Sleep and Performance in Elite Combat and Contact Athletes

Ian Charles Duncan

MBA  MMineEng  GradCert(ASSc)  BA

This thesis is presented for the degree of Doctor of Philosophy (Sleep Science)

The University of Western Australia
Centre for Sleep Science, School of Human Sciences

2017
Declaration

I, Ian Charles Dunican, certify that: This thesis has been substantially accomplished during enrolment in the degree.

This thesis does not contain material which has been submitted for the award of any other degree or diploma in my name, in any university or other tertiary institution.

No part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of The University of Western Australia and where applicable, any partner institution responsible for the joint-award of this degree.

This thesis does not contain any material previously published or written by another person, except where due reference has been made in the text and, where relevant, in the Declaration that follows.

The work(s) are not in any way a violation or infringement of any copyright, trademark, patent, or other rights whatsoever of any person. The research involving human data reported in this thesis was assessed and approved by The University of Western Australia Human Research Ethics Committee Approval.

This thesis contains published work and/or work prepared for publication, some of which has been co-authored.

Ian Dunican
December 2017
Authorship declaration: Co-authored publications

This thesis contains work that has been published and/or prepared for publication.

**Details of the work:** Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults.

**Authors:** Ian C Dunican, Kevin Murray, James A Slater, Kathleen J Maddison, Maddison J Jones, Brian Dawson, Leon M Straker, John A Caldwell, Shona L Halson and Peter R Eastwood.

**Publication status:** Published in Sleep and Biological Rhythms

Dunican et al., “Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults” Sleep and Biological Rhythms, October 2017, doi:10.1007/s41105-017-0130-x.

**Location in thesis:** Chapter 3

**Student contribution to work:** 90%

**Co-author signatures and dates:**

25th May 2018
### Details of the work: The effects of the removal of electronic devices for 48 hours on sleep in elite judo athletes.

**Authors:** Ian C Dunican, David T Martin, Shona L Halson, Reid Reale, Brian Dawson, John Caldwell, Maddison J. Jones and Peter R Eastwood.

**Publication status:** Published in the Journal or Strength and Conditioning Research


**Location in thesis:** Chapter 4

**Student contribution to work:** 90%

**Co-author signatures and dates:**

25th May 2018

---

### Details of the work: Sleep is an important factor when considering rugby union player load

**Authors:** Ian C Dunican and Peter R Eastwood.

**Publication status:** Letter to the Editor, published in the British Journal of Sports Medicine


**Location in thesis:** Chapter 5

**Student contribution to work:** 90%

**Co-author signatures and dates:**

25th May 2018
| Details of the work: Prevalence of sleep disorders and sleep problems in an elite super rugby union team |
| Authors: Ian C Dunican, Jennifer Walsh, Charles C Higgins, Maddison J Jones, Kathleen Maddison, John A Caldwell, David Hillman, and Peter R Eastwood. |
| Publication status: This chapter is currently in review with the Journal of Sports Science |
| Location in thesis: Chapter 6 |
| Student contribution to work: 90% |
| Co-author signatures and dates: |
| 25th May 2018 |

| Details of the work: Sleep behaviour in an elite Super Rugby team during game |
| Authors: Ian C Dunican, Charles C Higgins, Kevin Murray, Maddison J Jones, Brian Dawson, John A Caldwell, Shona L Halson and Peter R Eastwood. |
| Publication status: This chapter is currently in review with the Journal of Human Kinetics |
| Location in thesis: Chapter 7 |
| Student contribution to work: 90% |
| Co-author signatures and dates: |
| 25th May 2018 |
**Details of the work:** Caffeine use in a Super Rugby game and its relationship to post-game sleep

**Authors:** Ian C Dunican, Charles C Higgins, Maddison J Jones, Michael W Clarke, Kevin Murray, Brian Dawson, John A Caldwell, Shona L Halson and Peter R Eastwood

**Publication status:** Published in the European Journal of Sport Science

doi:10.1080/17461391.2018.1433238

**Location in thesis:** Chapter 8

**Student contribution to work:** 90%

**Co-author signatures and dates:**

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25th May 2018</td>
</tr>
</tbody>
</table>

**Student signature:**

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25th May 2018</td>
</tr>
</tbody>
</table>

I, Peter R Eastwood certify that the student statements regarding their contribution to each of the works listed above are correct. Due to the geographical location of the Co-Supervisors and changes in their roles, we are unable to obtain signatures.

**Coordinating supervisor signature:**

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25th May 2018</td>
</tr>
</tbody>
</table>
**Table of contents**

Declaration ......................................................................................................................... iii
Authorship declaration: Co-authored publications ....................................................... iv
Table of contents ................................................................................................................. ix
List of figures ....................................................................................................................... xv
List of tables ........................................................................................................................ xvii
Abbreviations ...................................................................................................................... xix
List of publications arising from this thesis ................................................................. xxii
List of media coverage arising from this thesis ............................................................. xxiii
Additional contributions to the field during this thesis ................................................... xxv
Acknowledgements ......................................................................................................... xxvii

**Chapter 1**  Introduction ........................................................................................................ 1

1.1 Background ...................................................................................................................... 1
1.2 Methods .......................................................................................................................... 1
1.3 Results ............................................................................................................................ 2
1.4 Conclusions ..................................................................................................................... 4

**Chapter 2**  Literature review: sleep, sleep disorders and performance in athletes ..................................................................................................................... 7

2.1 Sleep and circadian rhythms .......................................................................................... 7
  2.1.1 Introduction to sleep ..................................................................................................... 7
  2.1.2 Brief history of sleep science in humans ..................................................................... 8
  2.1.3 What is sleep? ............................................................................................................... 9
  2.1.4 Why do we sleep? ......................................................................................................... 9
  2.1.5 Circadian rhythms ...................................................................................................... 11

2.2 Measuring sleep ............................................................................................................. 12
  2.2.1 Objective measurement of sleep-Polysomnography .................................................. 12
  2.2.2 Objective measurement of sleep -wrist-activity monitors ......................................... 14
  2.2.3 Subjective measurement- sleep diaries and sleep questionnaires .............................. 15
  2.2.4 Biomathematical modelling for alertness ................................................................. 16

2.3 Sleep, sleep disorders and performance in athletic populations ................................ 19
  2.3.1 Sleep in athletes .......................................................................................................... 19
  2.3.2 Training and sleep in athletes ..................................................................................... 19
  2.3.3 Competition and sleep in athletes ............................................................................ 22

2.4 Sleep and caffeine in athletes ....................................................................................... 24
  2.4.1 Caffeine and the effect on sleep in athletes ................................................................. 24
  2.4.2 Caffeine and performance in athletes ....................................................................... 25

2.5 Sleep and electronic device use .................................................................................. 27
Chapter 3 Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults

3.1 Abstract ................................................................. 64
3.2 Introduction .......................................................... 65
3.3 Methods .................................................................. 67
  3.3.1 Participants .......................................................... 67
  3.3.2 Protocol ............................................................... 67
  3.3.3 Anthropometric measurements ................................. 68
  3.3.4 Sleep diaries .......................................................... 68
  3.3.5 Polysomnography .................................................... 68
  3.3.6 Wrist-Activity Monitors ............................................. 69
  3.3.7 Analyses ................................................................. 69
  3.3.8 Statistical analysis .................................................. 70
3.4 Results .................................................................. 71
  3.4.1 Time at Lights Out ................................................... 71
  3.4.2 Sleep Latency .......................................................... 72
  3.4.3 Time at Sleep Onset .................................................. 73
  3.4.4 Sleep Duration ........................................................ 74
  3.4.5 Wake after Sleep Onset .............................................. 75
  3.4.6 Time at Wake ......................................................... 76
Chapter 8

8.3.1 Experimental overview ................................................................. 167
8.3.2 Demographic and anthropometric measurements ......................... 168
8.3.3 Sleep measures-wrist activity monitor ......................................... 168
8.3.4 Sleep analysis-wrist activity monitor .............................................. 169
8.3.5 Sleep & Training Diary ................................................................. 169
8.3.6 Caffeine measures ......................................................................... 169
8.3.7 Caffeine analysis ............................................................................ 170
8.3.8 Statistical analysis .......................................................................... 170

8.4 Results ............................................................................................... 171
8.4.1 Sleep measures- wrist activity monitor ........................................... 171
8.4.2 Sleep measures - self-reported ....................................................... 174
8.4.3 Associations between self-reported and wrist-activity monitor measures of sleep .......................................................... 174
8.4.4 Caffeine saliva concentrations ......................................................... 175
8.4.5 Self-reported caffeine consumption ................................................ 175
8.4.6 Associations between sleep and caffeine ........................................ 176

8.5 Discussion .......................................................................................... 178
8.5.1 Limitations ...................................................................................... 182
8.5.2 Conclusion ........................................................................................ 183

