mm). Total sleep time was calculated as: [(wake-up time – sleep onset time) - (sleep onset latency + wake after sleep onset)]. Sleep efficiency (%) was calculated as the ratio between total sleep time and time in bed. Information about substance use (alcohol and caffeine quantity and time consumed; questions 10 and 11), sleep medication (type and dose (mg); question 12), sleeping environment, injuries and illnesses (question 13) were also collected from the sleep diary.

3.6 ASSESSMENT OF PERFORMANCE

Based on previous opinions,[277] batting strike rate and bowling economy were selected as performance measures in One-Day International and Twenty20 match formats. Alternatively, batting and bowling average were used for Test matches.[277] All individual player performance data were manually collected from each scorecard via the Entertainment and Sports Programming Network Cricinfo website[348] after every match. Batting strike rate and bowling economy were readily available on each match scorecard. However, batting average (Eq. 1) and bowling average (Eq. 2) per Test match was calculated as follows:

$$\text{Batting average} = \frac{\text{Total runs made}}{(\text{Number of times out})} \qquad \text{(Eq. 1)}$$

$$\text{Bowling average} = \frac{\text{Total runs conceeded}}{\text{Total wickets taken}} \qquad \text{(Eq. 2)}$$

Higher batting strike rates and batting averages were indicative of better batting performance, whereas lower bowling economy and bowling averages indicated better bowling performance.

3.7 PROCEDURE

A proposal letter and consent form explaining the study was sent out and reviewed by the national team's head coach, physiotherapist, doctor and strength and conditioning coach. This letter included the study's protocol, and the risks and benefits of participation (Appendix D). Once gatekeeper consent was received, a verbal explanation of the study, as well as information letters and consent forms, were given to all players. All consenting players completed the

Morningness-Eveningness Questionnaire[180] and Athlete Sleep Behaviour Questionnaire[272] on one occasion to determine chronotype and identify sleep behaviours. Before the start of each condition, the players were provided a sleep diary to complete every morning upon waking. After each condition, the players returned the sleep diary hard copies. All responses were recorded onto Microsoft Excel spreadsheets by the researcher.

3.8 DATA PRE-PROCESSING AND PREPARATION

Sleep data for the One-Day International and Twenty20 series collected during condition A (home) and condition B (away) were characterized into the specific sleep time-periods described below:

- Post-travel: The night after a day of short-haul/domestic travel (see Table 2 above). This time-period was also associated with the first night spent at a new venue.
- Pre-match: the night preceding a match day.
- Post-match: the night of the match played.

The data collected during the first seven days after the long-haul transmeridian flight from South Africa to Australia (condition B) was characterized into nights one to seven and included the first short-haul transmeridian flight from Perth to Canberra (refer to Table 2 above). This was the only period of recorded sleep medication use; therefore, players were divided into two groups determined from the results obtained by Question 11 (“Sleep medication”) of the altered Core Consensus Sleep Diary:

- Sleep medication group: players who reported taking sleep medication during this week.
- Non-sleep medication group: players who reported not taking sleep medication during this week.

Data collected for the Test series during condition C was characterized into the specific sleep time-periods described below:

- Pre-match: the night before the first day of the Test match.
- Day one: the night of the first day of the Test match.
- Day two: the night of the second day of the Test match.
- Post-match: the night of the last (third) day of the Test match.

3.9 STATISTICAL HYPOTHESES AND ANALYSES

3.9.1 Statistical hypotheses

3.9.1.1 Statistical hypotheses 1

Null hypothesis 1a: Sleep variables are equal for all time-periods.

$$H_0: \mu_i = \mu_{ii} = \mu_{iii}$$

$$H_a: \mu_i \neq \mu_{ii} \neq \mu_{iii}$$

Where: *i* = post-travel; *ii* = pre-match, *iii* = post-match

Null hypothesis 1b: Sleep variables are equal for both venues.

$$H_0: H\mu_{i,ii,iii} = A\mu_{i,ii,iii}$$

$$H_a: H\mu_{i,ii,iii} \neq A\mu_{i,ii,iii}$$

Where: *H* = condition A (home); *A* = condition B (away)

i = post-travel; *ii* = pre-match, *iii* = post-match

Null hypothesis 1c: Sleep variables are equal for both limited overs formats (One-Day International match and Twenty20 match).

$$H_0: O\mu_{i,ii} = T\mu_{i,ii}$$

$$H_a: O\mu_{i,ii} \neq T\mu_{i,ii}$$

Where: *O* = One-Day International match; *T* = Twenty20 match

i = pre-match, *ii* = post-match

Null hypothesis 1d: Sleep variables are equal across all time-periods of the multi-day format (Test match).

$$H_0: M\mu_1 = M\mu_2 = M\mu_3 = M\mu_4$$

$$H_a: M\mu_1 \neq M\mu_2 \neq M\mu_3 \neq M\mu_4$$

Where: *M* = Test match

1 = pre-match; 2 = day one; 3 = day two; 4 = post-match

Null hypothesis 1e: Sleep variables are equal for all player roles.

$$H_0: B\mu_{i,ii} = T\mu_{i,ii} = A\mu_{i,ii}$$

$$H_a: B\mu_{i,ii} \neq T\mu_{i,ii} \neq A\mu_{i,ii}$$

Where: *B* = bowlers; *T* = batsmen; *A* = allrounders

i = pre-match, *ii* = post-match

3.9.1.2 Statistical Hypothesis 2

Null hypothesis 2a: There are no significant correlations between stimulant use (alcohol and caffeine), age and elite experience with sleep indices.

$$H_0: r_{i,a} = 0$$

$$H_a: r_{i,a} \neq 0$$

Where: *i* = {1;2;3;4} = {sleep onset latency; wake-after sleep onset; total sleep time; subjective sleep score}

a = {1;2;3;4;5;6} = {units of alcohol; time of last alcoholic beverage; units of caffeine; time of last caffeinated beverage; age; experience level}

Null hypothesis 2b: Sleep variables are equal for all racial groups.

$$H_0: \mu_a = \mu_b = \mu_c = \mu_w$$

$$H_a: \mu_a \neq \mu_b \neq \mu_c \neq \mu_w$$

Where: a = Asian/Indian; b = Black African; c = Coloured; w = White

3.9.1.3 Statistical Hypothesis 3

Null hypothesis 3a: Sleep variables are equal for all nights between each group (medication and non-medication) for the first week of condition B.

$$H_0: M\mu_i = N\mu_i$$

$$H_a: M\mu_i \neq N\mu_i$$

Where: *M* = medication group; *N* = non-medication group

i = {1;2;3;4;5;6;7} = {night one; night two; night three; night four; night five; night six; night seven}

3.9.1.4 Statistical Hypothesis 4

Null hypothesis 4a: There are no significant relationships between pre-match sleep indices and match performance measures.

$$H_0: Or_{i,a} = 0 \text{ vs } H_a: Or_{i,a} \neq 0$$

$$H_0: Tr_{i,a} = 0 \text{ vs } H_a: Tr_{i,a} \neq 0$$

$$H_0: Mr_{i,c} = 0 \text{ vs } H_a: Mr_{i,c} \neq 0$$

Where: *O* = One-Day International matches; T = Twenty20 matches; M = Test matches

i = {1;2;3;4} = {sleep onset latency; total sleep time; sleep efficiency; subjective sleep score}

a = {1;2} = {batting strike rate; bowing economy}

c = {1;2} = {batting average; bowing average}

3.9.2 Statistical analysis

The complete dataset for each condition was explored whereby the assumption of normality was verified by Quantile-Quantile plots and the Shapiro-Wilks test. Non-normally distributed data were log-transformed (using $\log_{10}$) before analysis to create a normal distribution (required for sleep onset latency and wake after sleep onset). Group descriptive statistics are shown as mean ± standard deviation unless stated otherwise.

In elite cricket, player selection is based on factors such as the opposition team, the venue and the player's current form and specialties[349]; consequently, not every participant in this study was involved in all three conditions. Therefore, the sample size used differed depending on the objective investigated to maintain statistical integrity (e.g. in order to make direct comparisons in sleep behaviour between venues, only players who participated at both venues were assessed). Further, the division of players in each player role and racial group were unequal. A detailed description of all regression analyses performed in this study is shown in Table 3.

Likelihood ratio with corrected chi-squared tests were performed to establish the necessity of including each player as a random effect parameter,[350] to account for individual differences in sleep variables. Accordingly, linear mixed model regression was used to compare the differences in selected continuous sleep-dependent variables between time-period, match venue, player role, match format, medication and racial group. Ordinal sleep-dependent variables were compared using two-way repeated ordinal regression. The coefficient of variation was calculated to represent a potential source of individual variability during each time-period for both match venues as well as random within-subject variability in sleep over time. In the player role model, the wicket-keeper was assigned to the batsmen group as he was also regarded as a higher-order batsman. Tukey's post hoc was used for all significant pairwise comparisons. This modelling procedure has previously been employed in similar sleep-related sports science investigations.[17,59,150]

The mean score for each question of the Athlete Sleep Behaviour Questionnaire and a count summary of Question 13 ("Comments") of the altered Core Consensus Sleep Diary was calculated to identify major poor sleep behaviours which could adversely affect sleep quantity and quality. Spearman's rho (r_s) correlation analysis was used to assess the relationship between substance use (time of last/units of caffeinated and alcoholic beverage consumed), age and elite experience with selected sleep variables (sleep onset latency, wake after sleep onset, total sleep time and subjective sleep quality score) during condition A and condition B.

Spearman's rho (r_s) correlation analysis was used to assess the relationships between selected pre-match sleep variables (sleep onset latency, total sleep time, sleep efficiency and subjective sleep quality score) and match performance for One-Day Internationals and Twenty20s. For the Test match format, "pooled average" sleep variables were correlated to match performance measures, and was calculated by averaging pre-match, day one and day two time-periods during condition C.

Hedges' (g)[351] was used as a measure of effect size as it is unbiased and acts as a better estimate in cases of small sample groups (< 20) compared to Cohen's d.[351-353] Effect sizes were interpreted as per updated thresholds specific for sports science[354]: 0 - 0.19 trivial; 0.20 - 0.59 small; 0.6 - 1.19 moderate; 1.20 - 1.99 large and ≥ 2.00 very large). Effect size confidence intervals (95%) which overlapped ± 0.20 were deemed unclear. Strength of Spearman's rho (r_s) correlations were evaluated according to recent methods suggested by Hinkle[355]; negligible correlation = 0.00–0.30, weak correlation = 0.31 - 0.50, moderate correlation = 0.51 - 0.70, strong correlation = 0.71 - 0.90 and very strong correlation = 0.91 - 1.00. Statistical significance for all measures was accepted at $p < 0.05$. All analyses were performed using the statistical programme R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.6.0). The main packages were used: "lme4",[356] "ordinal",[357] and "RVAideMemoire".[358]

Table 3. Descriptive summary of all regression analysis performed on sleep dependent measures for each condition.

Model comparisons	Dependent variables	Sample used (n=)	Fixed effect(s)	Random effect
	Conditions A and B			
Time-periods and venue	**Continuous sleep measures:** Bedtime, sleep onset latency, wake-after sleep onset, wake-up time, get-up time, time in bed, total sleep time, sleep efficiency and nap duration **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	Only players that took part in both conditions A and B (n = 9)	Time-period (post-travel, pre-match, post-match) Venue (home, away) Time-period: venue interaction	Player
Match format	**Continuous sleep measures:** Bedtime, sleep onset latency, wake-after sleep onset, wake-up time, get-up time, time in bed, total sleep time and sleep efficiency **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	Only players who played both match format types (n = 12)	Format (One-Day International and Twenty20) Time-period: format interaction	Player
Player role	**Continuous sleep measures:** Bedtime, sleep onset latency, wake-after sleep onset, wake-up time, get-up time, time in bed, total sleep time and sleep efficiency **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	All players who participated in condition A and/or condition B (n = 6 bowlers, n = 11 batsmen, n = 3 allrounders)	Player role (bowlers, batsmen, allrounders) Time-period: player role interaction	Player

	Dependent variables	Sample used (n=)	Fixed effect(s)	Random effect
	Condition B			
Sleep medication (first week of condition B)	**Continuous sleep measures:** Bedtime, sleep onset latency, number of awakenings, wake-up time and total sleep time **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	All players who participated in condition B (n = 11)	Night (one-seven) Group type (medication, non-medication) Night:Group type interaction	Player
	Condition C			
Test match time-periods	**Continuous sleep measures:** Bedtime, sleep onset latency, wake-after sleep onset, wake-up time, get-up time, time in bed, total sleep time and sleep efficiency **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	All players who participated in condition C (n = 11)	Time-period (pre-match, day one, day two, post-match)	Player
	Conditions A, B and C			
Racial groups	**Continuous sleep measures:** Bedtime, sleep onset latency, wake-after sleep onset, wake-up time, get-up time, time in bed, total sleep time and sleep efficiency **Ordinal sleep measures:** Subjective sleep quality and morning freshness scores	All players who participated in the study (n = 3 Asian/Indian, n = 6 Black African, n = 6 Coloured, n = 11 White)	Racial group (Asian/Indian, Black African, Coloured and White)	Player

3.10 FEEDBACK

Individualised feedback in the form of consultancy reports were provided to the coaches, strength and conditioning specialist and management support staff of the national team involved in the study. Feedback included a copy of the results shortened into journal format after the completion of the study. The feedback was distributed to interested players as a token of appreciation for participation and with the hope that it will aid their future sleep behaviours.

CHAPTER IV

4 RESULTS

Firstly, the preliminary results of the team demographics, match duration and Morningness-eveningness Questionnaire are summarized. Thereafter, the significant differences in sleep behaviour between time-period, match venue, match format and player roles (research objective 1) are presented. Following that is an analysis of each question of the Athlete Sleep Behaviour Questionnaire and comments from the sleep diaries (research objective 2). Then, the relationships between sleep variables, substance use (alcohol and caffeine), age, elite experience and race are presented (research objectives 2 and 3). Thereafter, the efficacy of sleep medication after eastward transmeridian travel on sleep behaviour during the first week of condition B are shown (research objectives 2 and 3). Lastly, the correlations between pre-match sleep and cricket match performance for all match formats are presented (research objective 4).

It is important that the following results are seen in the context of the study's broader limitations. In particular, not all players were selected to play in both home and away tours, which decreased the possible sample size for a repeated measures analysis. The deregulation of several factors, most notably the lack of control for post-match commitments (e.g. social functions), type and amount of sleep medication prescribed, substance use (caffeine and alcohol), exposure to technology prior bedtime and environmental factors (accommodation and travel conditions), weakens the internal validity of the consequence these influences had on sleep. However, since these factors usually are not controlled for in real circumstances, the external validity of the results is high.

Owing to the quantity of data, only moderate to large significant differences will be discussed. Furthermore, statistical effects tables are not included in these results; instead, statistical values will be noted in the text. This is to reduce the number of tables and figures in this section. For an in-depth overview, statistical tables of time-period, match venue, player role, match format and racial group main effects are included in Appendix F. Bedtime, wake-up time and get-up time are presented using a 24-hour time model.

4.1 PRELIMINARY RESULTS

Four players were excluded from the study because of poor compliance (n = 3) and injury (n = 1); thus, 26 elite South African cricket players completed the overall study (age: 28.6 ± 4.0 years; height: 1.8 ± 0.1m; weight: 85.7 ± 10.8kg; elite experience: 3.7 ± 4.0 years). The overall compliance rate for the altered version of the Core Consensus sleep diary was 84.8% (condition A = 91.9%; condition B = 74.0%; condition C = 88.6%).

4.1.1 Match duration

Table 4 shows a summary of the average start and end match times (hh:mm) for each match format during all conditions. On average, Twenty20 matches started and ended later than One-day International matches

Table 4. Average match times (hh:mm) for all conditions.

	One-Day International	**Twenty20**	**Test**
Average start time			
Condition A	12:20	18:00	-
Condition B	13:00	18:20	-
Average	**12:40**	**18:10**	
Condition C	-	-	10:00
Average end time			
Condition A	18:51	21:29	-
Condition B	20:27	22:14	-
Average	**19:39**	**21:51**	**-**
Condition C	-	-	14:53

4.1.2 Morningness-Eveningness Questionnaire (Chronotype)

One player did not complete the Morningness-Eveningness Questionnaire. Eighteen were categorized as intermediate (72%), six players as ‘moderate morning’ (24%) and one player was ‘moderate evening’ (4%). There were no definite morning and evening chronotypes in the squad. The global Morningness-Eveningness Questionnaire score was 54.0 ± 6.5.

4.2 SLEEP PATTERN COMPARISONS

A breakdown of the different participant characteristics comparing sleep behaviour between time-periods, match venues and match formats is summarised by Table 5.

Table 5. Description of participant characteristics and data description for each analysis.

		Match format	
	Time-period and match venue	**One-Day International and Twenty20**	**Test**
Participants (n =)	9	12	11
Age (years)	27.1 ± 4.9	28.8 ± 5.2	28.4 ± 4.4
Body mass (kg)	87.9 ± 7.2	87.3 ± 7.6	82.0 ± 9.5
Height (m)	1.8 ± 0.1	1.8 ± 0.1	1.8 ± 0.1
Elite experience (years)	4.3 ± 4.2	5.1 ± 4.7	5.1 ± 4.4

4.2.1 Sleep differences between time-periods

Table 6 presents the differences in sleep behaviour (grouped conditions A and B) between time-periods (post-travel, pre-match and post-match).

Table 6. Sleep differences (mean ± standard deviation) between time-periods.

	Post-travel	**Pre-match**	**Post-match**
Bedtime (hh:mm)*^	23:02 ± 01:10	22:36 ± 01:08	00:40 ± 01:34
Sleep onset latency (hh:mm)	00:22 ± 00:29	00:21 ± 00:27	00:21 ± 00:30
Wake after sleep onset (hh:mm)	00:11 ± 00:20	00:12 ± 00:14	00:09 ± 00:11
Wake time (hh:mm)	07:26 ± 00:44	07:50 ± 00:51	07:39 ± 01:04
Get-up time (hh:mm)*	08:02 ± 00:43	08:29 ± 00:46	08:21 ± 01:15
Time in bed (hh:mm) *$^	08:59 ± 01:03	09:53 ± 01:06	07:41 ± 01:29
Total sleep time (hh:mm) *$^	07:53 ± 01:07	08:43 ± 01:03	06:31 ± 01:09
Sleep efficiency (%)	87.9 ± 9.2	88.4 ± 7.7	85.6 ± 9.3
Nap duration (hh:mm)	00:43 ± 00:41	00:23 ± 00:11	00:40 ± 00:25
Subjective sleep quality score (1-5)*^	3.8 ± 0.9	3.9 ± 0.9	3.1 ± 0.9
Morning freshness score (1-5) *$^	3.3 ± 1.2	3.8 ± 1.0	2.5 ± 1.1

* Significant difference between post-travel and post-match ($p < 0.05$)

^ Significant difference between pre-match and post-match ($p < 0.05$)

$ Significant difference between post-travel and pre-match ($p < 0.05$)

There was a significant effect of time-period on bedtime ($F_{(2,161)} = 44.69$; $p < 0.0001$), wake-up time ($F_{(2,161)} = 3.37$; $p = 0.04$), time in bed ($F_{(2,158)} = 49.60$; $p < 0.0001$), total sleep time ($F_{(2,160)} = 69.48$; $p < 0.0001$), subjective sleep quality ($\chi^2_{(2)} = 24.37$; $p < 0.0001$) and morning freshness score ($\chi^2_{(2)} = 43.75$; $p < 0.0001$). Players went to bed significantly later ($t_{(164)} = 9.13$, $p < 0.0001$, g = 1.49 [1.09;1.88]), spent less time in bed ($t_{(164)} = 9.85$, $p < 0.0001$, g = 1.66 [1.26;2.06]), obtained less total sleep ($t_{(164)} = 11.37$, $p < 0.0001$, g = 1.97 [1.55;2.39]), had lower subjective sleep quality (z = 3.99. p = 0.0002, g = 0.81 [0.44;1.17]) and morning freshness scores (z = 5.90, $p < 0.0001$, g = 1.28 [0.90;1.66]) on nights post-match compared to pre-match. Further, players went to bed later ($t_{(164)} = 7.04$, $p < 0.0001$, g = 1.15 [0.77;1.53]) and obtained significantly less time in bed ($t_{(164)} = 5.75$, $p < 0.0001$, g =1.00 [0.62;1.37]) and total sleep ($t_{(164)} = 6.90$, $p < 0.0001$, g = 1.19 [0.81;1.57]) on nights post-match compared to post-travel. Post-travel morning freshness scores were significantly lower than pre-match, however the difference was small and unclear (z = 2.70, p = 0.02, g = 0.47 [0.11;0.84]).

4.2.2 Sleep differences between match venues

All descriptive results (mean ± standard deviation) for both conditions are found in Appendix G. Sleep onset latency and sleep efficiency were significantly longer and lower during condition B (away) compared to condition A (home), respectively; however, the differences were small and unclear ($t_{(166)} = 2.98$, $p = 0.003$, $g = 0.41$ [0.11;0.72] and $t_{(168)} = 2.66$, $p = 0.008$, $g = 0.37$ [0.07;0.67] respectively). There was a significant interaction between time-period and venue for sleep efficiency ($F_{(2,161)} = 8.44$, $p < 0.0003$) whereby, post-travel sleep efficiency was significantly higher at home than away ($t_{(162)} = 4.88$, $p < 0.0001$, $g = 1.35$ [0.76;1.94]; Table 7). Post-travel sleep onset latency was significantly shorter at home compared to away ($t_{(161)} = 3.44$, $p = 0.01$, $g = 0.74$ [0.29;1.29]; Table 7).

Table 7. Sleep variable differences (Δ mean ± standard deviation) and effect sizes between home (condition A) and away (condition B) for each time-period.

	Post-travel	**Pre-match**	**Post-match**
	ΔHome – Away **g = *(effect size)***	**ΔHome – Away** **g = *(effect size)***	**ΔHome – Away** **g = *(effect size)***
Bedtime (hh:mm)	-00:11 ± 00:20 g = 0.16 *(trivial)*	-00:17 ± 00:02 g = 0.25 *(small)*	-00:18 ± 00:09 g = 0.19 *(trivial)*
Sleep onset latency (hh:mm)	-00:20 ± 00:30* g = 0.74 *(moderate)*	-00:03 ± 00:08 g = 0.13 *(trivial)*	-00:12 ± 00:25 g = 0.40 *(small)*
Wake after sleep onset (hh:mm)	00:07 ± 00:24 g = 0.37 *(trivial)*	00:06 ± 00:13 g = 0.43 *(moderate)*	-00:01 ± 00:02 g = 0.10 *(trivial)*
Wake-up time (hh:mm)	00:08 ± 00:03 g = 0.18 *(trivial)*	-00:30 ± 00:04 g = 0.61 *(moderate)*	-00:03 ± 00:17 g = 0.06 *(trivial)*
Get-up time (hh:mm)	-00:33 ± 00:15 g = 0.80 *(moderate)*	-00:25 ± 00:00 g = 0.54 *(small)*	00:02 ± 00:07 g = 0.03 *(trivial)*
Time in bed (hh:mm)	-00:21 ± 00:09 g = 0.34 *(small)*	-00:07 ± 00:13 g = 0.11 *(trivial)*	00:20 ± 00:20 g = 0.23 *(small)*
Total sleep time (hh:mm)	00:39 ± 00:11 g = 0.59 *(small)*	-00:15 ± 00:18 g = 0.24 *(small)*	00:27 ± 00:02 g = 0.39 *(small)*
Sleep efficiency (%)	10.4 ± 2.8* g = 1.35 *(large)*	-1.5 ± 1.1 g = 0.19 *(trivial)*	1.2 ± 1.4 g = 0.13 *(trivial)*
Nap duration (hh:mm)	-00:27 ± 00:51 g = 0.65 *(moderate)*	00:03 ± 00:02 g = 0.49 *(small)*	-00:28 ± 00:18 g = 0.10 *(small)*
Sleep quality score (units)	0.1 ± 0.0 g = 0.14 *(trivial)*	0.1 ± 0.2 g = 0.07 *(trivial)*	-0.2 ± 0.1 g = 0.19 *(trivial)*
Morning freshness score (units)	-0.7 ± 0.4 g = 0.68 *(moderate)*	-0.2 ± 0.5 g = 0.16 *(trivial)*	-0.4 ± 0.1 g = 0.31 *(small)*

*Significant difference between match venues (p < 0.05).

4.2.2.1 Individual analysis

The highest individual variability was found in sleep onset latency, particularly pre- and post-away matches (coefficient of variation = 136.82% and 132.07% respectively; Figure 3). The greatest individual variation in subjective sleep quality scores was found post-travel during the away condition (coefficient of variation = 24.23%; Figure 3). The lowest individual variability was found in total sleep time, particularly pre-away matches (coefficient of variation = 8.40%; Figure 3).

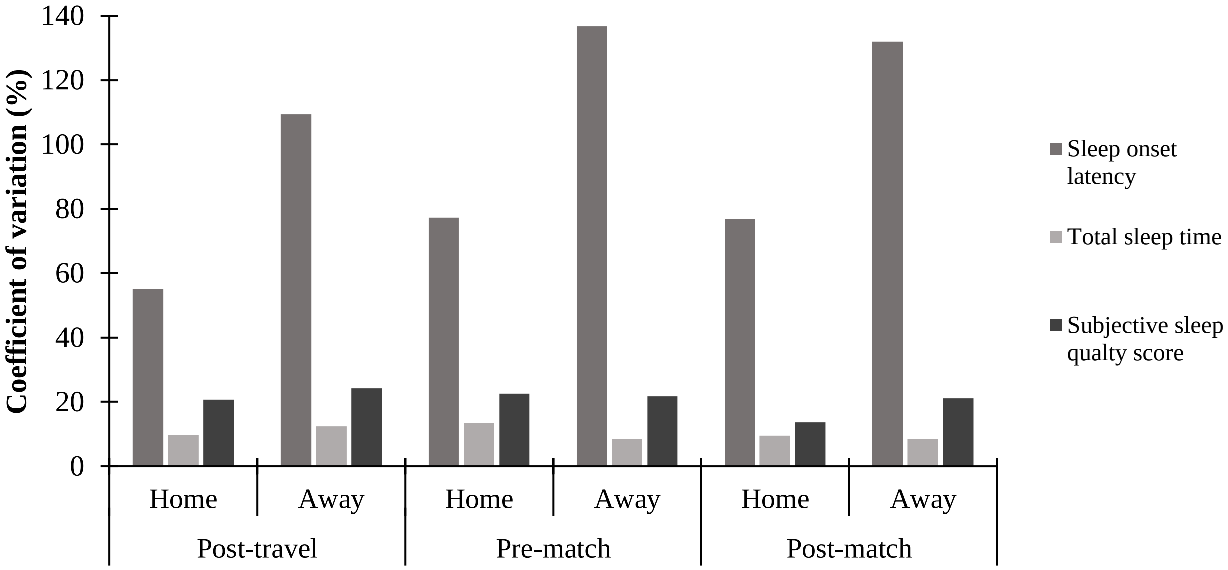

Figure 3. Coefficient of variation (%) in sleep onset latency, total sleep time and subjective sleep quality score across all time-periods during both condition A (home) and condition B (away).

The observational variations in indices of sleep quantity and quality (sleep onset latency, total sleep time and subjective sleep quality) for each player in comparison to the group average are displayed in Figure 4[a]. It is evident that most players often exceeded normative sleep onset latency durations, specifically two players post-travel during the away condition (Figure 4A). Further, the recommended total sleep time for athletes of 8 to 10 hours was not obtained by one player post-travel during the home condition or by any of the players post-match during both home and away conditions (Figure 4B). Figure 4C shows the even spread of individual subjective sleep quality scores, which is paralleled by the small coefficient of variation range (13.71% - 24.23%) found in Figure 3 above.

[a] The dotted line and shaded grey area represents the normative sleep onset latency duration (~11 minutes)[327] and recommended total sleep time (8-10 hours)[10,109] for athletes respectively.

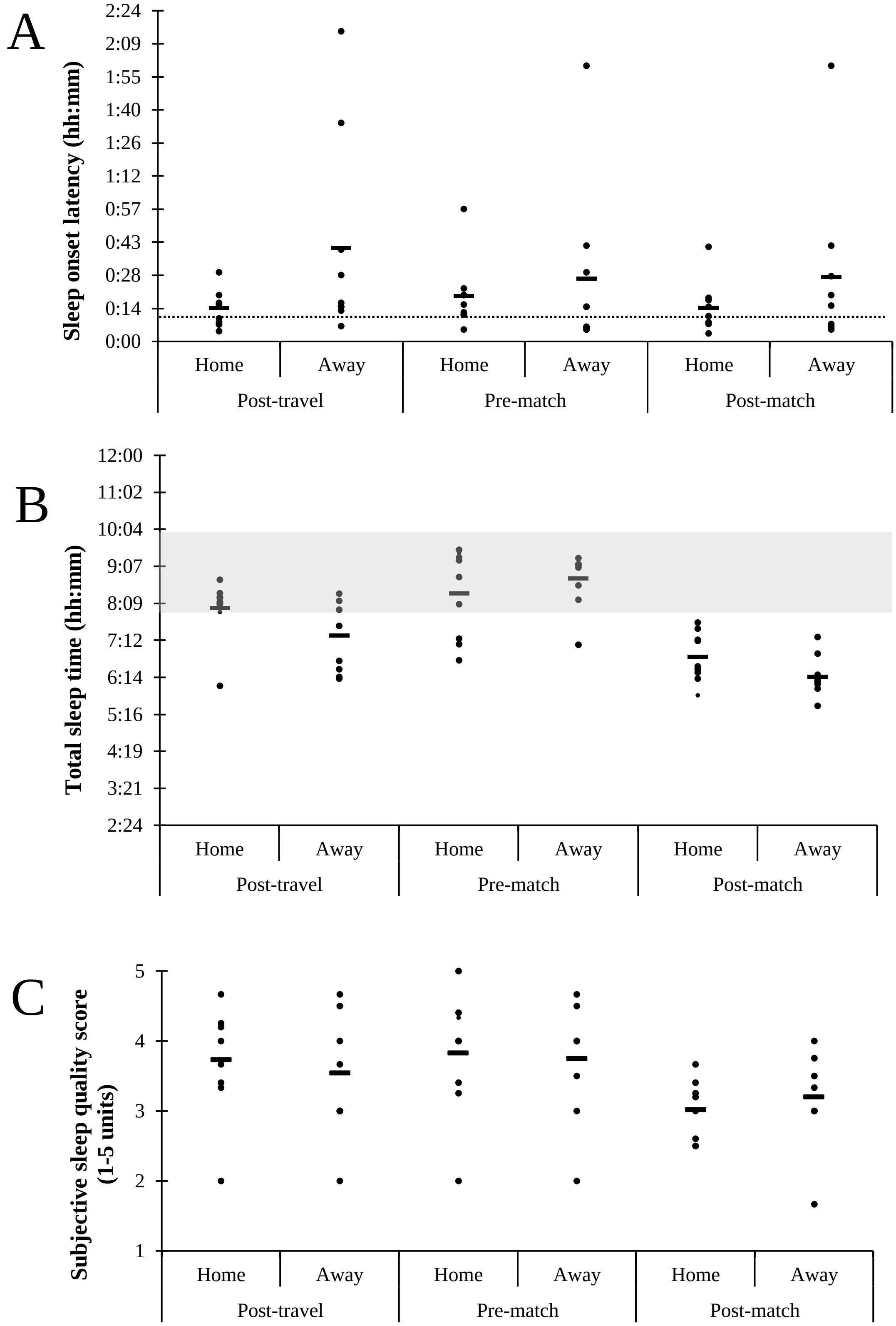

Figure 4. Mean data for (A) sleep onset latency (hh:mm), (B) total sleep time (hh:mm) and (C) subjective sleep quality score (1-5 units) for all players (n = 9) post-travel, pre-match and post-match during condition A (home) and condition B (away). Thick black line represents group mean.

4.2.3 Sleep differences between match formats

4.2.3.1 One-Day International and Twenty20 matches

All descriptive results for One-Day International and Twenty20 are found in Appendix H (Table H1). There were no significant interactions between time-period and match format for all sleep variables ($p > 0.05$). Although not significant, wake after sleep onset and get up time were longer (+ 00:05, $t_{(127)} = 2.31$, $p = 0.20$, $g = 0.61$ [0.22;1.26]; Figure 5) and later (+ 00:30, $t_{(188)} = 2.36$, $p = 0.18$, $g = 0.62$ [0.27;1.17]; Figure 6) before Twenty20 matches compared to One-Day International matches respectively.

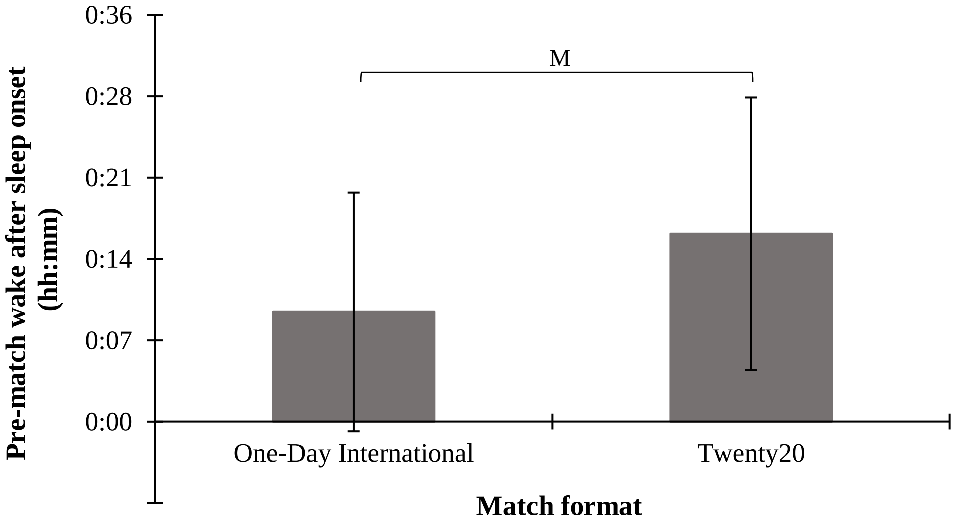

Figure 5. Differences (mean ± standard deviation) in pre-match wake after sleep onset (hh:mm) between One-Day International and Twenty20 formats. M= moderate effect size.