8.6 References .......................................................................................... 184

Chapter 9

9.1 Overview and summary of thesis ......................................................... 187
9.2 Study population-elite combat and contact athletes ............................... 188
9.3 Participation rates in these studies ....................................................... 189
9.4 Sleep behaviours in elite athletes ....................................................... 190
9.5 Measuring sleep in elite athletes ........................................................ 193
9.6 Sleep disorders and problems in rugby union players .......................... 194
9.7 Biomathematical modelling for alertness in elite athletes .................... 195
9.8 External influences on sleep -Electronic devices, caffeine and post- game behaviour .......................................................... 196
9.9 Limitations/ Challenges ...................................................................... 198
9.10 Practical recommendations ............................................................... 199
9.11 Future Studies ................................................................................... 201
9.12 Summary Statement .......................................................................... 202
9.13 References ......................................................................................... 203
<table>
<thead>
<tr>
<th>Appendix</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix A</td>
<td>Ethics approval letter (for Chapter 3)</td>
<td>207</td>
</tr>
<tr>
<td>Appendix B</td>
<td>Supplementary tables (for Chapter 4)</td>
<td>209</td>
</tr>
<tr>
<td>Appendix C</td>
<td>Ethics approval letter (for Chapter 4)</td>
<td>213</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Information to participants (for Chapter 4)</td>
<td>215</td>
</tr>
<tr>
<td>Appendix E</td>
<td>Informed consent form – minor (for Chapter 4)</td>
<td>217</td>
</tr>
<tr>
<td>Appendix F</td>
<td>Sleep and Training Diary (used in Chapters 4, 6, 7 and 8)</td>
<td>219</td>
</tr>
<tr>
<td>Appendix G</td>
<td>Ethics approval letter (for Chapters 6, 7 and 8)</td>
<td>225</td>
</tr>
<tr>
<td>Appendix H</td>
<td>Information to participants (for Chapters 6, 7 and 8)</td>
<td>227</td>
</tr>
<tr>
<td>Appendix I</td>
<td>Informed consent form – adult (for Chapters 6, 7 and 8)</td>
<td>231</td>
</tr>
<tr>
<td>Appendix J</td>
<td>Supplementary figures (for Chapter 8)</td>
<td>233</td>
</tr>
</tbody>
</table>
List of figures

Figure 1  Two-process model of sleep and wake..................................................17
Figure 2  Time at Lights Out (hours),.................................................................72
Figure 3  Sleep latency (Minutes).................................................................73
Figure 4  Time at sleep onset (hours),..........................................................74
Figure 5  Sleep duration (minutes)...............................................................75
Figure 6  Wake after sleep onset (minutes) .........................................................76
Figure 7  Time at wake (hours)........................................................................77
Figure 8  Sleep efficiency (%)........................................................................78
Figure 9  Electronic device usage between groups. ........................................102
Figure 10 Example of SAFTE graphical output of alertness .........................148
Figure 11 Measures of Sleep, Game vs Non-Game Group............................152
Figure 12 Measures of Alertness.....................................................................154
Figure 13 Measures of objective sleep vs self-reported sleep .....................173
Figure 14 Pre-Game vs Post-Game caffeine consumption ..........................175
Figure 15 Associations between sleep and caffeine.....................................177
Figure 16 Rugby players participation in studies...........................................190
Figure S1  (Supp Chapter 8) – Individual sleep related data .........................233
Figure S2  (Supp Chapter 8) – Proposed pharmacokinetics of caffeine..........234
List of tables

Table 1  Sleep stages and characteristics.................................................................13
Table 2  Wrist-Activity and PSG measures..............................................................71
Table 3  Descriptive characteristics of the sample population .................................101
Table 4  Actigraphy data ..........................................................................................105
Table 5  Demographic and Anthropometric Data.......................................................130
Table 6  Sleep Data-Polysomnography ..................................................................131
Table 7  OSA vs Non OSA.........................................................................................132
Table 8  PLM vs Non-PLM......................................................................................133
Table 9  Sleep related questionnaire data.................................................................134
Table 10 Descriptive characteristics of Game vs Non-Game Group..........................150
Table 11 Demographic and self-reported caffeine consumption (n=20) .................176
Table 12 Comparison of sleep measures from studies.............................................193
Table S1 (Supp Chapter 4) Training and electronic device use (self-reported) .....209
Table S2 (Supp Chapter 4) Sleep diary- data (self-reported) ...................................210
Table S3 (Supp Chapter 4) Cognitive Performance..................................................211
Table S4 (Supp Chapter 4) Physical Performance....................................................211
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASM</td>
<td>American Academy of Sleep Medicine</td>
</tr>
<tr>
<td>AHI</td>
<td>Apnea Hypopnea Index</td>
</tr>
<tr>
<td>AIS</td>
<td>Australian Institute of Sport</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>BCE</td>
<td>Before Christian Era</td>
</tr>
<tr>
<td>BW</td>
<td>Bodyweight</td>
</tr>
<tr>
<td>BMI</td>
<td>Body Mass Index</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>Cm</td>
<td>Centimetres</td>
</tr>
<tr>
<td>CG</td>
<td>Control Group</td>
</tr>
<tr>
<td>DRG</td>
<td>Device Restricted Group</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrocardiography</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>EOG</td>
<td>Electooculography</td>
</tr>
<tr>
<td>ESS</td>
<td>Epworth Sleepiness Scale</td>
</tr>
<tr>
<td>FDA</td>
<td>Federal Drug Administration</td>
</tr>
<tr>
<td>GABA</td>
<td>Gamma-Aminobutyric Acid</td>
</tr>
<tr>
<td>hr</td>
<td>Hour</td>
</tr>
<tr>
<td>HR</td>
<td>Heart rate</td>
</tr>
<tr>
<td>IRLSG</td>
<td>International Restless Leg Study Group</td>
</tr>
<tr>
<td>ISI</td>
<td>Insomnia Severity Index</td>
</tr>
<tr>
<td>Kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>LCMS/MS</td>
<td>Liquid chromatography tandem mass spectron</td>
</tr>
<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
</tr>
<tr>
<td>LO</td>
<td>Lights Out</td>
</tr>
<tr>
<td>LOA</td>
<td>Limits of Agreement</td>
</tr>
<tr>
<td>mg</td>
<td>Milligram</td>
</tr>
<tr>
<td>µg/ml</td>
<td>Milligrams per millimetre</td>
</tr>
<tr>
<td>min</td>
<td>Minutes</td>
</tr>
<tr>
<td>NFL</td>
<td>National Football League</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>NREM</td>
<td>Non-Rapid Eye Movement</td>
</tr>
<tr>
<td>OSA</td>
<td>Obstructive Sleep Apnoea</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>PLMs</td>
<td>Periodic Leg Movements</td>
</tr>
<tr>
<td>PLMI</td>
<td>Periodic Leg Movement Index</td>
</tr>
<tr>
<td>PSG</td>
<td>Polysomnography</td>
</tr>
<tr>
<td>PSQI</td>
<td>Pittsburgh Sleep Quality Index</td>
</tr>
<tr>
<td>PVT</td>
<td>Psychomotor Vigilance Test</td>
</tr>
<tr>
<td>REM</td>
<td>Rapid Eye Movement</td>
</tr>
<tr>
<td>RPE</td>
<td>Rating of Perceived Exertion</td>
</tr>
<tr>
<td>SAFTE</td>
<td>Sleep, Activity, Fatigue, and Task Effectiveness</td>
</tr>
<tr>
<td>SaO2</td>
<td>Blood Oxygen Saturation</td>
</tr>
<tr>
<td>SD</td>
<td>Sleep Duration</td>
</tr>
<tr>
<td>SE</td>
<td>Sleep Efficiency</td>
</tr>
<tr>
<td>SLTHT</td>
<td>Single Leg Triple Hop Test</td>
</tr>
<tr>
<td>SOL</td>
<td>Sleep Onset Latency</td>
</tr>
<tr>
<td>SWS</td>
<td>Slow Wave Sleep</td>
</tr>
<tr>
<td>TASO</td>
<td>Time at Sleep Onset</td>
</tr>
<tr>
<td>TIB</td>
<td>Time in Bed</td>
</tr>
<tr>
<td>TST</td>
<td>Total Sleep time</td>
</tr>
<tr>
<td>TV</td>
<td>Television</td>
</tr>
<tr>
<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>UWA</td>
<td>University of Western Australia</td>
</tr>
<tr>
<td>WASO</td>
<td>Wake After Sleep Onset</td>
</tr>
<tr>
<td>WMZ</td>
<td>Wake Maintenance Zone</td>
</tr>
</tbody>
</table>
List of publications arising from this thesis

Peer-reviewed, open-literature publications and book chapters


Ian C Dunican, Peter R Eastwood, “Sleep is an important factor when considering rugby union player load” British Journal of Sports Medicine, November 2016 doi:10.1136/bjsports-2016-097122.

Conference proceedings arising from this thesis

Ian C Dunican, Kevin Murray, James A Slater, Kathleen J Maddison, Maddison J Jones, Brian Dawson, Leon M Straker, John A Caldwell, Shona L Halson and Peter R Eastwood. “Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults” Western Australian Pregnancy Cohort (Raine) Study, 10th Annual Scientific Meeting, 20th October 2017, UWA.


Poster presentations arising from this thesis


Awards arising from this thesis

Travel Award for Early Career Researcher Research Excellence Award, 23rd International Symposium on Shift-work and Working Time, 19-23rd of June 2017.
List of media coverage arising from this thesis

Community publications, newspaper and e-publications


2. Ian C Dunican, Blitz, Martial Arts Magazine, “The role of sleep for recovery for combat athletes” 2017 (Self-authored)


9. Ian C Dunican, Daily Mail UK, What's the key to a good night's sleep? The answer lies in your pre-bed routine, 21st June 2016.


Radio

1. Ian C Dunican, Australian Broadcasting Corporation (ABC), Perth, Mornings with Peter Bell, “Fatigue, sleep and performance” November 8th, 2017.

2. Ian C Dunican, Australian Broadcasting Corporation (ABC), Drive, Regional WA “Ageing and poor sleep” October 17th, 2017.


10. Ian C Dunican, Mix 94.5, Clairsy, Matta and Kymba, Breakfast Show, Perth, Western Australia, 22nd June 2016.


Television and online viewing


2. Ian C Dunican, Channel 7 News “Western Force and Sleep”

3. Ian C Dunican, UWA media “Western Force and Sleep” Feb 6th, 2017


5. Ian C Dunican, UWA media, “Let Teenagers Sleep In,” June 2017


Podcasts


Additional contributions to the field during this thesis

Peer-reviewed, open-literature publications and book chapters


Conference papers and presentations

M Jones, P Peeling, B Dawson, S Halson, J Miller, I Dunican, M Clarke, C Goodman, P Eastwood; The effects of evening electronic device use on sleep in highly trained athletes, Sleep, Volume 40, Issue suppl_1, 28 April 2017, Pages A36, https://doi.org/10.1093/sleepj/zsx050.094


Invited reviewer

5. Ian C Dunican, Behavioural Sleep Medicine, May 2015.
6. Ian C Dunican, Behavioural Sleep Medicine, August 2015.
Acknowledgements

The undertaking of a Ph.D. has been a significant learning experience in my life and one that I have thoroughly enjoyed, even through the most difficult and arduous days. I am grateful for my experience at the University of Western Australia (UWA) in conjunction with the Australian Institute of Sport (AIS) and the Western Force. The decision to undertake a Ph.D. on a full-time basis after working for 18 years in military and mining was one that was carefully considered. If it was not for the belief, love and support that my wife Kathryn has placed in me, I would not be writing this thesis, that is brought to you today.

I would like to thank to my Supervisor Professor Peter Eastwood who has supported me in the development and execution of this thesis. I am appreciative of the time you have spent with me in guiding the development of this thesis and your energy and enthusiasm on this journey.

To my co-supervisors; Professor Brian Dawson (UWA), Dr. David Martin and Dr. Shona Halson (AIS), many thanks for your expert knowledge and feedback during this research. In particular I would like to thank Dr. John Caldwell who provided a wealth of experience, knowledge and guidance as an external supervisor and mentor.

To A/Professor Kevin Murray who coached, guided and educated me in statistics throughout this thesis and ignited a new interest in mathematics and statistics. To the staff at the Centre for Sleep Science, UWA. In particular many thanks to Dr. Jennifer Walsh and Dr Kathleen Maddison for their collaboration and guidance. I would also like to thank my fellow Ph.D. students who have collaborated, supported and problem solved with me, in particular Maddison Jones and James Slater.
Many thanks to the Australian Institute of Sport, Combat Centre, in particular the Judo athletes that participated in our research. To Dr. Reid Reale, Dr. Israel Halpern, Dr. Nathan Versey and Dr. Clare Humberstone who always supported and assisted me when I was at the Australian Institute of Sport.

Many thanks to the coaching and athletic staff and most importantly the players at the Western Force for participating in these research studies. In particular, I would like to thank Michael Foley, David Wessels, Charlie Higgins, Will Marwick and the athletic performance staff at the Western Force.

I would also like to thank and acknowledge the Raine Study participants, their families and the Raine study team for cohort management and data collection in the study in chapter three.

Many thanks to Fatigue Science, Vancouver, British Columbia, Canada for the supply of the Readiband™, Readiband Sync™ and Safety Alertness Fatigue Task Effectiveness (SAFTE™) biomathematical model and thanks to Cogstate Ltd Research, Melbourne, Victoria, Australia for the supply of Cogstate testing software.

Thanks to my friends who spent countless hours trail running with me and my friends in the Brazilian Jiu-Jitsu community. Maintaining a healthy and fit lifestyle has supported my ability to undertake this research.

This research was supported by an Australian Government Research Training Program (RTP) Scholarship.
“You must understand that there is more than one path to the top of the mountain”

Miyamoto Musashi
Chapter 1  Introduction

1.1  Background

Sleep is increasingly recognised as being an essential component of performance and recovery in elite athletes. Sleep may be negatively affected during training and competition as a result of factors such as the use of ergogenic aids including caffeine, the evening use of electronic devices and the potential presence of sleep disorders, all of which can also affect cognition, alertness and physical performance of athletes.

The five studies described in this Ph.D. thesis sought to: (1) validate a wrist-activity monitor to provide automated measures of sleep; (2) determine the effects on sleep and performance of elite judo athletes when electronic devices are temporarily removed; (3) describe the changes in sleep, wake and alertness in elite rugby players before and after an evening Super Rugby game; (4) describe game-related changes in saliva caffeine levels and sleep in elite rugby players before and after an evening Super Rugby game; and (5) determine the prevalence of undiagnosed sleep disorders in a professional rugby team.

1.2  Methods

Studies were undertaken in 50 middle-aged adults from a community population sample to determine the validity of a wrist-activity monitor (Readiband™) to assess sleep. Results from two wrist-activity monitors (Readiband and ActiGraph™) were compared against measurements obtained from an in-laboratory polysomnography (PSG) study and against each other when worn at home for 7-nights (Study 1). The Readiband device was then used to assess sleep in elite judo athletes and elite rugby union players. Study 2 examined the effects on cognition and physical performance of
the temporary removal of electronic devices. Over 6 consecutive days and nights, 23 elite Australian Judo athletes were monitored while attending a camp at the Australian Institute of Sport (AIS). In 14 athletes, all electronic devices were removed on days 3 and 4 of the camp (i.e. for 48 hours: the “device-restricted group”) while 9 were permitted to use their devices throughout the camp (the “control group”), electronic devices were returned to the device-restricted group on days 5 and 6. Self-reported sleep measures, electronic device use, and rate of perceived exertion during training periods were collected from each athlete. Study 3 assessed sleep/wake patterns and alertness using a biomathematical model, Safety Alertness Fatigue Task Effectiveness (SAFTE™), in 36 rugby players over a 7-day period that included the night of an evening game (of particular interest were the sleep patterns in those selected to play the game (n=23) and those who did not (n=13)). Study 4 described game-related saliva caffeine levels and associated sleep patterns in 23 rugby players by collecting and analysing saliva samples before (17:00) and after (21:30) an evening home game (19:00-21:00). Study 5 sought to determine the prevalence of sleep disorders in 25 elite rugby players using laboratory-based PSG and sleep-specific questionnaires.

1.3 Results

Study 1: Compared to a night of in-laboratory PSG, the Readiband device underestimated time at lights out, sleep onset, and wake after sleep onset, and overestimated sleep latency and sleep duration (p<0.001 for all) while the ActiGraph device underestimated sleep latency and wake after sleep onset and overestimated sleep efficiency and duration (p<0.001 for all). Similar differences in sleep measures were observed between devices when worn on the laboratory night and at home.
Study 2: Removal of electronic devices for a period of 48-hrs did not alter any sleep-related measures, physical or cognitive function between groups (device-restricted vs control group) in judo athletes. On the last morning of the camp the time of wake was later in both groups (p<0.05), which resulted in an increase in sleep duration, significantly so in the control group (p<0.05). When comparing Readiband measures of sleep to subjective reports of their sleep, athletes significantly overestimated their sleep duration by 58±85 mins (p<0.001) per night and underestimated time of sleep onset by 37±72 mins (p<0.001) per night.

Studies 3 and 4: In those rugby players selected to play in the game, sleep duration progressively increased on the three nights prior to the game (by 92 min, p<0.05). Compared to these three pre-game nights, players who were selected to play went to bed very late after the game (02:20±1:54 vs 22:57±1:00 hh:mm; p<0.001) and had decreased sleep duration compared to pre-game nights (296±179 vs 459±78 min; p<0.05) with four players not achieving any sleep after the game. Levels of alertness, as estimated by SAFTE, were >90% for all training and game times, for all 36 players. Post-game saliva caffeine concentrations were substantially greater than pre-game levels (0.40 vs 2.77ug/ml, p<0.001).

Study 5: Mild obstructive sleep apnea (OSA) (assessed by an apnea hypopnea index (AHI) >5 events per/hour) was present in 24% (n=6) of players. An abnormally high number of periodic leg movements during sleep (i.e. a period leg movement index > 15 events/hour) were seen in 12% (n=3) of players. All players (n=25) were categorised as having sub-threshold insomnia (Insomnia Severity Index (ISI) score between 8 and 14) and excessive daytime sleepiness (Epworth Sleepiness Scale (ESS) >10).
1.4 Conclusions

Obtaining meaningful field-based measurements of sleep and wake patterns in professional athletes, particularly those participating in combat sports such as judo and contact sports such as rugby, requires a device that is non-intrusive, robust, reliable, accurate and does not require user input. The initial study undertaken in this thesis showed that the Readiband wrist-worn activity monitor met all of these requirements and was similarly accurate to the ActiGraph device for measuring sleep when worn in a sleep laboratory and at home.