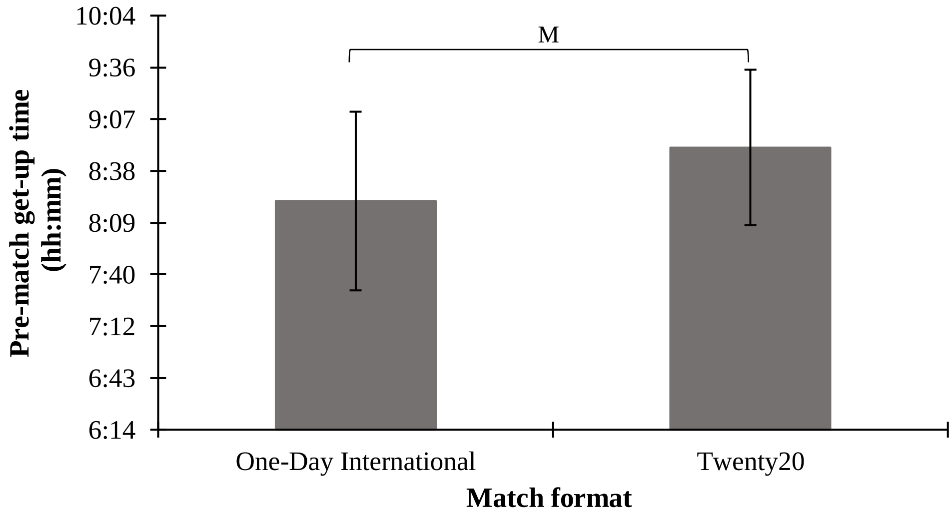

Figure 6. Differences (mean ± standard deviation) in pre-match get up time (hh:mm) between One-Day International and Twenty20 formats. M= moderate effect size.

4.2.3.2 Sleep behaviour across a Test match (condition C)

The descriptive sleep and main effect result for the Test match format is found in Appendix H (Table H2). Figures 7 and 8 present the gradual delay in bedtime, as well as the decrease of time in bed and total sleep time across the course of the Test match respectively.

Post-match bedtime was significantly later compared to pre-match ($t_{(54)} = 3.30$, $p = 0.01$, $g = 0.98$ [0.62;1.34]) and day one ($t_{(54)} = 3.77$, $p = 0.002$, $g = 1.10$ [0.73;1.46]) (Figure 7). Post-match time in bed and total sleep time were significantly shorter compared to pre-match ($t_{(54)} = 3.29$, $p = 0.01$, $g = 0.92$ [0.56;1.27] and $t_{(54)} = 2.76$, $p = 0.04$, $g = 0.75$ [0.40;1.12] respectively) and day one ($t_{(54)} = 3.12$, $p = 0.02$, $g = 1.00$ [0.64;1.36] and $t_{(54)} = 3.72$, $p = 0.003$, $g = 1.29$ [0.92;1.67] respectively) (Figure 8).

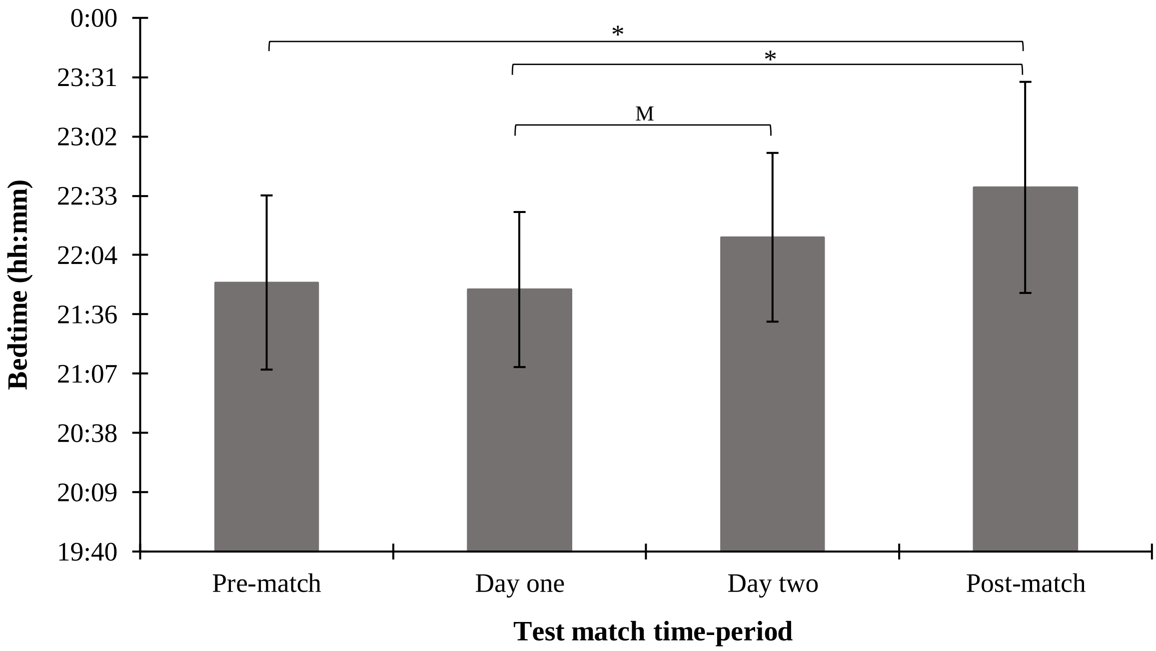

Figure 7. Differences (mean ± standard deviation) in bedtime (hh:mm) between Test match time-periods. *Significant difference ($p < 0.05$). M= moderate effect size

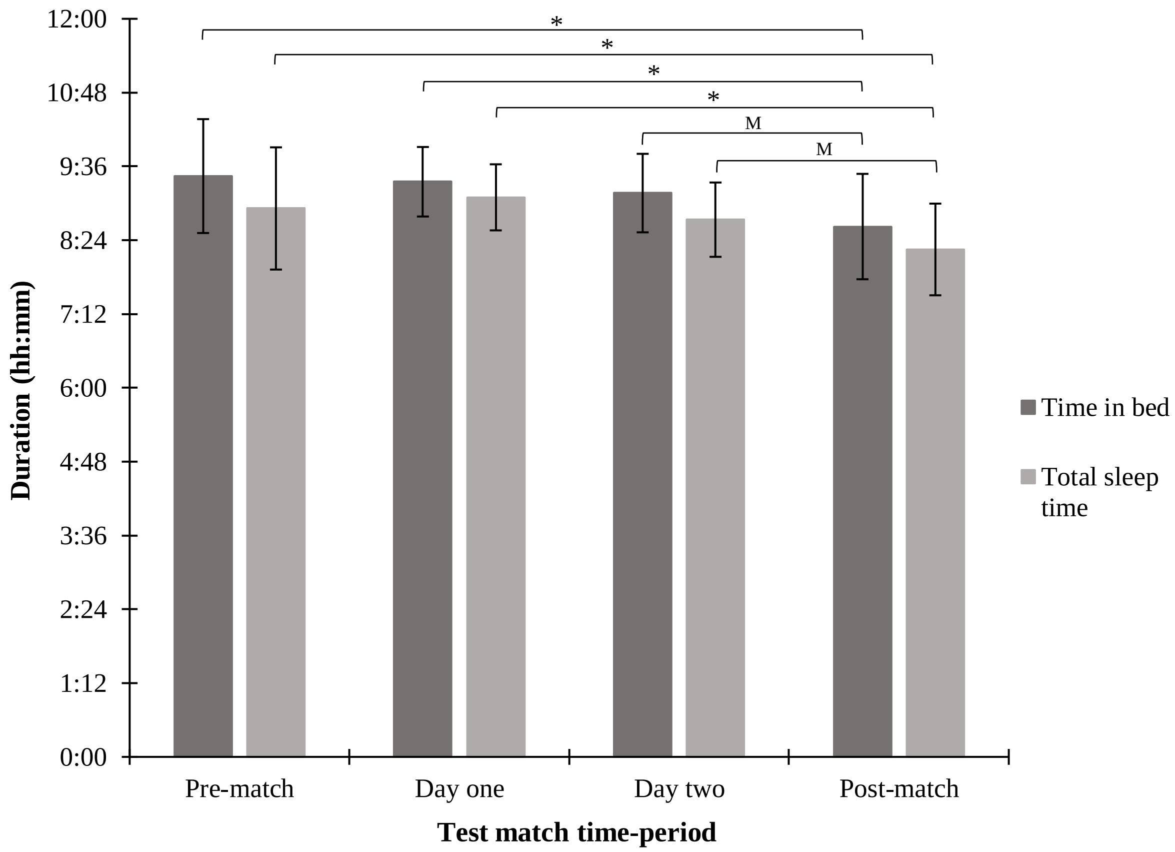

Figure 8. Differences (mean ± standard deviation) in time in bed (hh:mm) and total sleep time (hh:mm) between Test match time-periods. *Significant difference ($p < 0.05$). M = moderate effect size.

4.2.4 Sleep differences between player roles

Six bowlers (age: 27.5 ± 4.7 years; elite experience: 4.4 ± 4.8 years), 11 batsmen (age: 29.6 ± 3.2 years; elite experience: 4.4 ± 4.7 years), and three allrounders (age: 28.6 ± 4.5 years; elite experience: 2.9 ± 2.4 years) who participated in condition A and/or condition B were included in this analysis. Descriptive statistics (mean ± standard deviation) for the sleep variables for all player roles is shown in Appendix I.

There were no significant interactions between time-period and player roles for all sleep variables ($p > 0.05$). Although not significant, allrounders had longer pre-match sleep onset latencies ($t_{(25)} = 1.35$, $p = 0.67$, $g = 0.90$ [0.23;1.57]; Figure 9), shorter pre-match total sleep times ($t_{(49)} = 1.87$, $p = 0.44$, $g = 0.76$ [0.29;1.42]; Figure 10) and lower pre-match morning freshness scores ($z = 1.46$, $p = 0.69$, $g = 1.10$ [0.42;1.78]; Figure 11) compared to batsmen. Bowlers had longer pre-match wake after sleep onset durations compared to batsmen ($t_{(22)} = 2.22$, $p = 0.27$, $g = 1.04$ [0.44;1.64]; Figure 9).

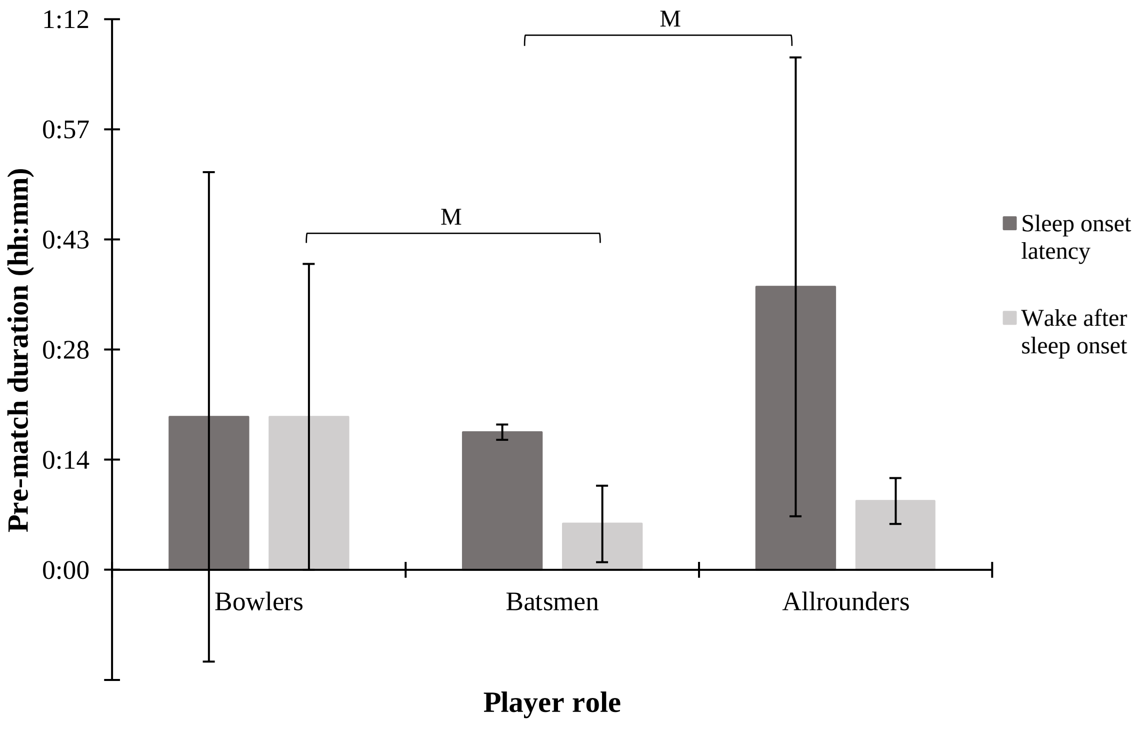

Figure 9. Differences (mean ± standard deviation) in pre-match sleep onset latency (hh:mm) and wake after sleep onset (hh:mm) between player roles. M = moderate effect size.

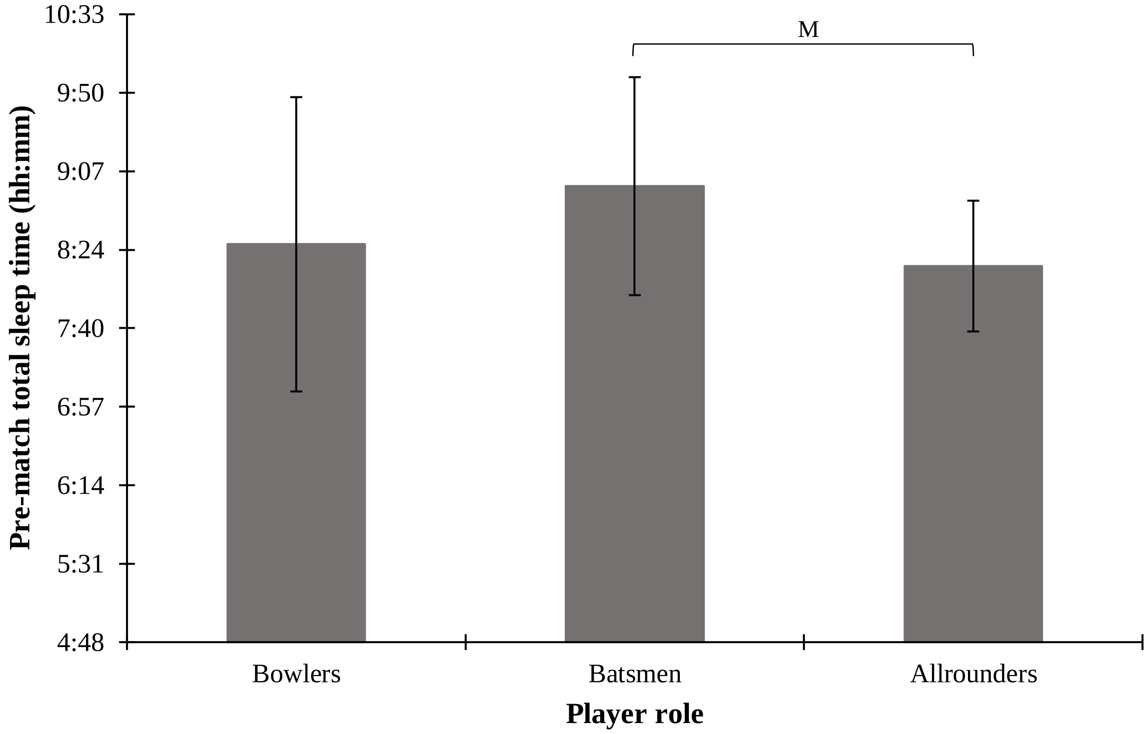

Figure 10. Differences (mean ± standard deviation) in pre-match total sleep time (hh:mm) between player role. M = moderate effect size.

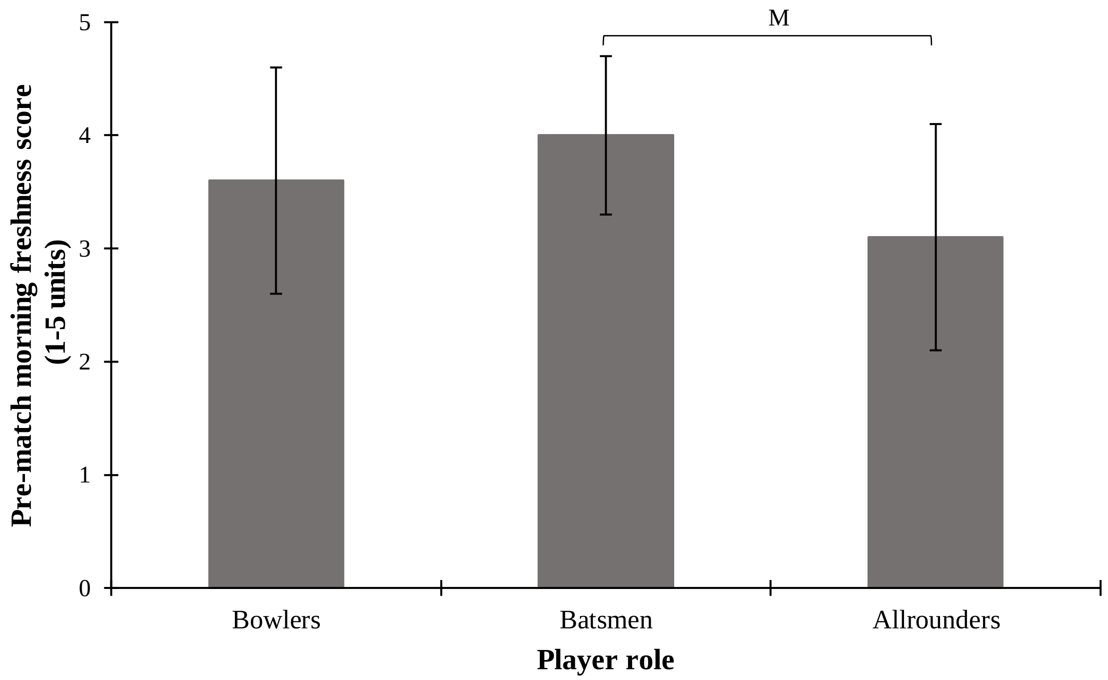

Figure 11. Differences (mean ± standard deviation) in pre-match morning freshness scores (1-5 units) between player roles. M = moderate effect size.

4.3 ATHLETE SLEEP BEHAVIOUR QUESTIONNAIRE AND SLEEP DIARY COMMENTS

One player did not complete the Athlete Sleep Behaviour Questionnaire, therefore, the mean global score for the Athlete Sleep Behaviour Questionnaire across the 25 players was 46.0 ± 5.2. Twenty-one players (84%) were in the ‘poor sleep behaviour’ category, and four players (16%) were in the ‘average sleep behaviour’ category. There were four items from the Athlete Sleep Behaviour Questionnaire results that obtained an average score of > 3.0: (1) “I use light-emitting technology in the hour leading up to bedtime (e.g. laptop, phone, television, video games)”, (2) “I sleep in foreign environments (e.g. hotel rooms)”, (3) “Travel gets in the way of building a consistent sleep-wake routine” and (4) “I go to bed with sore muscles” (Table 8).

Table 8. Average scores (mean ± standard deviation) for each question in the Athlete Sleep Behaviour Questionnaire.

Athlete Sleep Behaviour Questionnaire questions	Score
I take afternoon naps lasting two or more hours	2.0 ± 1.1
I use stimulants when I train/compete (e.g. caffeine)	2.4 ± 1.0
I exercise (train or compete) late at night (after 7pm)	2.2 ± 0.9
I consume alcohol within 4 hours of going to bed	2.5 ± 1.0
I go to bed at different times each night (more than ±1-hour variation)	2.8 ± 0.6
I go to bed feeling thirsty	2.1 ± 0.8
I go to bed with sore muscles	**3.2 ± 0.8**
I use light-emitting technology in the hour leading up to bedtime (e.g. laptop, phone, television, video games)	**4.2 ± 0.9**
I think, plan and worry about my sporting performance when I am in bed	3.0 ± 0.9
I think, plan and worry about issues not related to my sport when I am in bed	2.9 ± 0.9
I use sleeping pills/tablets to help me sleep	1.6 ± 0.8
I wake to go to the bathroom more than once per night	2.1 ± 0.8
I wake myself and/or my bed partner with my snoring	1.5 ± 0.7
I wake myself and/or my bed partner with my muscle twitching	1.8 ± 0.9
I get up at different times each morning (more than ±1-hour variation)	2.7 ± 0.9
At home, I sleep in a less than ideal environment (e.g. too light. too noisy. uncomfortable bed/pillow, too hot/cold)	1.7 ± 0.9
I sleep in foreign environments (e.g. hotel rooms)	**4.0 ± 0.5**
Travel gets in the way of building a consistent sleep-wake routine	**3.4 ± 0.8**

A total of 87 comments were recorded in the sleep diaries during the course of the study. The most commonly reported comments in the sleep diaries were related to sore/stiff muscles, flu symptoms and a noisy/hot sleeping environment (Table 9).

Table 9. Count summary of comments (Question 13) reported in the altered version of the Core Consensus sleep diary during all Conditions.

	Condition A	**Condition B**	**Condition C**
Comment	**Total reports (by n players)**	**Total reports (by n players)**	**Total reports (by n players)**
Sore/stiff muscles	18 (1)	22 (4)	7(5)
Flu	13 (3)	7 (3)	2(2)
Noisy/hot environment	1 (1)	3 (1)	2(1)
Fines[b]	11(11)	-	-
Overhydrated	-	-	1(1)

[b] A post-match social activity involving alcohol.

4.4 RELATIONSHIP BETWEEN SLEEP VARIABLES WITH SUBSTANCE USE, AGE, YEARS OF ELITE EXPERIENCE AND RACE

4.4.1 Substance use, age and years of elite experience

Table 10 displays the Spearman rho correlations which were computed to assess the relationships in selected sleep variables between substance use, age and experience level. Only significant correlations are reported in the text.

Table 10. Spearman rho (r_s) correlations between selected sleep variables and substance use, age and years of elite experience collected during condition A (home) and condition B (away).

	Sleep onset latency		Wake-after sleep onset		Total sleep time		Subjective sleep quality	
	Home	Away	Home	Away	Home	Away	Home	Away
Units of alcohol	-0.24*	-0.23*	0.36*	-0.15	-0.28*	-0.25*	-0.06	-0.13
Time of last alcoholic drink	-0.34*	-0.41*	-0.22	-0.10	-0.69*	-0.57*	-0.31*	-0.26
Units of caffeine	0.20	0.10	0.03	-0.17	-0.26*	0.13	0.02	0.10
Time of last caffeinated drink	0.10	0.35*	0.02	0.46*	0.06	-0.30	0.15	-0.32
Age (years)	0.17	0.10	-0.21	0.52*	-0.13	0.07	0.12	0.14
Elite experience (years)	-0.10	0.14	0.10	0.10	-0.14	0.36*	0.02	-0.18

*Significant correlation ($p < 0.05$)

During both condition A (home) and condition B (away), there were significant correlations between shorter total sleep times and late alcohol consumption ($r_{s\,(49)} = -0.69$, $p < 0.0001$ and $r_{s\,(27)} = -0.57$, $p = 0.001$ respectively). Similarly during both conditions A (home) and B (away), there were significant associations with shorter sleep onset latencies and late alcohol consumption, however the correlations were weak ($r_{s\,(49)} = -0.34$, $p = 0.001$and $r_{s\,(27)} = -0.41$, $p = 0.03$). During condition A (home), a significant but weak correlation existed between lower subjective sleep quality and later alcohol consumption ($r_{s\,(49)} = -0.31$, $p = 0.002$), as well as between longer wake after sleep onset durations and an increase in units of alcohol ($r_{s\,(20)} = 0.36$, $p = 0.03$). During condition B (away), there was a significant correlation between increases in age and longer wake after sleep onset durations ($r_{s\,(13)} = 0.52$, $p = 0.0003$), as well as a significant but weak correlation between greater elite experience and longer total sleep times ($r_{s\,(72)} = 0.36$, $p = 0.02$). There was a significant but weak correlation between longer wake after sleep onset durations and late caffeine consumption ($r_{s\,(13)} = 0.46$, $p = 0.04$) during condition B (away).

4.4.2 Race

All players who took part in conditions A, B and C were included in this analysis (Asian/Indian: n = 3; Black African: n = 6; Coloured: n = 6; White: n = 11). Table 11 presents the differences in sleep behaviour between race groups (Asian/Indian, Black African, Coloured and White). Race did not have a significant main effect on any of the selected sleep variables ($p > 0.05$). Although not significant, Asian/Indians had moderately longer sleep onset latencies compared to Coloureds ($t_{(25)} = 1.31$, $p = 0.56$, $g = 0.70$ [0.24;1.16]) and Whites ($t_{(24)} = 1.64$, $p = 0.37$, $g = 1.07$ [0.66;1.47]). Similarly, Asian/Indians had moderately longer wake after sleep onset durations ($t_{(20)} = 1.28$, $p = 0.12$, $g = 0.86$ [0.42;1.29]) and lower sleep efficiencies ($t_{(24)} = 1.41$, $p = 0.46$, $g = 0.68$ [0.28;1.07]) subjective sleep quality ($z = 1.61$, $p= 0.37$, $g = 0.86$ [0.46;1.26]) and morning freshness scores ($z = 1.73$, $p= 0.31$, $g = 0.89$ [0.47;1.27]) compared to Whites. Coloureds got up moderately later compared to Whites ($t_{(24)} = 2.19$, $p = 0.15$, $g = 0.64$ [0.32;0.95]). Further, Black Africans had moderately lower subjective sleep quality scores compared to Whites ($z = 2.08$, $p= 0.16$, $g = 0.71$ [0.43;0.97]).

Table 11. Sleep differences (mean ± standard deviation) between racial groups.

	Asian/Indian	Black African	Coloured	White
Bedtime (hh:mm)	22:57 ± 01:08	23:17 ± 01:33	23:05 ± 01:46	22:41 ± 01:35
Sleep onset latency (hh:mm)[ab]	00:40 ± 00:51	00:20 ± 00:24	00:16 ± 00:18	00:16 ± 00:11
Wake after sleep onset (hh:mm)[a]	00:15 ± 00:19	00:13 ± 00:09	00:09 ± 00:10	00:06 ± 00:07
Wake-up time (hh:mm)	07:33 ± 00:48	07:35 ± 00:55	07:34 ± 01:20	07:13 ± 00:48
Get-up time (hh:mm)[d]	07:58 ± 00:56	08:15 ± 00:57	08:20 ± 01:04	07:42 ± 00:56
Time in bed (hh:mm)	08:53 ± 01:12	08:49 ± 01:25	09:06 ± 01:40	08:53 ± 01:31
Total sleep time (hh:mm)	07:34 ± 01:12	07:40 ± 01:19	07:59 ± 01:40	08:03 ± 01:25
Sleep efficiency (%)[a]	85.8 ± 11.7	87.2 ± 8.7	88.0 ± 10.7	90.7 ± 6.0
Subjective sleep quality score (1-5)[c]	3.2 ± 1.0	3.3 ± 0.9	3.7 ± 0.9	3.9 ± 0.8
Morning freshness score (1-5)[a]	2.5 ± 1.4	3.1±1.1	3.5 ± 0.9	3.5 ± 1.0

[a] moderate effect size between Asian/Indian and White; [b] moderate effect size between Asian/Indian and Coloured; [c] moderate effect size between Black African and White; [d] moderate effect size between Coloured and White

4.5 SLEEP BEHAVIOUR AND SLEEP MEDICATION ONE WEEK AFTER LONG-HAUL TRANSMERIDIAN TRAVEL (CONDITION B)

A descriptive summary of the overall sleep behaviour for each medication group for the first week of condition B, as well as the results table for group type and night:group type interaction main effects can be found in Appendix J (Table J1 and Table J2 respectively). All players who took part in condition B were used in this analysis (n = 11; age 28.1 ± 4.8 years; body mass 88.1 ± 6.9 kg; height 1.9 ± 0.1m; elite experience 4.2 ± 3.8 years). Table 12 presents a summary of the results from Question 12 ("Sleep medication use") in the first week of condition B.

Table 12. Question 12 ("Sleep medication use") response summary.

Question 12	
Players indicated taking sleep medication (medication group)	n = 6
Players indicated not taking sleep medication (non-medication group*)*	n = 5
Average time of sleep medication administered (hh:mm)	22:49 ± 01:33
Average dose administered (mg)	2.50 ± 2.25

Moderate to large differences in sleep onset latency, total sleep time and sleep efficiency for the first week (nights one to seven) of condition B are shown in Figures 12-14[c].

[c] The airplanes represent days where travel took place (see Table 2 for details): 1st airplane = long haul flight from South Africa to Australia (23 October 2018); 2nd airplane (night six) = short haul flight from Perth to Canberra (29 October 2018).

4.5.1.1 Sleep onset latency

On average, the non-medication group had a significantly longer sleep onset latency compared to the medication group during the first week of condition B ($t_{(9)} = 2.81$, $p = 0.02$, $g = 0.75$ [0.25;1.26]). Specifically, the non-medication group had longer sleep onset latencies on night two ($t_{(30)} = 2.23$, $p = 0.61$, $g = 1.35$ [0.23;2.51]), night three, ($t_{(30)} = 3.14$, $p = 0.15$, $g = 1.21$[0.29;2.16]), night six ($t_{(46)} = 3.24$, $p = 0.10$, $g = 1.34$ [0.74;2.46]) and night seven ($t_{(35)} = 2.50$, $p = 0.44$, $g = 1.75$ [0.25;3.35]) compared to the medication group (Figure 12).

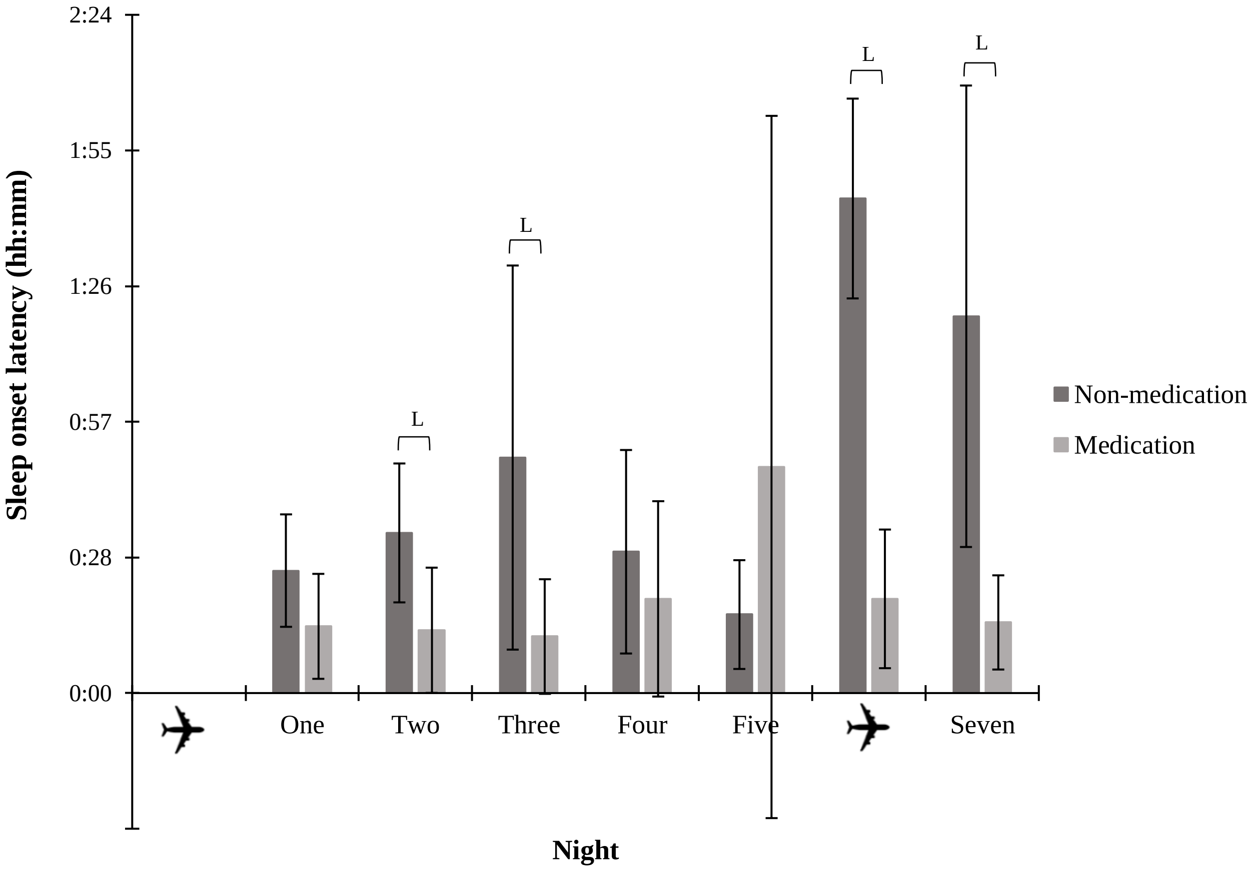

Figure 12. Differences (mean ± standard deviation) in sleep onset latency (hh:mm) between medication groups during the first week of condition B. L = large effect size.