The second study of the thesis found that removal of electronic devices for a period of 48-hrs had no effect on the time of sleep onset or sleep duration of elite judo athletes who were attending a training camp. It is possible that such a finding is limited to the young elite athletes who participated in the current study, as this age group will participate in late evening use of electronic devices and high social media use, and tend to have an “owl” chronotype, characterised by a delayed time of sleep onset. Such biological and behavioural factors make it difficult to encourage athletes to go to bed earlier and increase their sleep duration in this way, whereas allowing athletes to sleep later the next morning might be a more productive strategy to increase sleep duration. In this regard, it was notable that these young adult athletes increased sleep duration by delaying wake time when such an opportunity was provided on the final day of the training camp. A practical recommendation of this study could be that daily training start times should be delayed until after 08:00 in young athletes. In more general terms, the scheduling of training camps should be designed to consider sleep and recovery in order to optimise training efficacy, consolidation of skills and overall performance.

The third study, undertaken in rugby players showed that sleep duration progressively increased in the nights leading up to a Super Rugby home game,
particularly in those individuals selected to play in the game. The increase in sleep duration was mainly due to a delay in the wake time on the two days before a game. This delay in time of wake in the morning was supported by the athletic staff who scheduled training sessions for late morning or afternoon. These findings are consistent with those from the judo athletes (Study 2), in whom a delay in early morning scheduling led to an increase in sleep duration due to a delayed time at wake. In rugby players sleep after a game is significantly delayed and reduced compared to all other nights. This may be due to several factors including the effects of cognitive and physical stimulation associated with playing a game late in the evening, the need to participate in a post-game recovery session and contractual requirements to participate in post-game media conferences. It is also possible that increased post-game caffeine levels due to caffeine consumption may contribute to the delay in time of sleep onset, as was shown in Study 4.

A surprising finding in the fifth study was the extremely high prevalence (100%) of daytime sleepiness and sub-threshold insomnia. While the questionnaires used to determine sleepiness and insomnia, namely the ESS and the ISI, have been validated for use in the general population, it is likely that the high scores in the athletes are due to factors other than the presence of sleep disorders. Such factors could include the effects on sleep of daily training sessions, injury, travel resulting in circadian misalignment and pre-and post-competition. These findings point to the need to develop and validate sleepiness and insomnia questionnaires specifically for use in athletes.

The fifth study also showed that the prevalence of OSA in a rugby union team was 24%. This is comparable to OSA prevalence estimates in National Football League players (19%), but lower than recent estimates in the general population (up to 50%). It was notable that there was no difference in prevalence rates between forward and
backs, despite marked differences in BMI. Such a finding suggests that BMI, one of the strongest risk factors for OSA in the general population, might not be an important risk factor in the development of OSA in professional rugby union players. Regardless of the underlying mechanism, OSA results in fragmented sleep which could adversely affect elite athletic performance. In this regard, it was notable that 12% of players had an abnormally high number of periodic leg movements during sleep, which could also decrease sleep quality and impair performance. These findings suggest that elite sports teams should considering implementing processes to identify and manage players for sleep disorders.
Chapter 2  Literature review: sleep, sleep disorders and performance in athletes

2.1  Sleep and circadian rhythms

2.1.1  Introduction to sleep

Sleep is essential for human survival [1] and the human body’s basic physiological functioning, such as thermoregulation [2, 3] and immune function [4]. Sleep is a process that supports physiological and psychological recovery to enable next day physical [5] and cognitive performance [6]. Loss of sleep can lead to lapses in attention [7, 8] and a decline in neurocognitive performance [7, 9] including decrements in reaction time [10].

In recent years, there has been a significant increase in the number of published scientific papers relating to sleep and athletic performance [6, 11-38]. This literature review summarised our current knowledge of the relationships between sleep and performance in elite or highly trained athletes from both individual and team sports. Where major gaps in the literature currently exist, knowledge of similar associations from shift work and military research are reviewed to help inform the interactions between sleep and performance.

This literature review is divided into three sections. The first section provides an introduction to sleep, including the history of sleep and its function. The second section focuses on the current methods for measuring sleep, ranging from the objective gold standards to subjective self-reported measures. The third section focuses on sleep, sleep disorders and performance as they pertain to athletic populations.
2.1.2 Brief history of sleep science in humans

The precise function of sleep has puzzled and challenged the scientific and philosophical community for over 2,000 years. Early Greek philosophers hypothesised that we become sleepy or initiated sleep due to ‘vapours from the food we consumed’ [39]. In 350 BCE, Aristotle developed the first scientific theory of sleep whereby he hypothesised that the function of sleep was for digestion and that a person awakes from sleep when digestion is complete [39]. Such food-related hypotheses continued for over 1,500 years through to the middle ages.

In 1729, the first recorded observations of the presence of biological rhythms came from a French scientist and chronobiologist, Jean Jacques d'Ortuous de Marian who was intrigued by the daily opening and closing pattern of the mimosa plant. De Marian placed the plant in a dark room for several days and observed that even in the absence of sunlight, that the plants continued their diurnal pattern of leaf opening and closing [40]. This observation would later support the discovery of circadian rhythms in humans [40, 41].

Further insight into the dynamic changes in human physiology during sleep came with the invention of the electroencephalogram (EEG) in the 1930s. In 1937, Loomis [42] discovered that during sleep the waves generated by the brain slowed and became larger in amplitude, compared to when wake. Further understanding of sleep physiology came in 1952, when Aserinsky placed EEG electrodes near the eyes of a child whilst they slept and observed regular bursts of electrical activity [43]. This led Aserinsky & Kleitman to coin the phrase Rapid Eye Movement (REM) and was considered to be the “time for dreaming” with REM periods occurring on average every 90 minutes, and during which time the brain was believed to become active [42,
This discovery led to the development of sleep stages by Rechtschaffen & Kales who categorised sleep into distinct stages of REM and non-REM (NREM) sleep.

### 2.1.3 What is sleep?

One of the many definitions for sleep is “A condition of body and mind which typically recurs for several hours every night, in which the nervous system is inactive, the eyes closed, the postural muscles relaxed, and consciousness practically suspended” [45] With sleep accounting for one third of our lives, it can be classified into two distinct types, being Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM). These classifications include specific stages of sleep that have been categorised according to the criteria of the American Academy of Sleep Medicine (AASM). In this system NREM sleep consists of two light stages of sleep (N1 and N2), and a deeper stage of sleep, slow wave sleep (N3). Progression and maintenance of each stage is characterised by specific changes in EEG, movement, respiration, and eye movements [46].

During a typical sleep period over an 8-hr period, an individual will spend 5% in N1, 50% in N2, 20% in N3, and 25% in REM. These sleep stages, and the length of time spent in each stage, oscillate throughout the night. The first cycle lasts between 70-100 mins in duration with subsequent sleep cycles lasting 90-120 mins. The most prevalent being NREM and prioritised early in the sleep period. REM sleep durations tend to increase over the course of the sleep period.

### 2.1.4 Why do we sleep?

The precise reason why humans sleep is still unknown [47]. However, many theories of the purpose of sleep have been developed. Much of our understanding of the physiological and psychological processes that occur during sleep comes from


research into deprivation of sleep. Sleep loss and deprivation has vast impacts on cognition, physical performance, metabolism, growth hormone function and memory consolidation [48-50].

Cognitive performance is greatly affected by a lack of sleep and its decline is related in part, to the sustained hours of wakefulness. This has been observed by a dose response relationship with increasing sleep restriction and a negative impact on cognitive performance. In a landmark study by Van Dongen and colleagues [7], the impact of sleep restriction of four, six and eight hours per night for 14 days, or 3 days of total sleep deprivation, resulted in significant cumulative negative effects on reaction time, as assessed using psychomotor vigilance testing (PVT). The study also demonstrated that the greater the hours of wakefulness the greater the decrements on PVT performance.

Sleep has been found to support physical recovery in humans following exercise or strenuous work [51] and is an important process to enable subsequent peak physical performance. It is during N3 sleep that growth hormone is released. This is important for supporting physical repair and recovery for next day performance [52]. Physical repair requires the release of growth hormone, such as testosterone, which is a key component for skeletal muscle health which is also important for physical health and wellbeing in humans [53].

Sleep disruption leading to sleep loss will negatively affect the regulation of these growth and other hormones resulting in a negative effect on metabolic and endocrine functions including, decreased glucose tolerance, decreased insulin sensitivity, and an increase in evening cortisol [54]. In conjunction with growth hormone, appetite
regulation is controlled by hormones such as leptin and ghrelin, both of which are linked to the timing and duration of sleep [54].