4.5.1.2 *Total sleep time*

The non-medication group obtained less total sleep time on night one ($t_{(12)} = 2.50$, $p = 0.49$, $g = 1.39$ [0.24;2.73]) and night seven ($t_{(13)} = 2.68$, $p = 0.18$, $g = 1.47$ [0.25;2.91]) compared to the medication group (Figure 13).

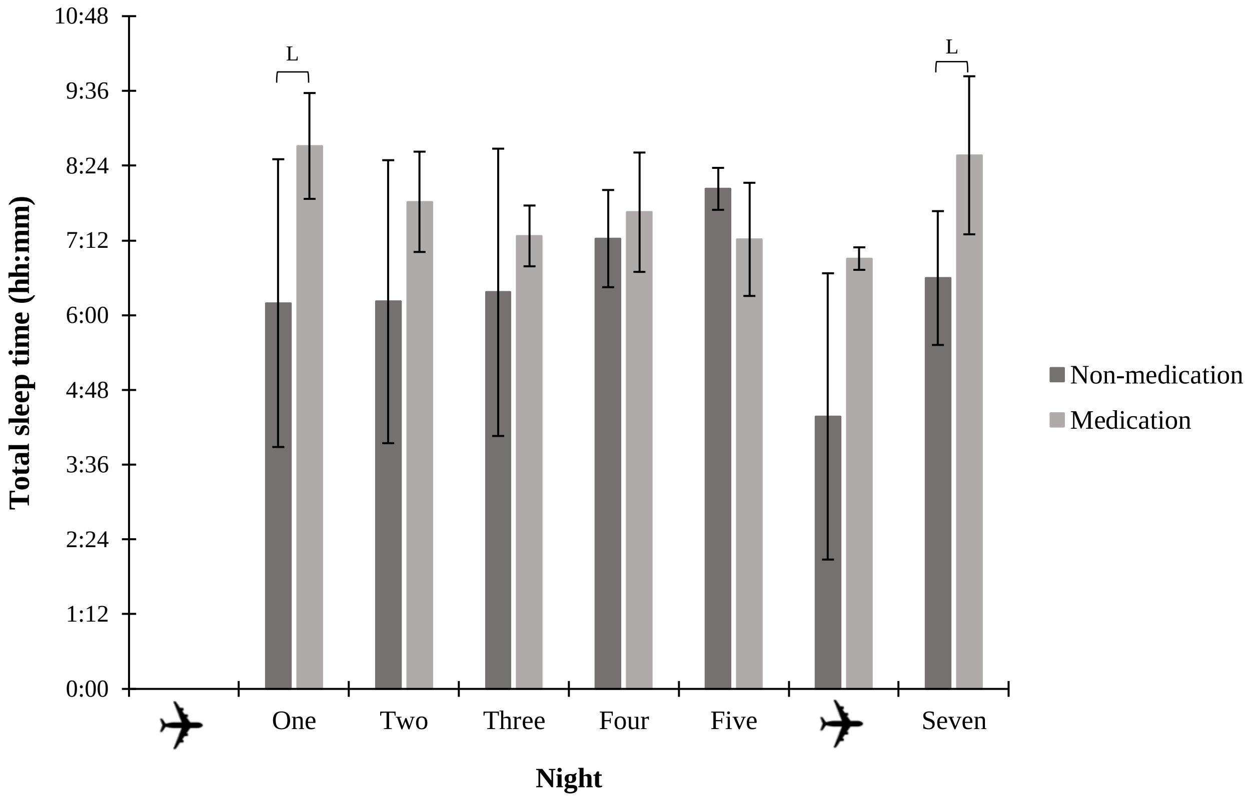

Figure 13. Differences (mean ± standard deviation) in total sleep time (hh:mm) between the medications group during the first week of condition B. L = large effect size.

4.5.1.3 Sleep efficiency

The non-medication group had a significantly lower sleep efficiency on night six ($t_{(25)} = 4.60$, $p = 0.01$, $g = 1.98$ [0.38;2.55]) compared to the medication group. Although not significant, the non-medication group had lower sleep efficiencies on night two ($t_{(15)} = 2.74$, $p = 0.59$, $g = 1.17$ [0.24;2.16]) and night seven ($t_{(17)} = 2.89$, $p = 0.27$, $g = 1.96$ [0.56;2.16]) compared to the medication group (Figure 14).

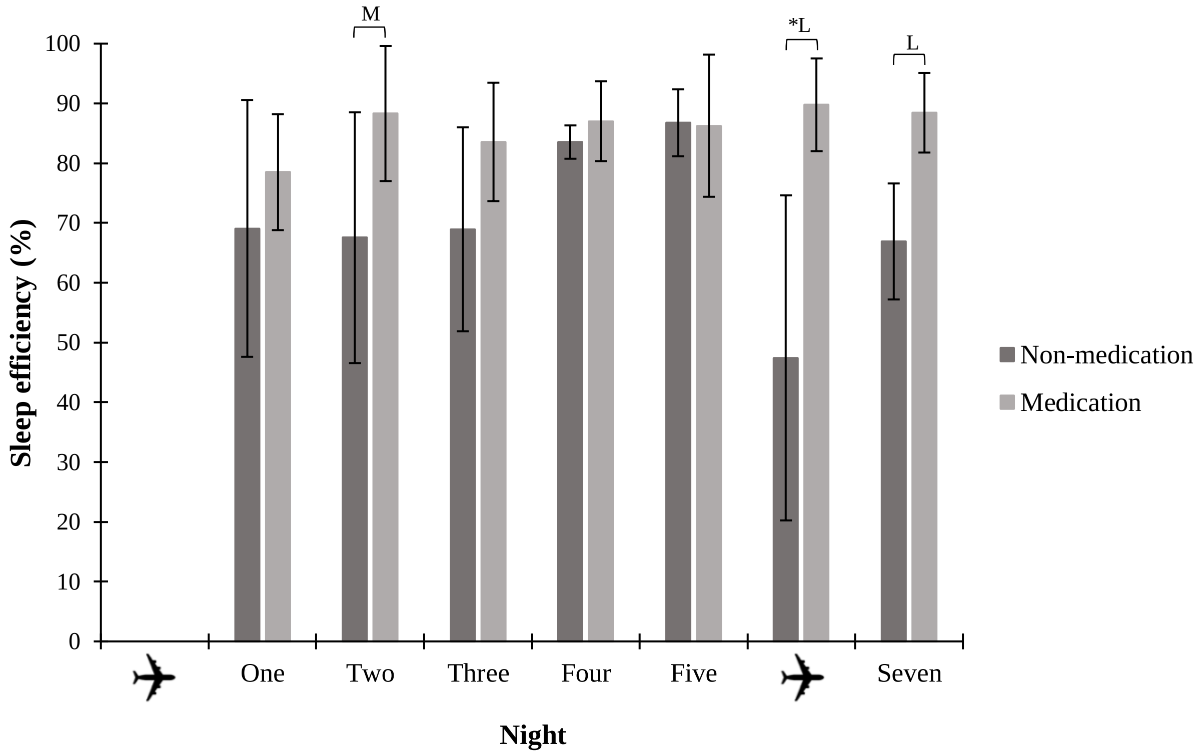

Figure 14. Differences (mean ± standard deviation) in sleep efficiency (%) between the medications group during the first week of condition B. *Significant difference ($p < 0.05$); M = moderate effect size; L = large effect size.

4.6 RELATIONSHIP BETWEEN PRE-MATCH SLEEP AND MATCH PERFORMANCE

Table 13 displays multiple noteworthy correlations between pre-match sleep and batting performance, particularly during One-Day International and Test matches. There was a significant moderate correlation between longer pre-match sleep onset latency and poorer One-Day International batting strike rate ($r_{s\,(28)} = -0.57$; $p = 0.03$). There were significant moderate correlations in better Test match batting averages and longer pooled average total sleep times ($r_{s\,(12)} = 0.59$, $p = 0.03$), higher pooled average sleep efficiencies ($r_{s\,(12)} = 0.53$, $p = 0.04$) and higher pooled average subjective sleep quality scores ($r_{s\,(12)} = 0.52$, $p = 0.04$). With bowling, higher pre-match subjective sleep quality scores were associated with better bowling economy during Twenty20 matches ($r_{s\,(8)} = -0.52$; $p = 0.03$).

Table 13. Spearman rho (r_s) correlations between selected sleep variables and performance measures for One-Day International, Twenty20 and Test matches.

	Batting Strike Rate		Bowling Economy	
Pre-match sleep variables	**One-Day International**	**Twenty20**	**One-Day International**	**Twenty20**
Sleep-onset latency	0.26	-0.57*	-0.24	-0.18
Total sleep time	0.36*	0.23	0.15	-0.19
Sleep efficiency	-0.15	0.37	-0.14	-0.29
Subjective sleep quality	0.34*	0.20	-0.10	-0.52*

	Test	
Pooled average sleep variables	**Batting Average**	**Bowling Average**
Sleep-onset latency	0.04	0.12
Total sleep time	0.59*	0.10
Sleep efficiency	0.53*	-0.29
Subjective sleep quality	0.52*	0.10

*Significant correlation ($p < 0.05$).

CHAPTER V

5 DISCUSSION

This chapter aims to systematically communicate the findings of this study, in relation to the literature, which addressed the following research questions: (1) Is there evidence of sleep disruption among elite South African cricket players during competition? (2) Which factors affect the sleep of elite South African cricket players? (3) Which inter-individual differences in sleep behaviour exist within an elite South African cricket team? (4) Are there associations between pre-match sleep and cricket player match performance?

To the best of the authors' knowledge, this is the first comprehensive analysis of sleep behaviour during competitive periods in elite cricket players for all formats of the game. The main finding of this study is that sleep disruptions were present in the sample under investigation at that time, particularly after periods of travel and match play (regardless of venue). There were also some associations between poor sleep behaviour and compromised performance particularly in batting. which support the usefulness of sleep monitoring practices in elite cricket as a means of providing a competitive edge.

5.1 SLEEP BEHAVIOURS IN ELITE CRICKET PLAYERS DURING COMPETITION

Alongside the workloads of training, the demands during congested in-season competitive periods can challenge elite cricket players, coaches and support staff to maintain consistent sleep.[50] The following results support research hypothesis 1 of this study, as they provide evidence of sleep disruption in elite South African cricket players, particularly post-match and during away competition.

5.1.1 Differences in sleep behaviour between time-periods

Fundamentally, there were no signs of anxiety or concerns in terms of total sleep achieved by the players pre-match as this was the only time period which attained the recommended 8-10 hours of sleep for athletes.[10,109] Although these results align with those in Australian Rules football[62,63] and rugby players,[27,57] where there was an increase in both pre-match time spent in bed and sleep duration, these findings contradict previous objective research, which have shown disrupted sleep before an important competition.[58,148,159,223] These contradictions could be attributed to methodological differences between studies, as sleep duration is often overestimated when collected using subjective measures (e.g. sleep dairies and questionnaires) as opposed to wrist actigraphy. It is also possible that this cohort of elite cricket players may have developed effective strategies during the competitive season to cope with pre-match anxiety. This could be achieved through the increased participation in international cricket leagues (e.g. Indian Premier League and Big Bash League) which provide unique opportunities for players to represent the same team as their regular opponents,[82] thereby increasing social and match exposure. Based on previous suggestions based on rugby[27,57] and Australian football,[62,63] the suitable pre-match sleep behaviour is likely because the elite cricket players in this study believe that adequate sleep quality and quantity could optimise performance the next day; thus, prepared accordingly.

Further, typical sleep efficiencies (an indirect measure of sleep quality) of ~90%[329] was not met in the current study, however, they were similar to the pre-match and post-match sleep efficiencies found in elite football[162] and soccer players.[17] However, the results surpassed the average sleep onset latency duration of ~ 11 minutes[327] by almost two-fold. Players may have supplemented night time sleep with day time napping during periods of travel and match play; however, they still obtained significantly less total sleep time during these periods compared to pre-match. Although post-travel and post-match nap durations surpassed the advised 30-minute mark,[322] napping did not appear to particularly delay sleep onset latency (a consequence previously found among young male athletes[322]) given the similarity in sleep onset latencies across all time periods (~21 minutes). Consequently, further interpretations (i.e. nap duration recommendations) are beyond the scope of this study.

The poor post-match sleep is supported by other findings in team-sport athletes (soccer,[17,59] netball,[29] volleyball,[67] Australian rules football[62] and rugby union[58]). This undesirable outcome should not be taken lightly, as the adverse consequence of inadequate sleep on essential growth hormone production compromises recovery processes and can increase the risk of injury,[77,131,314] a particular consequence found in elite soccer.[19] The risk is further reinforced by the results from the Athlete Sleep Behaviour Questionnaire and comments reported in the sleep diary, which indicated that going to bed with sore muscles was a common problem for the cohort, similar to rugby league players.[163] Given the matches in the current study were televised and played in front of many spectators, it is likely that the psychophysiological stress associated with these factors could have further affected the adequacy of sleep after the match,[7,14] as experienced by female volleyball players.[68] Psychophysiological stress is highly complex and there are numerous factors that could impact sleep post-match. These could include heat and humidity exposure throughout the day,[235,238] exercise arousal (i.e. increased cortisol and body temperature)[19,143] and the biological effect of artificial floodlights on the sleep-wake cycle during the evening matches.[19,28,166]

There were large inter-individual difference in sleep behaviours in the players which has been shown in other in other team-sports athletes.[11,28,63,66] Although group averages are useful, it does not capture individual variation when exposed to different sleep compromising circumstances. Even though many players did not always obtain the minimum 8-hour sleep quantity recommendation, does not imply that they did not meet their individual sleep need (as this is influenced by several genetic, behavioural, medical and environmental factors).[110,111] The large variability found in this study (particularly in sleep onset latency) indicate that stressors around competition (e.g. pre-match anxiety, social pressures and effects of travel) might have a considerably greater effect on some athletes compared to others[21,150] emphasising the importance of individualized sleep monitoring.

5.1.2 Differences in sleep behaviour between match venues

Although players spent nights in different hotel rooms and travelled during both the home and away competitions, the combination of transmeridian short-haul air travel (where large distances were travelled)[167] and the "first night effect" had more of an adverse influence on post-travel sleep efficiency and sleep onset latency while competing away in Australia. However, there was no difference in post-travel total sleep duration between venues, which supports the findings in elite Australian rules football.[62,63] Although travelling around Australia often involved crossing time zones, these results may suggest that the demands of domestic air travel within Australia may be insufficient to cause substantial sleep loss. The lack of difference in pre-match and post-match sleep behaviour between home and away matches was similar to findings from Australian rules football[63] and elite female basketball.[66] These findings are however different to those seen in female volleyball players,[68] whereby indices of sleep quality were poorer the night before away matches compared to home matches. Training status may also have an impact as physically fit individuals adjust quicker to circadian disruptions to the sleep-wake cycle.[62,206] This highlights the complexity of factors that impact sleep. It is recognised as a limitation that sleep was not recorded before and during the long-haul eastward inbound flight from South Africa to Australia during condition B, especially as the degree of sleep disruptions may be determined, although anecdotally, by the comfort experienced during the class of travel (economy vs business). Therefore, no comparisons between the effects of long-haul and short-haul flights could be made. Further, because of logistical reasons and access to players, no baseline sleep was recorded.

5.1.3 Differences in sleep behaviours between each match format

Because of the differences in match format characteristics,[43,55] diverse sleeping patterns and behaviours between these formats were expected. Pre-match anxiety could be used to justify the longer wake after sleep onset was before Twenty20 matches due to its faster pace and intensity; however, a definitive conclusion cannot be made. Players had moderately later get-up times before Twenty20 matches, which is probably due to the later average start time of Twenty20 matches compared to One-Day International matches.

A gradual reduction in sleep quantity occurred across the course of Test matches as a result of later bedtimes. This may be because Test matches are played over three to five days consecutive days[3,55,81] which could increase the risk of sleep debt accumulation (previously shown to adversely affect sport performance[6,138,169] and post-match recovery[3,7,32]). Further, reduced sleep quantity during competition could increase the risk of illness as seen in endurance athletes,[268] Australian footballers[320] and adolescent cricketers.[56] However, this is speculative, and warrants further investigation.