### 2.1.5 Circadian rhythms

The rhythmic pattern that pertains to sleep is a circadian rhythm. The word “Circadian” comes from the Latin words “Circa” meaning “about” and “Dia” meaning “a day” and describes our internal biological rhythms which oscillate on a near 24-hr cycle [55]. The endogenous pacemaker responsible for its regulation is called the suprachiasmatic nuclei (SCN) and is located at the base of the hypothalamus [56]. The SCN is often referred to as the body’s master clock, as it coordinates the rhythmic fluctuations of many physiologic and behavioral processes, including cardiovascular, digestive, and respiratory processes, morning cortisol secretions, body temperature [57] and metabolic changes [58]. The circadian clock receives external inputs from the environment known as zeitgebers (i.e. time givers). The major naturally occurring circadian zeitgeber is natural light, which entrains the SCN to the Earth’s solar day [59], although artificial light also contributes to entrainment of the SCN. In addition, other zeitgebers support this entrainment using social cues such as meal times, work or training times.

Circadian rhythms govern our sleep-wake cycle. Within a 24-hr period, the circadian pacemaker will typically promote wakefulness for 16-hrs, followed by promotion of sleep for 8-hrs. The sleep-wake rhythm is also associated with rhythmic fluctuations in sleep-related hormones, whereby, upon waking, morning cortisol increases and melatonin decreases [60, 61]. In the afternoon, we experience a circadian nadir often referred to as the “post-lunch dip”. During this period, it can be difficult to maintain cognitive vigilance, hence the development of a culture of “Siesta” in
certain countries to allow for a short sleep period or nap. In the evening, the 2-3 hours before bedtime is known as the “forbidden zone” or the Wake Maintenance Zone (WMZ) [62]. The WMZ is the most difficult time to sleep due to low sleep propensity [63]. Likewise, during the WMZ, cardiovascular efficiency and muscular strength are at their peak. Later in the evening, progressing into the night, cortisol levels decline and melatonin in synthesised in the pineal gland. These endogenous processes in conjunction with an increase in sleep pressure from sustained wakefulness result in an increased drive for sleep. During the late evening body temperature declines and the onset and subsequent functions of sleep occur.

2.2 Measuring sleep

2.2.1 Objective measurement of sleep-Polysomnography

Polysomnography (PSG) is the objective gold standard for measuring, monitoring and assessing sleep in humans [64, 65]. The PSG method can be used to investigate and diagnose sleep disorders including, but not limited to, obstructive sleep apnea (OSA) and periodic leg movements (PLMs) [65-67].

Typically, during a PSG study a person is instrumented by a sleep technician. The most widely accepted protocols are described by the American Academy Sleep Medicine (AASM) [68, 69]. Electroencephalogram (EEG), electrooculogram (EOG) and chin electromyogram (EMG) are measured using surface electrodes. Respiration is monitored with nasal prongs, an oronasal thermistor, thoracic and abdominal respiratory bands. Blood oxygen saturation ($\text{SaO}_2$) and heart rate are monitored continuously from a pulse oximeter on the index finger. Leg movements are monitored by EMG electrodes placed over the tibialis anterior muscle. A position sensor, microphone and a live video feed via an infrared camera are used to monitor body
position and snoring. The data from the PSG is then scored for the staging of sleep according to the AASM rules (2012 being the most recent rules) [70]. An overview and description of these sleep stages are shown in Table 1 below.

Table 1  Sleep stages and characteristics

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description of Stages of Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake</td>
<td>• Electroencephalography (EEG) low amplitude.</td>
</tr>
<tr>
<td></td>
<td>• Mixed frequency 8-13 Hertz (Hz) activity recorded over the occipital region eye closure,</td>
</tr>
<tr>
<td></td>
<td>attenuating with eye opening.</td>
</tr>
<tr>
<td></td>
<td>• Electrooculography (EOG) 0.5-2 Hz present in wakefulness with the eyes open or closed.</td>
</tr>
<tr>
<td>NREM N 1</td>
<td>• Low-amplitude, predominantly 4-7 Hz.</td>
</tr>
<tr>
<td>Light Sleep</td>
<td>• Vertex sharp waves.</td>
</tr>
<tr>
<td></td>
<td>• Sharply contoured waves with duration &lt;0.5 seconds maximal over the central region.</td>
</tr>
<tr>
<td></td>
<td>• No presence of alpha waves.</td>
</tr>
<tr>
<td>NREM N 2</td>
<td>• K-complex’s: prominent negative, sharp wave immediately followed by a positive component.</td>
</tr>
<tr>
<td>Light Sleep</td>
<td>• EEG, with total duration &gt;0.5 seconds.</td>
</tr>
<tr>
<td></td>
<td>• Sleep spindles: sinusoidal waves with frequency 11-16 Hz (most commonly 12-14 Hz) with</td>
</tr>
<tr>
<td></td>
<td>a duration &gt;0.5 seconds in the central derivations.</td>
</tr>
<tr>
<td>NREM N 3</td>
<td>• Low wave activity with a frequency 0.5 Hz-2 Hz and peak-to-peak amplitude &gt;75</td>
</tr>
<tr>
<td>Deep Sleep</td>
<td>µV, measured over the frontal regions.</td>
</tr>
<tr>
<td>REM Sleep</td>
<td>• Rapid Eye Movement (REM), conjugate, irregular and sharply peaked eye movements.</td>
</tr>
<tr>
<td></td>
<td>• Low chin Electromyography (EMG) tone.</td>
</tr>
<tr>
<td></td>
<td>• Saw tooth waves sharply contoured 2-6 Hz waves maximal in amplitude over the central</td>
</tr>
<tr>
<td></td>
<td>region.</td>
</tr>
<tr>
<td></td>
<td>• Transient muscle activity with short irregular bursts of EMG activity usually with a</td>
</tr>
<tr>
<td></td>
<td>a duration &lt;0.25 seconds on the chin or anterior tibia.</td>
</tr>
</tbody>
</table>

The PSG examination of sleep provides a gold standard measurement of sleep timing, including; time in bed (TIB) (the total time spent in bed, from lights out until time at wake); total sleep time (number of minutes from time of sleep onset to time at wake, minus number of minutes awake); sleep efficiency (SE) (total sleep time divided by time in bed multiplied by 100); sleep onset latency (SOL) (number of minutes from
time at lights out to time of sleep onset); rapid eye movement (REM) latency (number of minutes from sleep onset until the first epoch of REM sleep) and time awake after sleep onset (WASO; number of minutes awake after sleep onset).

2.2.2 Objective measurement of sleep -wrist-activity monitors

A major limitation of PSG is the difficulty of its application in normal living environments. For this reason, alternative measures of sleep approximation were developed, including wrist activity monitors. Wrist-activity monitors are often referred to as actigraphy devices. They are a watch sized device [71], typically worn on the non-dominant wrist of a person [72]. These devices use a tri-axial accelerometer to determine periods of ‘movement’ and or ‘non-movement’. The periods of ‘non-movement’ can be defined as periods of sleep and the periods of ‘movement’ as periods of wake. The wrist-activity monitors can be worn continuously for extended periods (7-30 days) depending on the capability and battery life of the device.

Wrist-activity monitors can provide an alternative to measuring sleep/wake periods for many applications such as in shiftworkers, military roles and applied research settings with elite athletes. They can also be used as a preliminary screening method for certain sleep disorders such as circadian rhythm disorders, shiftwork disorder and insomnia [73]. They are most useful for the collection of longitudinal data in conjunction with sleep diaries for the diagnoses of sleep disorders such as insomnia [74] and may assist in objectively determining the effects of jet-lag.

In recent years there has been an huge increase in the availability of consumer based wrist-activity monitors that incorporate an accelerometer to measure sleep and activity [75, 76]. Many of these devices can be connected to other devices such as a smartphone and or a tablet to download the previous night’s sleep and provide instant
measures of sleep behaviour. A number of these consumer based devices have undergone validation against in-laboratory measures of sleep from PSG [74, 75]. In general, the sleep measures reported from these devices include sleep duration, awakenings, time at sleep onset and the time at wake. The positive nature of the user experience of these wrist-activity monitors is the main reason for the increased use of wrist-activity monitors amongst the general community. Such popularity in the general population and in elite athletes is beneficial in terms of improving awareness and understanding of an individual’s sleep [77], as sleep has been an area of health and performance that has been historically ignored. However, due to the rapid increase in the number of devices, the validity of these devices and their automated propriety scoring algorithms remains unknown for many.

2.2.3 Subjective measurement- sleep diaries and sleep questionnaires

In accordance with AASM recommendations, wrist-activity monitoring should be used in conjunction with sleep diaries [78]. The sleep diary allows the participant to self-report sleep measures such as lights out (LO), sleep latency (SL), time at sleep onset (TASO), wake after sleep onset (WASO) and time at wake (TAW). The diary is particularly useful when comparing a participant's self-reported sleep (i.e. perceived) behaviour against objective sleep measures from a wrist-activity monitor [79]. Many wrist-activity monitors (e.g. ActiGraph™) require certain sleep diary measures to be inputted into the device's algorithm for the calculation of certain sleep measures. However, the use of a sleep diary can be problematic as there is known variability between self-reported measures of sleep and actual sleep timing obtained from objective methods [80]. Furthermore, many studies that exclusively report sleep diary data as the primary sleep measures are less reliable due to missing data or participant incorrect recall [81].
Sleep-related questionnaires are commonly used to assess state and trait levels of sleepiness and or the potential prevalence of a sleep disorder. The administration of this method is non-intrusive, easy to complete and easy to score by the administrator of the questionnaires. Commonly used validated sleep related questionnaires include; the Epworth Sleepiness Scale (ESS), Insomnia Severity Index (ISI), Berlin Questionnaire, Morning Evenign Questionnaire (MEQ) and the Pittsburgh Sleep Quality Index (PSQI) [19]. These sleep related questionnaires have been developed for use in general population, and in particular in those with existing sleep disorders.

2.2.4 Biomathematical modelling for alertness

Biomathematical modelling is described as the use of a combination of biological factors and mathematical formulas to provide a numerical output that can be equated to performance, risk, alertness or cognitive impairment depending on the model. The development and current use of biomathematical modelling for alertness can be attributed to two main studies [82, 83] which introduced the concepts of the two-process model and the three-process model [84]. More recent models have built upon these theories and included additional inputs, such as the effect of light [85]. These models have been designed to allow the proactive use of natural or artificial light to promote circadian adaptation.

The two-process model consists of the interaction between the homeostatic sleep pressure (S), which builds up with wakefulness, and the circadian process (C) relating to the biological time of day [82]. As a basic principle, the longer a person is awake, the greater the drive for sleep. When sleep occurs, the drive for sleep dissipates (Figure 1). The three-process model includes sleep and the circadian process and a third process based upon waking (W) or sleep inertia [83]. Sleep inertia is the groggy
transient state from sleep to awake. The duration of sleep inertia is greatly influenced by time of day and the individual’s physiology [84].

![Diagram of sleep and wake cycles](image)

**Figure 1** Two-process model of sleep and wake

Biomathematical modelling has been used successfully for the design, evaluation and assessment of work hours or for optimisation of physical and human resources in military, rail and aviation [86-88]. In an aviation setting, these models have aided in designing schedules to predict and minimise jet-lag or to optimise pilot and crew’s alertness state post travel. Whilst these models have been utilised in a variety of applications, to date there is no published research where biomathematical modelling has been utilised for the design, evaluation or assessment of training and travel schedules to optimise alertness for elite athletes (individual or teams).

There are a number of models available for use in research or commercial applications, including the Fatigue Audit Inter Dynamics (FAID), UK Health and Safety Executive Fatigue Index (HSE FI), Circadian Alertness Simulator (CAS), or Safety Alertness Fatigue Task Effectiveness (SAFTE). Each model has advantages and disadvantages. These have been assessed against a set of criteria in a comparison of mathematical model predications of fatigue and performance [89].
SAFTE is one model that has been used in applied settings such as the military, shift workers and may be beneficial for planning of athletic activities. The SAFTE algorithm was specifically designed by military scientists for use in military applications and mission planning, whereas other models were developed from data sets in railroad operations (e.g. FAID), commercial aviation (e.g. CAS), and general health and safety (e.g. HSE FI). The SAFTE algorithm incorporates the three-process model of homeostatic sleep reservoir, circadian oscillator and a sleep inertia function [90] to generate a measure of alertness on a scale of 0-100% [91]. The algorithm allows input of variables such as geographical location (longitude and latitude) for calculation of natural light and dark cycles, duration of work sessions, and sleep variables such as sleep onset and wake times [92]. Derived measures of alertness from the SAFTE algorithm have been correlated with and validated against performance on PVT ($R^2 = 0.88, p<0.001$) [92], whereby, the greater the alertness score, the lower the likelihood of lapses in cognitive performance, as assessed by reaction time. The algorithm has also been validated in the aviation and rail transportation industries [90, 93].

While biomathematical modelling is beneficial for several applications, such as developing fatigue risk management systems, investigating incidents, or simply assessing a work pattern, the use of such modelling is accompanied by several limitations. These current limitations include the inability to incorporate alcohol or caffeine consumption, individual fitness for work, and sleep disorders into the algorithms, as such measures can drastically alter an individual’s predictions of alertness and performance. Future models designed for use in elite athletic populations for training, travel and competition readiness would benefit from including the effects of caffeine and alcohol.
2.3 Sleep, sleep disorders and performance in athletic populations

2.3.1 Sleep in athletes

It has been estimated that 88% of athletes do not achieve the 7-9 hrs of sleep per night as recommended by the Sleep Health Foundation [94]. Studies report that athletes tend to achieve, on average, 6 hrs 50 min of sleep per night, with athletes from individual sports achieving slightly less than those from team sports, being 6 hrs 30 min of sleep on average per night [95, 96]. These studies report that athletes from individual sports tend to have earlier sleep onset times with increased sleep latencies, and greater sleep disturbances leading to periods of awakening after sleep onset and overall earlier rise times, compared to those in team sports. These disturbances are mainly attributed to anxiety and stress prior to next day competitions [19], whereas in team sports, the pressure for success in competition is distributed among all members of the team as opposed to solely on an individual. Furthermore, compared to a non-athletic population, athletes overall have abnormally high sleep latencies [37], and more time awake during sleep resulting in a lower sleep efficiency [95]. Future research in this area should include objective research methods such as in-laboratory or portable PSG studies, in order to detect sleep problems and disturbances in this population.

2.3.2 Training and sleep in athletes

A potentially important factor that may influence sleep in athletes is the scheduling of training sessions. An Australian study of 70 athletes from swimming, cycling, triathlon, mountain biking, race walking, basketball and Australian Rules Football (AFL) found that early morning training sessions between 05:00-09:00 (hh:mm) were associated with shorter sleep durations despite earlier sleep onset times [94]. It is possible that repeated early morning sessions may curtail sleep over consecutive days.
and cumulatively lead to building sleep debt. Such sleep debt has been shown to negatively affect an individual and team performance [96].

The timing and scheduling of training sessions is an important factor in ensuring adequate opportunities for sleep in athletes to maximise performance. For example, in elite male basketball players, physical performance and sleep duration is significantly improved when afternoon training sessions occur, compared to morning training sessions [97]. Contrary to early morning training sessions, evening training sessions in soccer players are found to delay the time of sleep onset [24]. However, evening training does not appear to negatively affect sleep duration, as soccer players tend to increase sleep duration by delaying the time of wake the next morning. This is mainly due to the absence of scheduled next day early morning training sessions [24].

The development of training schedules may negatively affect the recovery of athletes by reducing the opportunity for sleep in athletes [23]. Similar outcomes are observed in industrial settings that involve irregular working hours such as mining [98, 99], rail or aviation [100, 101], whereby early morning shifts truncate sleep opportunity and lead to a reduction in the overall sleep duration attained prior to the commencement of work [98, 99]. There are additional benefits that are not related to athletic performance when athletes achieve 7-hrs or more of sleep each night, including a lower prevalence of depression, anger and an improvement in vigour [102]. Conversely, when sleep duration is reduced, depression, anger, injuries and the potential for performing poorly in competition significantly increase [103].

A relatively simple strategy to increase sleep duration in athletes is to consider the sleep habits and behaviours of the specific athletic population and to schedule training sessions that complement their normal sleep behaviours. Consideration should also be
given to the scheduling of intermitting days off and/or specific periods of the day free from training such as ‘mornings’ or ‘afternoon’. Implementation of these strategies have been shown to successfully improve sleep duration, sleep efficiency and lower stress-related measures in junior rowing athletes [104].

The sleep environment has also been found to have a significant impact on sleep quality. Athletes are often required to change their normal ‘home’ sleeping environment to a ‘training camp’. In one study requiring elite AFL athletes to sleep at a training camp, TIB and WASO increased resulting in a lower sleep efficiency [105]. Although overall sleep duration was similar between ‘home’ and ‘training camp’, when observing individual sleep efficiency differences, those with higher sleep efficiency at home had a greater decline in sleep efficiency when sleeping during a training camp [105]. Further research is required relating to the effects of sleeping environments when travelling on performance in athletes. Such information would allow a more considered approach to allocation of athletes to different sleeping environments. For example, individual preferences could be given greater priority and athletes with sleep disorders that could potentially disturb other athletes, could be provided individual accommodation rather than be allocated to a shared sleeping environment.

Similar results have also been observed in rugby league athletes, whereby players slept less during a training camp than at home [106]. Contrary to these findings, a study in younger soccer athletes (16-years of age) during a 17-day training camp found no differences in sleep measures, however overall sleep duration was already significantly less than the Sleep Health Foundation recommendations (7-hrs). To compensate for this reduction in sleep duration during the training camp, the use of daytime naps has been shown to be beneficial in increasing total sleep duration over 24-hrs without being detrimental to night time sleep [106]. Overall, these studies highlight the
potential for variation in sleep environment to lead to decrements in sleep attainment and sleep efficiency.

2.3.3 Competition and sleep in athletes

Maintaining a consistent sleep routine in athletic populations may be problematic due to the timing of games (e.g. day, evening, night) and the timing of specific training sessions. Several team sports, such as AFL, rugby union, soccer, and basketball, all play games at variable times of day. This variation in game time is associated with variable sleep before and after a game.