5.1.4 Differences in sleep behaviour between each player roles

No significant differences in any pre and post-match sleep behaviour were found among player roles in this study, possibly accredited to the unbalanced nature of the team structure (six bowlers vs eleven batsmen vs three allrounders). However, some discrepancies existed between player roles which should not go unnoticed. For example, allrounders exhibited poorer pre-match sleep behaviour compared to batmen. The possible reasons behind these differences are unknown; however, when scrutinised further, the batsmen of the team are more experienced than the allrounders (4.4 ± 4.7 years and 2.9 ± 2.4 years respectively). Thus, speculatively, through greater experience, batsmen have better coping mechanisms to manage pre-match nerves. Batsmen only have one primary performance responsibility (i.e. batting) while allrounders have two (bowling and batting)[55]; therefore, the added responsibility may contribute to pre-match anxiety and increase sleep onset latency. However, the same reasoning cannot be used to explain the longer pre-match wake after sleep onset obtained by bowlers compared to batsmen, whom each have one key responsibility.

5.2 POTENTIAL FACTORS ACCOUNTING FOR DISTURBED SLEEP AND VARIABILITY AMONG ELITE CRICKET PLAYERS

The findings in this section support research hypothesis 2 as they provide evidence of sleep disruptions caused by the effects travel and timing of alcohol and caffeine consumption. However, the results did not wholly support research hypothesis 3, as only small to moderate relationships were found in experience level, age and race with various sleep indices. It is important to keep in mind in the context of the discussion below, that the correlation design used in this study prevents conclusions regarding causation from being made.

5.2.1 Athlete Sleep Behaviour Questionnaire and sleep diary comments

Most (84%) of the cohort were considered to practice ‘poor’ sleeping behaviour which exceeds that of elite Japanese athletes,[113,144] German ballet dancers,[145] and Dutch athletes[146] (who were classified ‘poor sleepers’ using the Pittsburgh Sleep Quality Index). The findings were, however, similar to the pre-season and in-season Athlete Sleep Behaviour Questionnaire global scores found in elite Australian cricket players[56] and rugby league players[163] respectively. These results highlight the commonality of risk factors and issues that athletes experience, regardless of nationality. Based on the main poor sleep practices identified in this study, corrective information on consistent sleep routines, optimal sleeping environments (quiet, cool and dark), avoiding substances and light-emitting technology use before bed and relaxation strategies could be provided to the players, as previously done in elite Australian cricket,[56] netball[9] and tennis players.[326] However, adjusting behaviours, which are an integral aspect of an elite athletes lifestyle, such as those associated with frequent travel and sleeping in foreign environments, are more challenging.

5.2.2 Sleep medication

In line with previous research,[216] sleep medication had a significant effect on sleep initiation, maintenance and quality as those who did not take sleeping medication presented indices of poorer sleep behaviour compared to the sleep medication group during the first week (which involved eastward transmeridian flights). However the results of this study did not concur with those found in British athletes after westward travel to the United States.[217] This discrepancy suggests that the effectiveness of sleep medication may depend on the direction travelled, with more success shown after eastward flights compared to westward flights. Although these findings advocate that sleep medication may promote better sleep, it was only effective on nights closer after transmeridian travel; thereafter, its influence slowly diminished. Thus, it may be worthwhile to make use of behavioural interventions (e.g. appropriately timed physical activity and/or light exposure) as a means to accelerate the adaptation rate of the sleep-wake cycle following travel,[207] given the limited efficacy and possible adverse side-effects of sleep medication.[217]

5.2.3 Alcohol and caffeine consumption

Some associations between sleep and alcohol consumption were in line with expectations (i.e. increases in units of alcohol and time of last alcoholic drink consumed were significantly correlated with a decrease in total sleep time, sleep onset latency and subjective sleep quality score regardless of venue).[240] However, the significant association between late alcohol consumption timing and a decrease in wake after sleep onset during the home condition does not support the adverse effect alcohol has on obtaining undisrupted sleep throughout the night.[240,241] These results may be deceptive because of the subjective methods used in this study, as players (particularly under the influence of alcohol) might not be able to accurately recall the previous night's sleep.[259]

The relationship between longer wake after sleep onset durations and late caffeine consumption found during the away tour is likely because (i) caffeine blocks adenosine receptors which often leads to difficulties falling asleep[248-250] and (ii) players possibly consumed more caffeine during condition B to help alleviate the effects of time zone changes. However, no indication of a dose-response between units of caffeine consumed and markers of inadequate sleep was found during both conditions. Similar to the limitation discussed with respect to alcohol, caution needs to be applied to self-reported measures of caffeine consumption as it is possible that the players knowledge of caffeine sources is not well understood.[27] Irrespectively, both alcohol[241] and caffeine consumption should be limited after 16:00 or at least six hours prior to bedtime to prevent adverse effects on subsequent sleep.[248,249]

5.2.4 Chronotype

Differences in chronotype affect an individual's sleeping pattern[183,184] and ability to cope with jetlag[15,177,183]; however, chronotype would not have had a considerable contribution to the individual differences in sleep behaviour in this study, as most (72%) of the players were intermediate types. It would be unlikely to observe extreme chronotypes in cricket players as the game is mainly played over the course of a day, and sometimes into the night during One-Day International and Twenty20 matches. Therefore, the high predominance of intermediate types in this group corresponds with previous chronotype exploration in cricket players[184] and support the concept that timing of sport-specific training and competition schedules may directly influence an athletes chronotype.[178,184]

5.2.5 Age and elite experience

Similar relationships in age and experience level with sleep behaviour were anticipated (as older athletes have generally acquired more international travel and playing experience)[169]; however, this was not the case in this study. Instead, the results during condition B (away) showed an increase in the duration of awakenings throughout the night in older players, while the more experienced players were less affected by competing away in terms of total sleep achieved. This result supports the opinion that younger individuals have more flexibility in their sleeping habits and cope better with the effects of time zone transitions,[190] and concurs with previous research whereby more experienced Australian soccer players were less affected by transmeridian travel.[169] However, given the weakness of the associations, further research is required to substantiate these findings. Nonetheless, it is recommended that coaches focus on, and provide support to, older yet less experienced cricket players in the team, particularly during away competitions.

5.2.6 Race

Although the relationship between race and sleep behaviour is not well understood, previous research has predominantly found racial minorities to be at a higher risk for sleep disorders.[199,200] The results of this study support this consensus as Asian/Indian and Black Africans exhibited poorer sleep behaviour compared to Whites, which is unsurprising given South Africa's unique oppressive background[71] and controversial efficacy of the quota system.[70] However, due to the sensitive nature of the topic, inferential speculations cannot be made; thus, future qualitative research is required to directly pin-point the exact reasons for the sleep disparities in the context of South African cricket. Nonetheless, the findings of this study are not only relevant to South Africa, but to international cricket as a whole. Social exclusion remains rife in many cricketing nations (e.g. poor Maori representation in New Zealand cricket) and, although present day cricket has progressed from its colonial past, racism still plagues the sport.[73] With evidence of degraded sleep quantity and quality as a result of increase psychosocial anxiety through racial discrimination,[74,75] the necessity for proper sleep management plans aimed at minority groups should not be undervalued.

5.3 SLEEP AND CRICKET MATCH PERFORMANCE

The current study assessed the relationship between sleep and performance in a 'field-based' design by using performance measures specific to each cricket match format. The findings support research hypothesis 5, as three noteworthy correlations were found between pre-match sleep and match performance for all match formats: (1) shorter sleep onset latencies were associated with better One-Day International batting performance, (2) higher subjective sleep quality scores were associated with better Twenty20 bowling performance and (3) longer total sleep times, higher sleep efficiencies and higher subjective sleep quality scores were associated with better Test match batting performance.

Sleep disruption typically adversely effects cognitive rather than physical performance[6] which may explain why performance was more affected during batting than bowling. To elucidate, bowlers (particularly fast bowlers) are found to have the greatest physiological workloads compared to that of any of the other positions on the field,[43,55] whereas, arguably, batsmen, who although experience high physiological workloads (e.g. short sprints between wickets[288]) mainly require high levels of mental stamina,[95] quick decision-making skills[93] and reactive ability.[87] It is difficult to measure the degree in which sleep specifically affected performance due to the complex nature of cricket and the many factors which could influence performance such as unpredictable weather conditions, team cohesion, pitch type, spectator pressures and opposition strength.[273] Nonetheless, our results do motivate the possibility of influential effects sleep may have on cricket match performance; promoting the usefulness of sleep monitoring as a competitive advantage. However, more research is needed to strengthen this prospect and delve into the relationship between sleep and more specific aspects of cricket performance (e.g. batting and bowling accuracy, sprint performance and reaction time).

5.4 LIMITATIONS AND FUTURE RESEARCH

The most evident limitation of this study was only using subjective methods to collect sleep data, despite efforts to incorporate wrist actigraphy. Prior to condition A, each player was provided a wrist actigraphy device (ActTrust, CAT; Condor Instruments, São Paulo, Brazil). However, players were prohibited from wearing 'unnecessary' equipment during matches (to conform with International Cricket Council's Player Match Officials Area Regulations Article 4 (4.1.1))[359] and occasionally forgot to wear the ActTrust devices on nights post-match. Because of poor compliance and lack of data, all actigraphy was considered unreliable and excluded from the study's final analysis. This limitation emphasises the practicality issues and difficulty of sleep-related academic research in elite sports teams. Future investigations should aim to use both subjective and objective methods in conjunction to obtain sleep data in elite cricket players.

Another limitation of this study is that data were only collected during a competitive period whereas the inclusion of rest and training time periods could have resulted in a more transparent overview of the sleep characteristics of the players, suggested for future research. However, it would be challenging to monitor players simultaneously during a period of rest and training as elite cricket players are often involved in both domestic and international club tournaments throughout the year. Although this study provides new and informative evidence on the sleep behaviour of elite South African cricket players, data was only collected over three competitive tours out of the whole season (~ 10 weeks collectively). Longer-term studies across the multiple competitive cricket tours would provide further insight into the variations that may occur in the sleep behaviour of elite cricket players during competition. Further, although travel departure and arrival times were not provided for this study, total travel duration should be considered for future research. As there are differences between male and female sleep behaviours,[13,194] it is advised to replicate this study using elite female cricket players to allow for comparisons between genders to be made.

CHAPTER VI

6 CONCLUSION AND PRACTICAL APPLICATIONS

6.1 CONCLUSION

The current study aimed to provide a detailed overview of the sleep behaviour existing in a cohort of elite South African cricket players during periods of competition. From a narrative standpoint, the sleep behaviour in the current study concur with that observed in other team-sport athletes. Although the pre-match sleep behaviour was of little concern, the poor post-match sleep behaviour warrants further exploration focusing on recovery in elite cricket players (given the physically and psychologically taxing nature of competitive cricket matches). The high individual variation, and particularly poorer sleep behaviour of the allrounders and racial minorities of the cohort, emphasise the importance of personalised sleep monitoring in team-sports. Further, the notable relationships between measures of batting performance and sleep encourages the use of sleep monitoring to act as a competitive advantage. In a sport such as cricket, where frequent international travel and night matches are common, it is crucial that future research aims to take on an integrated approach to investigate sleep behaviours in elite cricket players and its effect on subsequent performance and recovery after matches. The findings of this study add to the limited body of knowledge specific to sleep in cricket and it is anticipated to stimulate further applied investigation in this area.

6.2 PRACTICAL APPLICATIONS

The following practical applications are based on the outcomes within this thesis. The results:

- Provide incentive for players and coaches to prioritise sleep and implement sleep monitoring into coaching programmes.
- Advise that coaching staff incorporate effective recovery strategies to account for the impaired sleep behaviour experienced after night matches. Strategies may include more regulation regarding post-match commitments and re-scheduling travel arrangements to allow for extended sleep-in opportunities the next morning.
- Recommend improvements to modify poor sleep behaviours such as reducing bedtime light-emitting technology use and late-evening alcohol consumption.
- Highlight the need for coaches to monitor each player independently, given players will respond differently to sleep compromising situations, with specific supervision over

older and less experienced players during away tours as well as the racial minority groups.

- Inform on associations between sleep and batting performance, which further stresses the importance of sleep monitoring as a means of competitive advantage.

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APPENDIX A: SUMMARY OF STUDIES WHICH HAS QUANTIFIED THE SLEEP OF ELITE ATHLETES DURING TRAINING AND COMPETITION

Table A1. Summary of several previous studies which has quantified the sleep of elite athletes during training and competition.

					Mean±standard deviation				
	Sport type	**Monitoring period**	**Method**	**Subjects (Age)**	**Time in bed (hh:mm)**	**Sleep onset latency (hh:mm)**	**Total sleep time (hh:mm)**	**Wake after sleep onset (hh:mm)**	**Sleep efficiency (%)**
Training									
Driller et al.[56]	Elite cricket	Pre-season training	Actigraphy	9 Males (23±4)	09:46±00:39	01:02±00:30	07:43±00:36	00:34±00:18	80±3
Knufinke et al.[146]	Multi-sport	Training	Sleep diaries	98 Males + Females (18.8±3.0)		00:20±00:14	08:11±00:44	00:13±00:19	
Schaal et al.[151]	Synchronized swimming	Normal training Intensified training	Actigraphy	10 Females (20.4±0.4)	08:19±00:08 08:32±00:13	00:28±00:06* 00:17±00:02*	06:53±00:09* 07:13±00:11*		82.7±1.6* 84.7±1.3*
Dumortier et al.[152]	Elite senior gymnastics	Training	Sleep diaries	7 Females (20.9±2.8)	09:33±00:38	00:36±00:11	08:30±00:31	00:05±00:05	89.0±3.5
Thornton et al.[153]	Rugby	Training camp	Actigraphy	31 Males (24.5±3.9)	08:16±01:13	00:21±00:19	07:17±01:07	00:42±00:17	88.1±4.2
Thornton et al.[154]	Rugby	Pre-season training	Actigraphy	14 Males (26.1±2.9)	07:29±01:21		06:55±01:14	00:35±00:16	92.3±3.0
Sargent et al.[155]	Multi-sport	Training	Actigraphy	70 Males + Females (20.3±2.9)	08:18±01:18		06:30±01:24		85.6±7.2
Sargent et al.[156]	Olympic Swimming	Training Rest	Actigraphy	7 Males + Females	09:18±01:42* 07:42±00:54*	00:32±00:22 00:41±00:43	07:06±01:12* 05:24±01:18*		77.2±7.5 70.7±15.1

				(22.5±1.7)					
Suppiah et al.[157]	Badminton	Rest	Actigraphy	11 Males		00:01±00:01	07:09±00:56*	00:42±00:26	
	Bowling	Training		(14.8±0.9)		00:05±00:08	06:07±00:39*	00:38±00:16	
Suppiah et al.[158]	Sprinting	Rest	Actigraphy	29 Males	08:18±01:13*		06:48±01:12*	01:27±00:41*	80.9±6.7
	Shooting	Training		(14.7±1.3)	06:45±00:29*		05:28±00:33*	01:15±00:23*	80.9±8.6
Miller et al.[161]	Australian Rules Football	Training	Actigraphy	51 Males (27.3±3.4)	08:29±01:19	00:18±00:22	06:49±01:13	01:10±00:33[ab]	85.5±5.7
	Soccer				08:02±02:11	00:10±00:15	06:42±02:00	00:57±00:24[a]	85.5±5.7
	Rugby				08:25±01:41	00:09±00:11	07:10±01:34	00:56±00:23[b]	88.5±4.2
Competition									
Lastella et al.[17]	Soccer	Training	Sleep diary and actigraphy	7 Males	08:18±01:42[a]	00:12±00:16	07:00±01:36[a]		87.8±4.7
		Pre-match		(25.2±3.2)	09:18±01:30[b]	00:10±00:17	07:54±01:12[b]		88.0±3.9
		Post-match			05:30±02:06[ab]	00:05± 00:07	04:30±01:54[ab]		84.5±3.3
Fullagar et al.[21]	Soccer	Competition	Sleep diaries	15 Males (25.5±4.9)		00:20±00:17	08:32±01:11		91.6±3.7
Fullagar et al.[28]	Soccer	Post day match	Sleep diaries	16 Males		00:22±00:03	08:20±00:41*	00:11±00:04	
		Post night match		(25.9±7.5)		00:26±00:15	05:43±01:36*	N/A	
O'Donnell et al.[29]	Elite netball players	Pre-match (home)	Sleep diary	10 Females			08:29±00:44[a]		
		Post-match (home)		(23±6)			06:52±00:40[a]		
		Pre-match (away)	Actigraphy	11 Females	10:07±01:17*	00:23±00:15	08:31±01:02[b]		82.4±6.4
		Post-match (away)		(23±4)	08:25±01:07*	00:22±00:26	06:46±00:47[b]		79.4±6.1
Caia et al.[30]	Rugby League	Training	Actigraphy	7 Males	07:54±00:24	00:20±00:14	06:54±00:24		87.3±3.0
		Competition		(24.3±2.1)	08:00±00:30	00:17±00:08	06:54±00:24		85.9±1.8
Shearer et al.[57]	Rugby Union	Pre-match	Actigraphy	28 Males	09:38±01:11	00:28±00:25	07:37±01:14	01:30±01:02	78.3±11.3
		Post-match		(24.4±2.9)	07:56±01:48	00:38±00:34	06:02±01:27	01:03±01:03	74.7±11.1
Dennis et al.[61]	Australian Rules Football	Pre-match	Actigraphy	22 Males			06:54±01:04		79.0±7.0
		Post-match		(23.8 ±3.2)			07:17±01:01		82.0±7.0
Richmond et al.[63]	Australian Rules Football	Pre-match (home)	Actigraphy and sleep diary	19 Males			09:41		93.0
		Pre-match (away)		(24.1±3.3)			09:32		92.0