A study by Sargent and Roach (2016) examining night AFL games in Australia found that post-game sleep duration was significantly reduced compared to the nights before the game, with sleep onset time significantly delayed after the game [107]. Similarly, in elite soccer players following a night game, sleep duration was shown to be significantly reduced with the players self-reported perception of recovery significantly lower the next morning [11]. In rugby union players in the Celtic League in Wales, United Kingdom (UK) and in Super Rugby in Australia following a night game, post-game sleep duration was shown to be significantly reduced compared to pre-game nights. These observed reductions in sleep measures were due to a delay in the time of sleep onset and an earlier time of wake the next morning after a game [37, 108]. Contrary to these findings, in another study, elite AFL athletes reported no differences in any measure of sleep when comparing pre-season measures to games within the season [109] and similarly within elite rugby league players [110]. Whilst there were no differences, sleep duration was less than 7-hrs per night in both conditions suggesting that an increase in sleep duration might benefit these athletes in both pre-season and in-season.
It is reasonable to think that players would compensate for game-related shorter sleep durations and delay in time at sleep onset by delaying the time of wake the next morning. However, such behaviour has not been reported. This may be partly explained by an increase in self-reported perceived muscle soreness the morning after a game as was reported in rugby league players [111]. It is also possible that other factors could contribute to sleep loss after a game including caffeine use, electronic device use [37], stimulation from playing the game, bright lights of a stadium and post-game socialising behaviours including alcohol consumption [112]. A relatively simple strategy to support athletes in managing these factors and to increase sleep duration is to provide education on sleep hygiene principles and other practices that can easily applied.

When investigating the nights prior to a rugby union game with players in the Celtic League, actigraphic-measured TIB increased, thereby supporting the opportunity to increase sleep duration in the nights prior to a game [37]. In elite female basketball athletes in Australia also using wrist-activity monitors, similar findings were evident [113]. Athletes increased sleep duration on pre-game nights and had a significant reduction in sleep on the nights after a game. Similarly in non-athletic disciplines, military special forces operatives use a similar approach whereby sleep duration is increased on the nights prior to deployment for a mission [114]. This type of strategy may potentially negate the negative effects of subsequent sleep loss that may occur during a mission.

Time of day for competition when traveling across time zones are also known to impact game performance and competition. Travelling across time zones can be beneficial depending on the direction of travel and the time of day of competition. When travelling west to east for an evening game (19:00-22:00 hh:mm), athletes will tend to have a circadian advantage. This is due to the athletes normal circadian phase
being close to the peak of athletic performance [115]. In the United States (US) it was found that teams from the National Basketball Association (NBA) and the National Hockey League (NHL) who travelled across the US in a westwardly direction (e.g. Los Angeles to New York) had a significant circadian disadvantage, compared to those who travelled west to east [116]. A similar trend was also evident in NFL teams that travelled westwardly [116]. In contrast, a retrospective analysis of 40 years of NFL games (evening games compared to day games) for west coast based teams showed that when they travelled to the east coast for evening games they had a circadian advantage for the evening games [117]. These previous studies highlight the need to better understand the effects of jet lag and time of day of competition on measures of sleep in athletes and their potential impact on performance.

2.4 Sleep and caffeine in athletes

2.4.1 Caffeine and the effect on sleep in athletes

Caffeine may be beneficial for performance; however, it is also known to negatively affect sleep and physical recovery. When consumed overnight during shiftwork activities or endurance activities, caffeine can disturb daytime sleep by increasing wakefulness, decreasing sleep efficiency and slow wave sleep [118]. This is due to a combination of the consumed caffeine and the natural increase in morning cortisol levels, thereby affecting the quality of sleep [119]. This may also be explained by the pharmacokinetics of caffeine, whereby after consumption a peak in caffeine plasma levels are reached within 60-mins, with a half-life ranging from four to six hours [120]. Sleep duration and sleep quality are negatively affected when caffeine is consumed within four to six hours of sleep onset [121].
In athletic populations, caffeine can negatively affect post-competition sleep. In male cyclists, caffeine consumption of 3mg/kg in the late afternoon significantly increases sleep latency and decreases sleep efficiency [122]. A similar dose of caffeine ingested by male and female athletes in the afternoon also increases the symptoms of sleep maintenance insomnia, with increases in the number and duration of awakenings overnight leading to sleep loss [123]. Increased doses of caffeine of 6mg/kg and 9 mg/kg increases muscle force and power output in resistance exercise, however, 54% of participants reported problems with sleep [124].

Sleep, caffeine, and performance have been well studied in the setting of military operations. Generally, these studies show positive effects on an array of performance measures and the deleterious effects on sleep quantity and quality [125]. However, knowledge of the source of caffeine and its strategic use remains unclear to athletes. Athletes often unknowingly consume caffeine during training sessions or competitive events via cola, energy drinks, and gels without knowledge of quantity, timing, or the potential negative effects on sleep [120, 126]. The relative absence of studies in this area highlights an opportunity for further research relating to caffeine and the effect on post-competition sleep and recovery.

2.4.2 Caffeine and performance in athletes

Caffeine is one of the oldest and most commonly used psychoactive drugs since its discovery in 2737 BCE. It is found naturally in a variety of foods and beverages and is often used as an ergogenic aid for cognition and physical improvements and to counteract the effects of sleep loss and general fatigue [127].

Caffeine is beneficial in improving cognitive performance such as attention, psychomotor vigilance and memory in athletes [128, 129] before and during exercise.
It has been shown to improve physical performance in prolonged endurance type exercise [131-133]. Whilst there is no consensus on the specific ergogenic mechanism of action of caffeine the most commonly presented mechanism is improved central nervous system function, whereby caffeine acts as a stimulant to increase alertness and reduce the effects of fatigue [134]. Additional theories include; improved muscle performance, whereby skeletal and cardiac muscle contractility is enhanced, thereby improving power and strength [135]; and improved metabolism, specifically improved oxidisation and utilisation of fat as a fuel source, thus sparing glycogen [136].

In individual athletic competitions, such as the Ironman triathlon, 84% of athletes believe that the use of caffeine improves their concentration [137]. However, in a study of running athletes, 5-km treadmill time trial was not improved when runners ingested 140mg caffeine (Guayaki Yerba Maté Organic Energy Shot™), or 80mg of caffeine (Red Bull Energy Shot™) in a randomized, placebo-controlled crossover design [138]. Conversely in highly trained cross-country skiing athletes, caffeine was shown to enhance performance on an 8-km skiing test [139]. Taekwondo athletes administered a dose of 5mg/kg of caffeine demonstrated improved reaction time and an increase in combat specific intensity during a simulated competition [140].

The use of caffeine in team sports such as soccer [141, 142] and rugby union [143, 144] has also been shown to improve physical performance. Rugby union players who consume 3 mg/kg of caffeine improved sprint times during competition compared to those who did not [143]. Although caffeine is widely used for such ergogenic requirements, the current literature suggests variability in objectively measured performance measures and self-reported improvements in performance.
In military operations, wakefulness of more than 24-hrs is often required for operational needs. Specific test batteries developed from possible military scenarios involving sleep loss have been used to assess the physical and cognitive effects of caffeine [145]. The test battery consisted of a run to exhaustion, forced march, sandbag piling task, cognitive testing included; marksmanship and psychomotor vigilance testing [145]. In this study combat troops consumed caffeine gum (400 mg serve via chewing gum and subsequent 100 mg serves) or a placebo. Those who consumed the caffeine demonstrated improved time to complete the sandbagging task and time to exhaustion on the run improved by 25%, compared to the placebo group.

These results indicated that the use of caffeine in overnight military operations that resulted in sleep loss would be an effective strategy. Indeed, in extended periods of wakefulness (>64-hrs) a slow release caffeine dose of 300 mg given twice a day shows improvement in vigilance and performance and may serve as an alternative to other stimulants such as amphetamines [146] and or medications such as modafinil, a drug that promotes wake and alertness [147]. Whilst caffeine may improve physical performance, degradation in cognitive performance also occurs due to sleep loss. For example, one study showed that administration of caffeine (100-400 mg) following sleep loss resulted in an improvement in reaction time to fire at a target, however marksmanship shooting accuracy was decreased [148].

### 2.5 Sleep and electronic device use

The usage and prevalence of electronic devices are increasing in the general population [149] and inevitably in athletic populations. Athletes are commonly required to use electronic devices to maintain a social media presence for the promotion of events or for the promotion of the team. Athletes also anecdotally report using electronic devices
such as smartphones and tablets when they are away for competition or training to keep in contact with family and friends. In non-athletic populations, late night use of electronic devices for social media has been shown to negatively affect sleep by decreasing the total time available for sleep [150]. Further, artificial light exposure associated with the use of electronic tablet devices, computers and/or smartphones has been shown to negatively affect an individual's ability to fall asleep and thereby decrease sleep efficiency [152, 153].