Mah et al.[65]	College Basketball	In season	Actigraphy and sleep diaries	11 Males (19.4±1.4)			06:41±01:02		
Staunton et al.[66]	Elite Basketball	Pre-match (home) Pre-match (away) Post-match (home) Post-match (away)	Actigraphy	17 Females (Not reported)			07:42±01:42 07:54±01:36 07:24±01:48 07:36±01:18		91.0±4.0 92.0±4.0 92.0±3.0 93.0±4.0
Erlacher et al.[68]	Volleyball	Pre-match (home) Pre-match (away)	Questionnaire	10 Females (22.1±5.3)		5-10 min 10-20 min			
Romyn et al.[148]	Netball	Training Competition		8 Females (19.6 ± 1.5)		00:28±00:22 00:17±00:10	08:11±00:27 08:07±00:24	00:35±00:07 00:32±00:05	85.2±3.5* 89.0±0.8*
Walsh et al.[150]	Elite Swimming	Rest Training Competition	Actigraphy and sleep diaries	12 Males + Females (21±2)		00:17±00:09[a] 00:19±00:12[b] 00:27±00:11[ab]	07:51±00:47 07:39±00:44 07:56±00:42		82.0±5.0 85.0±5.0 82.0±3.0
Driller and Cupples[163]	Rugby league	Pre-match (home) Pre-match (away) Post-match (home) Post-match (away)	Actigraphy	9 Male (27±3)	10:17±01:51 10:23±01:50 07:05±01:28 07:10±01:34	00:46±00:51 00:43±00:40 01:04±01:17 00:30±00:23	08:19±01:59 08:17±01:26 04:49±01:46 05:01±01:13	00:07±00:05 00:12±00:08 00:16±00:13 00:19±00:14	81±11 80±9 68±17 71±12
Carriço et al.[162]	Elite football	Post-match	Actigraphy	25 Males (26.3±4.7)	07:40±00:42	00:24±00:09	06:36±00:45	00:30±00:16	85.0±5.0
Lastella et al.[218]	Marathon runners	Pre-race	Sleep diary survey	103 Males + Females			05:51±01:25	00:47±00:05	

*,[a, b] Significant difference ($p<0.05$) in sleep variable found between each monitoring period/sample group

APPENDIX B: SUMMARY OF STUDIES WHICH INVESTIGATED SLEEP AND VARIOUS PERFORMANCE OUTCOMES

Table B1. Summary of some previous studies which has investigated the effects of sleep loss (through restriction) on various performance outcomes.

Reference	Subjects	Intervention	Exercise protocol	Performance measure	Result
Richmond et al.[63]	N= 19 Australian Football league players	Total sleep duration monitored 8.9 h baseline 9.7 h pre-home match 9.5 h pre-away match	Match performance	Time between possessions Time between possessions and team assists	NS between sleep durations NS between sleep durations
Staunton et al.[66]	N= 17 elite basketball players	Total sleep duration monitored 7.1 h baseline 8.2 h double-header 7.3 h match day	Match performance	Basketball efficiency statistic	More sleep → increased basketball efficiency statistic
Abedelmalek et al.[281]	N= 12 football players	Restricted to 4.5 h for 1 night	Wingate anaerobic test	Mean power Peak power	Decreased Decreased
HajSalem et al.[282]	N=21 judokas	Partial disruptions at the end of 1 night	Wingate anaerobic test Muscular strength tests	Mean power Peak power Handgrip test	Decreased Decreased NS
Souissi et al.[283]	N = 12 judo competitors	3 h of sleep per night for 2 nights	Wingate anaerobic test Muscular strengths tests	Mean power Handgrip test MVC (elbow flexors)	Decreased Decreased Decreased

Souissi et al.[284]	N = 11 Physical education students	~3–4 h of sleep obtained per night for 2 nights	Wingate anaerobic test	Maximal power Peak Power Mean Power	Decreased Decreased Decreased
Reilly and Deykin[285]	N= 8 trained participants	2.5 h of sleep obtained per night for 3 nights	Incremental treadmill test to exhaustion	Endurance running Performance	NS
			Muscular strength tests	Isometric handgrip test	NS
Sinnerton and Reilly[286]	N= 8 swimmers	2.5 h obtained sleep per night for 4 nights	Swimming tests (50m and 400m)	Speed	NS
			Muscular strength test	Back strength Grip strength Lung function	NS NS NS
				POMS Fatigue Confusion Vigour Depression Anger Tension	 Increase Increase Decrease Increase Increase Increase
Mougin et al.[287]	N= 7 cyclists	3 h of sleep obtained for 1 night	20 min steady state work (75 % VO2max) on a cycle ergometer followed by an incremental test to exhaustion	Maximal sustained exercise Intensity	NS
				HR VE VO2peak	Increase Increase Decrease

Omiya et al.[291]	N= 16 healthy males	~ 3h sleep obtained for 1 night	Cardiopulmonary- exercise test	HR (Anaerobic threshold) VO2 (Anaerobic threshold)	Decreased Decreased
Mougin et al.[293]	N= 8 highly trained participants	~ 4 h of sleep obtained for 1 night	Wingate anaerobic test	Mean power Peak power VO_2peak	NS NS NS
Mejri et al.[294]	N = 10 taekwondo athletes	Partial disruptions at the beginning and end of the night	YoYo intermittent recovery test level one	Total distance covered HR peak RPE	NS NS NS
Reilly and Piercy[300]	N= 8 healthy participants	3 h of sleep obtained per night for 3 nights	Maximal and submaximal weightlifting tasks	Biceps curl RPE POMS Fatigue Confusion Vigour Depression Anger Tension	Decreased- submax. NS- max. Increased Increased Increased Decreased NS NS NS
Bonnet[302]	N= 11 healthy adults	~ 1 h lost per night for 2 nights	Clyde Mood Scale	Reaction time Mood	Increased Decreased
Axelsson et al.[303]	N= 9 healthy participants	4h obtained per night for 5 nights		Reaction time	Increased
Jarraya et al.[305]	N= 12 Handball goalkeepers	4–5 h obtained for 2 nights	Stroop test Barrage test	Reaction time Selective attention and reading ability	Increased Decreased

				Visual-spatial ability and recognition	Decreased
Lo et al.[306]	N= 26 healthy male adolescents	7 nights of 5 h time in bed	Cognitive test battery	Sustained attention Working memory Executive function Subjective sleepiness Mood	Decreased Decreased Decreased Increased Decreased
Otmani et al.[307]	N= 20 healthy volunteers	4 h of sleep obtained for 1 night	Simulated car driving protocol	Alertness	Decreased
Edwards and Waterhouse[308]	N= 60 differently experienced dart players	~3–4 h of sleep obtained	Darts	Mean score Number of zeros Variability Subjective alertness	Decreased Increased Increased Decreased
Cook et al.[310]	N= 10 professional rugby players	1 night/week for ten weeks Sleep restricted group (3-5 hours total sleep time)	Rugby passing skill test	Passing Accuracy	Decreased
Reyner and Horne[311]	N= 16 tennis players	~ 5 h obtained for 1 night	Tennis serving drills	Serving accuracy	Decreased

NS- No Significance ($p > 0.05$)

APPENDIX C: FINAL ETHICAL CLEARANCE LETTER

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: +27 (0)46 6038468
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07 October 2018

Kayla McEwan – g14m2665@campus.ru.ac.za
Candice Christie – c.christie@ru.ac.za
Jonathan Davy – j.davy@ru.ac.za

Dear Kayla, Candice and Jono,

Final Ethical Clearance – Application HKE-2018-06

Your application for ethical clearance for the study titled "Sleep quantification and the effects of sleep loss in elite South African cricket players" (reference number HKE-2018-06) has received final ethical approval from the HKE Ethics Committee. This clearance is valid until the end of 2018.

The stipulations include testing the South African Protea Cricket team. Please note that any significant changes made to the study and procedures need to be communicated to the HKE Ethics Committee (this includes changes in investigators), and another full review may be requested.

Upon completion of your study, please submit a short report indicating when and whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the HKE Ethics committee should be aware of.

Sincerely,

Miriam Mattison

M.C. Mattison
2018 HKE Ethics Chairperson
Department of Human Kinetics and Ergonomics
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APPENDIX D: STUDY INFORMATION LETTER

RHODES UNIVERSITY
Where leaders learn

Dear Sir/Madam

Thank you for showing interest in being involved in this project entitled:

"SLEEP QUANTIFICATION AND BEHAVIOUR IN SOUTH AFRICAN ELITE CRICKET PLAYERS"

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in investigating the following:

- Quantifying the sleep quantity and quality of elite South African cricket players during periods of training and competition, across all three formats of cricket.
- Identifying the incidence rate of pre-training and pre-competitive sleep loss in an elite South African cricket population.
- Pin-pointing the major reasons for why sleep loss occurs, if indeed it does occur.

WHAT WILL BE REQUIRED

The consenting players of the team will be required to complete two questionnaires - The Morningness-Eveningness Questionnaire (Horne and Ostberg, 1976) and the Athlete Sleep Behaviour Questionnaire (Driller et al., 2018) – on one occasion. Further, they will be provided an altered version of the Core Consensus Sleep Diary (Carney et al., 2012) which they will then be required to fill in every morning for several weekly periods. Players may be selected to wear an ActTrust (CAT; Condor Instruments, São Paulo, Brazil) on their non-dominant wrist always (except in water), which will be provided. Player demographic data (age, weight, height and elite experience level) will also be collected.

RISKS

The risks involved in this study are that that data may be unintentionally disclosed to the public, however, precautions have been put in place to prevent this from occurring. Further, the players who wear an ActTrust watch may experience some discomfort/irritation.

BENEFITS

After completion of the study, each player will be more informed about the importance of sleep, as well as have a greater understanding of their individual sleeping patterns and chronotype. These results may aid players in effectively adjusting their sleeping routines which could improve their athletic performance and reduce risk of injury.

CONFIDENTIALITY

Please note that players as well as management support staff will have the right to withdraw from participation at any point for any reason whatsoever. All personal data will also be kept strictly confidential and anonymity will be ensured throughout the process. Each participant's data will be coded for the sake of anonymity and only primary researchers will keep and have access to the lists of participant names and the corresponding codes that identified them. All data will be stored in electronic or written form with all electronic data being stored on the personal computers of the researchers. Any data recorded on communal research laptops will be transferred and removed from said laptop.

All participants, coaches and management staff are offered to provide their email address if they wish to be kept informed of the results of the study and they express an interest in wanting feedback on the project.

If you have any questions or concerns please feel free to ask me at any time.

Yours Sincerely

Kayla McEwan	Dr Jonathan Davy	Prof. Candice Christie
kaymcewan14@gmail.com	j.davy@ru.ac.za	C.Christie@ru.ac.za

APPENDIX E: ALTERED VERSION OF THE CORE CONSENSUS SLEEP DIARY

GENERAL INSTRUCTIONS

What is a Sleep Diary? A sleep diary is designed to gather information about your daily sleep pattern.

How often and when do I fill out the sleep diary? It is necessary for you to complete your sleep diary every day. If possible, the sleep diary should be completed within one hour of getting out of bed in the morning.

What should I do if I miss a day? If you forget to fill in the diary or are unable to finish it, leave the diary blank for that day.

What if something unusual affects my sleep or how I feel in the daytime? If your sleep or daytime functioning is affected by some unusual event (such as an illness, or an emergency) you may make brief notes on your diary.

What do the words "bed" and "day" mean on the diary? This diary can be used for people who are awake or asleep at unusual times. In the sleep diary, the word "day" is the time when you choose or are required to be awake. The term "bed" means the place where you usually sleep.

Will answering these questions about my sleep keep me awake? This is not usually a problem. You should not worry about giving exact times, and you should not watch the clock. Just give your best estimate.

SLEEP DIARY ITEM INSTRUCTIONS

Use the guide below to clarify what is being asked for each item of the Sleep Diary.

Question 1 - Bedtime: What time did you get into bed? Write the time that you got into bed. This may not be the time you began "trying" to fall asleep.

Question 2 - Sleep onset time: What time did you try to go to sleep? Record the time that you began "trying" to fall asleep.

Question 3 - Sleep onset latency: How long did it take you to fall asleep? Beginning at the time you wrote in question 2, how long did it take you to fall asleep.

Question 4 - Wake after sleep onset: How many times did you wake up, not counting your final awakening? How many times did you wake up between the time you first fell asleep and your final awakening? In total, how long did these awakenings last? What was the total time you were awake between the time you first fell asleep and your final awakening. For example, if you woke 3 times for 20 minutes, 35 minutes, and 15 minutes, add them all up (20+35+15= 70 min or 1 hr and 10 min).

Question 5 - Wake-up time: What time was your final awakening? Record the last time you woke up in the morning.

Question 6 - Get-up time: What time did you get out of bed for the day? What time did you get out of bed with no further attempt at sleeping? This may be different from your final awakening time (e.g. you may have woken up at 6:35 a.m. but did not get out of bed to start your day until 7:20 a.m.)

Subjective sleep quality score: How would you rate the quality of your sleep? “Sleep Quality” is your sense of whether your sleep was good or poor.

Question 7 - Sleep quality score: How would you rate the quality of your sleep? “Sleep Quality” is your sense of whether your sleep was poor or good (1= very poor; 2 = poor; 3 = fair; 4 = good; 5 = very good)

Question 8 - Morning freshness score: How restful or refreshed did you feel when you woke up for the day? This refers to how you felt after you were done sleeping for the night, during the first few minutes that you were awake: (1= Not at all rested; 2= slightly rested; 3= somewhat rested; 4 = well-rested; 5 = very well rested)

Question 9 - Daytime napping: How many times did you nap or doze? A nap is a time you decided to sleep during the day, whether in bed or not in bed. “Dozing” is a time you may have nodded off for a few minutes, without meaning to, such as while watching TV. Count all the times you napped or dozed at any time from when you first got out of bed in the morning until you got into bed again at night. In total, how long did you nap or doze? Estimate the total amount of time you spent napping or dozing, in hours and minutes. For instance, if you napped twice, once for 30 minutes and once for 60 minutes, and dozed for 10 minutes, you would answer “1 hour 40 minutes.” If you did not nap or doze, write “N/A” (not applicable).

Question 10 - Alcohol consumption: How many drinks containing alcohol did you have? Enter the number of alcoholic drinks you had where 1 drink is defined as one 12 oz beer (can), 5 oz wine, or 1.5 oz liquor (one shot). What time was your last drink? If you had an alcoholic drink yesterday, enter the time of day in hours and minutes of your last drink. If you did not have a drink, write “N/A” (not applicable).

Question 11 - Caffeine consumption: How many caffeinated drinks (coffee, tea, soda, energy drinks) did you have? Enter the number of caffeinated drinks (coffee, tea, soda, energy drinks) you had. What time was your last caffeinated drink? If you had a caffeinated drink, enter the time of day in hours and minutes of your last drink. If you did not have a caffeinated drink, write “N/A” (not applicable).

Question 12 - Sleep medication use: Did you take any over-the-counter or prescription medication(s) to help you sleep? If so, list medication(s), dose, and time taken: List the medication name, how much and when you took EACH different medication you took tonight to help you sleep. Include medication available over the counter, prescription medications, and herbals (example: "Sleepwell 50 mg 11 pm"). If every night is the same, write “same” after the first day.

Question 13 - Comments: If you have anything that you would like to say that is relevant to the sleep environment, any injury, illnesses or additional comments, feel free to write it here.

Question	Example	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6	Date 7
1. What time did you get into bed?	10:15 pm.							
2. What time did you try to go to sleep?	11:00 pm.							
3. How long did it take you to fall asleep?	15 minutes							
4. How many times did you wake up in the night? In total, how long did these awakenings last?	1 time 5 minutes							
5. What time did you wake up for the day?	07:00 am							
6. What time did you get out of bed for the day?	07:15 am							
7. How would you rate the quality of your sleep?	1=Very Poor; 2=Poor; 3= Fair; 4= Good; 5= Very Good							
8. How rested did you feel when you woke-up for the day?	1= Not at all rested; 2= Slightly rested; 3= Somewhat rested; 4= Well-rested; 5= Very well-rested							
9. Did you nap in the day? If so how long?	2 times 30 minutes							
10. How many drinks containing alcohol did you have? What time was your last alcoholic drink?	3 drinks Last drink at 23:00 pm							
11. How many caffeinated drinks (coffee, tea, soda, energy drinks) did you have What time was your last caffeinated drink?	2 drinks Last drink at 18:00 pm							
12. Did you take any over-the-counter or prescription medication(s) to help you sleep? If so, list medication(s), dose, and time taken	Yes Sleepwell 50 mg 11 pm							
13. Comment	e.g. Noisy environment, sore muscles, fines, flu, nervous							

APPENDIX F: STATISTICAL EFFECTS TABLES

Table F1. Statistical results table for time-period, venue, player role and format main effects.

	Main effect														
	Time-period			**Match venue**			**Player role**			**Match format**			**Race**		
	df	**F**	**p**	**df**	**F**	**p**	**df**	**F**	**p**	**df**	**F**	**p**	**df**	**F**	**p**
Bedtime	2;161	44.69	<0.0001	1;162	1.19	0.28	2;13	3.15	0.16	1;193	0.32	0.57	3;23	0.58	0.63
Sleep onset latency	2;161	2.20	0.11	1;162	9.79	0.002	2;17	0.41	0.67	1;193	1.38	0.24	3;23	0.99	0.41
Wake after sleep onset	2;111	0.12	0.89	1;112	0.29	0.59	1;17	1.74	0.20	1;128	2.49	0.12	3;21	2.22	0.11
Wake-up time	2;161	3.37	0.04	1;162	0.62	0.43	2;15	1.97	0.40	1;193	0.32	0.57	3;23	0.49	0.69
Get-up time	2;161	3.03	0.05	1;162	3.70	0.06	2;17	1.20	0.33	1;193	0.02	0.90	3;23	2.30	0.10
Time in bed	2;161	49.60	<0.0001	1;162	0.08	0.78	2;10	1.03	0.39	1;193	0.24	0.62	3;23	0.40	0.75
Total sleep time	2;161	69.48	<0.0001	1;162	3.74	0.05	2;17	3.70	0.03	1;193	0.10	0.92	3;23	0.49	0.70
Sleep efficiency	2;161	1.71	0.18	1;162	8.56	0.004	2;13	0.10	0.91	1;193	1.08	0.30	3;23	1.07	0.38
Nap duration	2;25	1.15	0.33	1;26	2.02	0.17	-	-	-	-	-	-	-	-	-
	Time-period			**Venue**			**Player role**			**Format**			**Race**		
	df	χ^2	**p**	**df**	χ^2	**p**	**df**	χ^2	**p**	**df**	χ^2	**p**	**df**	χ^2	**p**
Subjective sleep quality score	2	24.37	0.001	1	0.74	0.39	2	0.43	0.81	1	0.35	0.55	3	4.36	0.23
Morning freshness score	2	43.71	<0.0001	1	3.52	0.06	2	3.26	0.20	1	1.85	0.17	3	4.32	0.22

df= degrees of freedom (numerator; denominator)

APPENDIX G: DESCRIPTIVE RESULTS FOR MATCH VENUE

Table G1. Sleep variable differences (mean ± standard deviation) on the night post-travel, pre-match and post-match for condition A (home) and condition B (away).

	Post-Travel		**Pre-match**		**Post-match**		**Time-period:Venue interaction main effect**	
	Home	**Away**	**Home**	**Away**	**Home**	**Away**	**F-value**	**p-value**
Bed time (hh:mm)	22:57 ± 01:01	23:09 ± 01:22	22:28 ± 01:07$_a$	22:45 ± 01:10$_a$	00:32 ± 01:30	00:50 ± 01:40	0.010	0.99
Sleep onset latency (hh:mm)$_\$$	00:14 ± 00:10$_a$	00:34 ± 00:41$_a$	00:20 ± 00:23	00:23 ± 00:31	00:15 ± 00:15$_a$	00:27 ± 00:41$_a$	2.28	0.11
Wake after sleep onset (hh:mm)	00:15 ± 00:29$_a$	00:08 ± 00:04$_a$	00:14 ± 00:18$_a$	00:08 ± 00:04$_a$	00:09 ± 00:12	00:10 ± 00:09	0.53	0.59
Wake time (hh:mm)	07:29 ± 00:43	07:21 ± 00:46	07:36 ± 00:51$_b$	08:07 ± 00:46$_b$	07:37 ± 00:56	07:41 ± 01:14	1.87	0.16
Get-up time (hh:mm)	07:48 ± 00:33$_b$	08:21 ± 00:49$_b$	08:18 ± 00:45$_a$	08:43 ± 00:45$_a$	08:22 ± 01:12	08:20 ± 01:20	1.97	0.14
Time in bed (hh:mm)	08:50 ± 01:07$_a$	09:12 ± 00:57$_a$	09:50 ± 01:12	09:57 ± 00:59	07:50 ± 01:19$_a$	07:29 ± 01:40$_a$	1.17	0.31
Total sleep time (hh:mm)	08:09 ± 01:09$_a$	07:30 ± 00:58$_a$	08:36 ± 01:11$_a$	08:52 ± 00:53$_a$	06:43 ± 01:09$_a$	06:15 ± 01:07$_a$	3.00	0.05
Sleep efficiency (%)$_\$$*****	92.2 ± 6.4$_c$	81.7 ± 9.1$_c$	87.7 ± 8.1	89.2 ± 7.0	86.2 ± 8.7	85.0 ± 10.1	8.44	0.0003
Nap duration (hh:mm)	00:31 ± 00:08$_b$	00:58 ± 01:00$_b$	00:25 ± 00:13$_a$	00:22 ± 00:10$_a$	00:26 ± 00:11	00:55 ± 00:30	0.61	0.55
							χ_2	**p-value**
Subjective sleep quality score (1-5)	3.8 ± 0.9	3.7 ± 0.9	3.9 ± 1.0	3.8 ± 0.8	3.1 ± 0.9	3.2 ± 0.8	1.36	0.51
Morning freshness score (1-5)	3.0 ± 1.0$_b$	3.7 ± 1.4$_b$	3.8 ± 0.8	3.9 ± 1.3	2.3 ± 1.1$_a$	2.7 ± 1.1$_a$	1.42	0.49

$\$$ Significant venue effect;

*Significant time-period:venue interaction effect

$_a$ Small, $_b$ Moderate and $_c$ Large magnitude of difference between venues

APPENDIX H: DESCRIPTIVE RESULTS FOR ALL MATCH FORMATS

Table H1. Pre-and post-match sleep behaviour differences (mean ± standard deviation) during One-Day International and Twenty20 match formats.

	Pre-match		Post-match		Time-period:Format interaction main effect	
	One-Day International	Twenty20	One-Day International	Twenty20	F-value	p-value
Bed time (hh:mm)	22:38 ± 01:12	22:43 ± 01:18	00:45 ± 01:44	00:41 ± 01:44	0.11	0.90
Sleep onset latency (hh:mm)	00:20 ± 00:24	00:21 ± 00:27	00:19 ± 00:28	00:20 ± 00:29	0.10	0.92
Wake after sleep onset (hh:mm)	00:09 ± 00:10[m]	00:16 ± 00:12[m]	00:08 ± 00:09	00:12 ± 00:13	1.27	0.29
Wake time (hh:mm)	07:47 ± 00:49	08:02 ± 00:59	07:45 ± 01:13	07:24 ± 00:52	2.64	0.07
Get-up time (hh:mm)	08:21 ± 00:49[m]	08:51 ± 00:43[m]	08:27 ± 01:20	07:57 ± 01:09	4.86	0.01
Time in bed (hh:mm)	09:43 ± 01:10	10:08 ± 01:10	07:42 ± 01:23	07:15 ± 01:41	1.81	0.17
Total sleep time (hh:mm)	08:41 ± 01:09	08:46 ± 00:55	06:33 ± 01:04	06:17 ± 01:18	0.70	0.49
Sleep efficiency (%)	89.5 ± 6.9	87.1 ± 7.9	86.0 ± 9.0	87.5 ± 9.5	2.58	0.08
					χ^2	p-value
Subjective sleep quality score (1-5)	3.8 ± 0.9	3.8 ± 0.9	3.1 ± 0.9	3.3 ± 0.9	1.10	0.58
Morning freshness score (1-5)	3.8 ± 1.0	3.7 ± 0.9	2.5 ± 1.1	2.4 ± 1.1	0.73	0.69

[m] Moderate magnitude of difference between One-Day International and Twenty20 formats.

Table H2. Sleep behaviour differences (mean ± standard deviation) throughout a Test series (Condition 3).

					Time-period main effect	
	Pre-match	**Day one**	**Day two**	**Post-match**	**F-value**	**p-value**
Bed time (hh:mm)	21:51±00:42[A]	21:48±00:37[BD]	22:13±00:40[D]	22:37±00:51[AB]	5.70	0.002
Sleep onset latency (hh:mm)	00:13±00:07	00:13±00:07	00:16±00:15	00:12±00:09	0.18	0.91
Wake after sleep onset (hh:mm)	00:06±00:02	00:13±00:24	00:08±00:05	00:13±00:16	0.53	0.66
Wake time (hh:mm)	06:46±00:33	06:53±00:11	06:58±00:20	06:52±00:17	0.89	0.45
Get-up time (hh:mm)	07:18±00:33	07:09±00:11[D]	07:23±00:10[D]	07:15±00:10	1.69	0.18
Time in bed (hh:mm)	09:26±00:55[A]	09:21±00:33[B]	09:10±00:38[C]	08:37±00:51[ABC]	4.49	0.01
Total sleep time (hh:mm)	08:55±00:59[A]	09:05±00:32[BD]	08:44±00:36[CD]	08:15±00:44[ABC]	4.90	0.004
Sleep efficiency (%)	91.2±5.0	93.1±5.4	91.4±4.9	91.6±4.9	0.75	0.55
					χ^2	**p-value**
Subjective sleep quality score (1-5)	3.1±0.7[A]	2.9±0.6	2.8±0.9	2.5±0.7[A]	6.13	0.11
Morning freshness score (1-5)	3.8±0.7	3.7±1.0	3.7±0.7	3.5±0.7	2.50	0.47

[A] Moderate magnitude of difference between pre-match and post-match;

[B] Moderate magnitude of difference between day one and post-match;

[C] Moderate magnitude of difference between day two and post-match.

[D] Moderate difference between day one and day two.

APPENDIX I: DESCRIPTIVE RESULTS FOR PLAYER ROLES

Table I1. Pre-and post-match sleep behaviour differences (mean ± standard deviation) between bowlers, batsmen and allrounders.

	Pre-match			**Post-match**			**Time:player role interaction main effect**	
	Bowlers	**Batsmen**	**Allrounders**	**Bowlers**	**Batsmen**	**Allrounders**	**F-value**	**p-value**
Bed time (hh:mm)	23:04 ± 01:08	22:16 ± 01:06	22:24 ± 01:09	00:59 ± 01:25	00:29 ± 01:39	00:30 ± 01:11	0.21	0.81
Sleep onset latency (hh:mm)	00:20 ± 00:32	00:18 ± 00:18[a]	00:37 ± 00:30[a]	00:22 ± 00:39	00:14 ± 00:12	00:29 ± 00:23	0.61	0.54
Wake after sleep onset (hh:mm)	00:20 ± 00:20[a]	00:06 ± 00:05[a]	00:09 ± 00:03	00:11 ± 00:10	00:06 ± 00:09	00:07 ± 00:02	0.72	0.49
Wake time (hh:mm)	08:05 ± 00:56[a]	07:38 ± 00:59	07:25 ± 00:59[a]	07:42 ± 01:03	07:29 ± 01:17	07:29 ± 00:50	0.59	0.56
Get-up time (hh:mm)	08:39 ± 00:46[a]	08:19 ± 00:57	08:07 ± 00:37[a]	08:25 ± 01:16	08:05 ± 01:22	07:55 ± 01:07	0.00	0.99
Time in bed (hh:mm)	09:34 ± 01:12	10:03 ± 01:04[a]	09:43 ± 01:09[a]	07:26 ± 01:29	07:35 ± 01:33	07:24 ± 01:30	0.25	0.78
Total sleep time (hh:mm)	08:27 ± 01:21	08:59 ± 01:00	08:15 ± 00:36	06:13 ± 01:08	06:39 ± 01:20	06:25 ± 01:01	0.42	0.66
Sleep efficiency (%)	88.3 ± 8.9	89.8 ± 8.9	85.5 ± 7.4	85.0 ± 12.0	88.2 ± 6.7	87.7 ± 7.5	0.89	0.41
							χ^2	**p-value**
Subjective sleep quality score (1-5)	3.5 ± 0.9[a]	4.1 ± 0.7[a]	3.8 ± 1.0	3.1 ± 1.1	3.2 ± 0.9	3.5 ± 0.7	4.27	0.12
Morning freshness score (1-5)	3.6 ± 1.0	4.0 ± 0.7	3.1 ± 1.0	2.1 ± 1.0[a]	2.6 ± 1.1	2.7 ± 0.8[a]	6.33	0.05

[a] Moderate magnitude of difference in between player roles.

APPENDIX J: SLEEP MEDICATION USE DURING THE FIRST WEEK OF CONDITION B

Table J1. Overall sleep behaviour (mean ± standard deviation) for the first week of condition B between the medication and non-medication group.

	Night 1	Night 2	Night 3	Night 4	Night 5	Night 6	Night 7
Bedtime (hh:mm)							
Medication group	22:40±01:10	23:08±01:25	23:22±01:44	23:18±01:25	23:46±00:51	00:37±01:06	23:28±01:39
Non-medication group	22:54±00:50	23:01±00:59	23:04±01:24	23:26±01:00	22:55±00:08	23:30±00:42	22:37±00:28
Sleep onset latency (hh:mm)							
Medication group	00:14±00:11	00:13±00:13	00:12±00:12	00:20±00:20	00:48±01:14	00:20±00:14	00:15±00:10
Non-medication group	00:26±00:11	00:34±00:14	00:50±00:40	00:30±00:21	00:16±00:11	01:45±00:21	01:20±00:48
Wake after sleep onset (hh:mm)							
Medication group	00:06±00:03	01:01±00:57	00:07±00:03	00:32±00:38	00:07±00:03	00:07±00:03	00:13±00:05
Non-medication group	00:15±00:10	00:12±00:06	00:48±01:02	00:15±00:07	00:12±00:03	00:15±00:00	00:15±00:04
Wake up time (hh:mm)							
Medication group	07:58±01:04	08:00±00:32	07:44±00:41	08:02±00:08	08:08±00:07	08:10±00:44	08:49±00:52
Non-medication group	06:11±01:22	06:21±01:44	07:18±00:50	07:42±00:20	07:46±00:28	07:37±00:53	07:37±00:37
Get-up time (hh:mm)							
Medication group	09:53±01:11[$]	08:06±00:36	08:13±00:14	08:09±00:11	08:11±00:07	08:22±00:46	09:25±00:58
Non-medication group	07:36±00:39[$]	07:59±00:17	08:00±00:18	08:06±00:21	08:10±00:11	08:52±00:10	08:28±00:58
Total sleep time (hh:mm)							
Medication group	08:43±00:50	07:49±00:48	07:16±00:29	07:39±00:57	07:13±00:54	06:53±00:10	08:34±01:16
Non-medication group	06:11±02:18	06:13±02:16	06:22±02:18	07:13±00:46	08:01±00:20	04:22±02:17	06:35±01:04
Sleep efficiency (%)							
Medication group	78.5±9.7	88.3±11.3	83.3±9.9	83.6±9.9	86.3±11.9	89.8±7.8[$]	88.4±6.7
Non-medication group	69.1±21.5	67.5±21.0	69.0±17.1	83.5±2.8	86.8±5.6	47.4±27.2[$]	66.9±9.7
Subjective sleep quality score (1-5)							
Medication group	2.5±0.5	2.7±0.5	2.7±0.5	2.5±1.0	2.4±0.5	2.3±1.0	2.6±0.9
Non-medication group	2.4±0.5	3.0±0.7	2.8±0.4	2.8±1.0	2.7±0.6	1.8±0.5	2.3±1.0

Table J2. Main effect (Group type and Night:Group type) results for each sleep variable during the first week of condition B.

Bedtime	**df**	**F-value**	**p-value**
Group type	1;7	0.09	0.77
Night:Group type interaction	6;43	0.59	0.74
Sleep onset latency	**df**	**F-value**	**p-value**
Group type	1;9	7.90	0.02
Night:Group type interaction	6;43	2.48	0.04
Wake after sleep onset			
Group type	1;9	0.92	0.36
Night:Group type interaction	6;23	0.97	0.47
Wake-up time	**df**	**F-value**	**p-value**
Group type	1;8	4.98	0.06
Night:Group type interaction	6;42	1.91	0.10
Get-up time	**df**	**F-value**	**p-value**
Group type	1;9	4.66	0.06
Night:Group type interaction	6;43	6.89	<0.0001
Total sleep time	**df**	**F-value**	**p-value**
Group type	1;9	3.60	0.09
Night:Group type interaction	6;43	5.54	0.0003
Sleep efficiency	**df**	**F-value**	**p-value**
Group type	1;9	5.11	0.05
Night:Group type interaction	6;43	5.34	0.0004
Subjective sleep quality score	**df**	χ^2	**p-value**
Group type	1	0.64	0.42
Night:Group type interaction	6	1.29	0.97

df= degrees of freedom (numerator; denominator).