2.5.1 Sleep and electronic device use in non-athletic populations

Research in non-athletic populations suggests that electronic devices negatively affect sleep onset and the quality of NREM sleep [153, 154]. In pre-adolescents, an increase in the number of electronic devices with screens in a bedroom was associated with higher adiposity and an increase in device-interaction time resulted in a reduced sleep efficiency [155]. With 70% of adolescents reporting two or more electronic devices in their bedroom at night [156], this may lead to a negative impact on sleep. Adolescents report negative impacts such as non-optimal sleep duration on weekday nights (71%) and on weekend nights (53%), with one in five adolescents reporting nightly bedtime delay as a consequence of electronic device use [157]. These negative impacts on sleep were as a result of electronic device use prior to sleep [158]. When using laboratory-based PSG techniques, similar findings are observed [159]. The effect of using light emitting e-readers before sleep resulted in an increase in time to fall asleep by 10-mins as opposed to those reading books with print. This also resulted in less time spent in REM sleep, with next day alertness diminished.

In addition to light exposure from electronic devices, the type of activity prior to sleep may be an important factor in assessing the impact on sleep. The use of violent
video gaming has been shown to reduce sleep duration by 27-mins, with a 7% decrease in sleep efficiency and an increase in sleep latency compared with those participating in regular video gaming [160]. The use of a computer for watching shows or movies in bed was positively related to the severity of insomnia symptoms [161]. Only 5% of the respondents reported never using or being exposed to electronic media in bed before going to sleep with the average nightly use at 47-mins prior to sleep. Similarly, the use of smartphones prior to bed also affected sleep [162]. Contrary to these findings, in young adults, light emission from television screens prior to bed did not have any negative effects on the release of melatonin [163]. The lack of effect may be related to the difference in light emissions from a television compared to a computer.

2.5.2 Sleep and electronic device use in athletes

Currently, there is a limited number of studies in athletes that have investigated the relationships between electronic device use, sleep, and athletic performance. In a laboratory-based study using PSG, highly trained netball athletes were randomised to two conditions using electronic devices or reading magazines for 2-hrs prior to sleep over five consecutive nights [35]. However, the use of electronic devices 2-hrs prior to sleep did not negatively impact sleep or next-day performance in these athletes. In addition, removal of electronic devices for a 2-hr period prior to sleep for 28 nights had no effect on sleep, cognition or physical performance compared to a control group using electronic devices ad libitum [164]. When investigating differences between sleep and electronic device use during training and competition times, no effects on sleep measures in elite netball athletes were observed [165].

The long-term effects of electronic device use on individual health outcomes are not fully understood. As the development and applications of such devices continue to
evolve, so too will the prevalence of electronic devices. The ability to keep abreast of such developments and the effect on sleep and performance is a challenge in the research of sleep and performance in athletic populations. To date, the simple solution of shutting down electronic devices and eliminating our exposure to light emitting devices by 21:00 (hh:mm) may be the most useful starting point for children, adolescents and adults [67].

2.6 Sleep disorders in athletes

2.6.1 General overview of sleep disorders

The term “sleep disorders” is a general statement that pertains to over 80 sleep disorders [166, 167] that are distributed amongst eight categories within the International Classification of Sleep Disorders (ICSD- 3rd Ed) [168]. Categories include sleep related breathing disorders, dystonia’s, parasomnias and circadian rhythm disorders. Sleep disorders affect approximately 30% of the general population and the short-term effects can include a reduction in cognitive [169] and physical performance [170]. The long-term effects include cardiovascular disease [171], diabetes [172] and testosterone reduction. This section of the review will focus on the main sleep disorders that are prevalent in the community [173] and therefore may be present amongst athletes. These include Obstructive sleep apnea (OSA), insomnia, sleep disturbances and movement disorders.

2.6.2 Diagnosis of sleep disorders

Assessment of sleep and sleep disorders in athletes can be challenging, due to the cost and the applicability of devices such as wrist-activity monitors, the availability of sleep technicians and the time available to process and analyse the data. For example, using laboratory-based PSG is of no use to a person who may be having trouble adapting to
a new time zone (jet-lag) or is struggling with insomnia. Therefore, choosing the most appropriate method for assessing sleep must be done based on athlete needs and an appropriate pre-screening process [174].

For any athletic organisation or researcher, a segregation methodology may be used to direct the athlete to the appropriate screening process including in-laboratory PSG or home-based PSG, depending on pre-test probability. The pre-test probability should be based on factors including, but not limited to, the subject’s medical history, biometric data such as body mass, neck circumference and the referring condition. A notable advantage of a home-based PSG is that it may offer a better reflection of an athlete’s normal sleep to support the diagnose of sleep disorders [65-67]. Indeed, such an approach has been shown to increase participation in a research study investigating the relationship between sleep and physical activity in 56 adolescent subjects [175].

### 2.6.3 Sleep disorders and performance in athletes

Sleep disorders are associated with impaired aerobic performance in athletes and non-athletes alike [176]. Within athletic populations, few studies have examined the presence of sleep disorders using the gold-standard assessment, PSG [6, 174, 177].

When investigating the prevalence or presence of sleep disorders in athletes, questionnaire-based methods are popular due to ease of administration and the relatively low cost. However, most sleep related questionaries have been developed for use in the general population or in those with existing sleep disorders, the validity and applicability are unknown when used in athletic populations. To address this, specific questionnaires have been developed that allow subjective, self-report and sleep-screening for elite athletes [36]. The questions relate to sleep difficulty, sleep disorder breathing, chronotype and travel disturbances. One questionnaire designed to
focus more on pre-competition sleep contains specific questions about sleep habits before an important competition [178].

2.6.4 Obstructive sleep apnea in athletes

Obstructive sleep apnea is the most prevalent sleep disorder [173] in the general population with a 9% prevalence rate in Australian adults [179], and is characterised as repeated events of partial or complete obstruction of the upper airway during sleep. Obstructive sleep apnea has been linked with cardiovascular disease and hypertension [180] and is independently associated with glucose intolerance and insulin resistance leading to type 2 diabetes [181] and an elevated blood pressure [182].

Studies investigating risk factors in the general population have shown that neck circumference and Body Mass Index (BMI) are good predictors of the severity of OSA [183]. For example, a BMI that is greater than 30 kg/m² increases the risk of OSA [184, 185] and reduces sleep duration due to an increase in awakenings during TIB. A study of 1001 participants found that participants with a mean BMI of 30±7 kg/m² in the overweight category (BMI 25-30 kg/m²), obese category (BMI 30-35 kg/m²) and the extremely obese category (BMI 35+ kg/m²), had reduced sleep duration due to an increase in the severity of OSA [186]. When those with OSA partook in regular aerobic based exercise, their severity of OSA was significantly reduced with improvements to sleep efficiency. This highlights the benefit of exercise may play in the management of OSA which is most likely attributed to a loss in body mass, thereby reducing the girth of the neck and reducing the severity of OSA [187, 188].

Despite the high prevalence of OSA in the general population, very little is known about the prevalence of OSA in athletes [189]. In rugby union players, a generic questionnaire for the presence of potential sleep disorders found that 8% of rugby
union players had self-reported apnoeic events and 38% were self-reported snorers resulting in a 28% prevalence of daytime sleepiness in rugby union players [189].

Of the limited data available, the prevalence of OSA is high in athletes; 19% of National Football League (NFL) players (n=137) were identified as having OSA [177]. This study used a single channel, home based, unattended, portable, sleep apnea monitor. Whereas, when 51 collegiate football players were evaluated for OSA with a single-channel (finger pulse oximetry) photoplethysmography, a prevalence rate of 8% was reported [190]. In another study, 302 players from eight professional football teams in the NFL completed specific sleep related questionnaires including the ESS and the Stanford sleepiness scale. Players were stratified into risk categories based upon the scores from these questionnaires and a multivariable apnea prediction index developed that included questions about the frequency of symptoms from OSA, body mass index (BMI), age and gender. Based on this, 73 players were identified as being at high risk of OSA and 229 players at low risk. Random sampling from both groups resulted in 52 players flagged to undergo full PSG assessment of sleep. This resulted in 14% of NFL players having OSA [191]. It is of interest that there were no differences in the prevalence of OSA between player groups and anthropometric characteristics (e.g. between linesman and non-linesman). In elite ice hockey, 107 players were assessed for the prevalence of sleep disorders using sleep related questionnaires [174]. Based upon the questionnaire scores, those players suspected of having a sleep disorder underwent a home-based PSG study. This resulted in 13% (n=14) of the 107 athletes screened for a potential sleep disorder meeting the criteria for OSA. Together, these studies indicate that the prevalence of OSA in athletes is high, however little is known about the potential effects of such disorders on athletic
performance [192] and the validity of OSA related questionnaires, designed and developed for the general population, in athletic populations.

2.6.5 Insomnia in athletes

Insomnia can be defined as the chronic inability to fall asleep or remain asleep for an adequate length of time [193]. Insomnia can be experienced at different times in an individual’s life and may be stress-related. Insomnia may also be experienced on a long-term basis [168, 194]. Recent data reports that insomnia is present in 20% of Australian adults, being more prevalent in females (23%) compared to males (20%) [173].

Insomnia is categorised into three types, (i) sleep onset insomnia, (ii) sleep maintenance insomnia, and (iii) early morning awakening insomnia. Insomnia can be further segregated into two additional categories (i) primary insomnia (3% in Australian adults)[179], which is defined as sleeplessness that cannot be attributed to a medical, psychiatric or environmental causes and (ii) secondary insomnia, which is sleeplessness that can be attributed directly to another condition. Insomnia is one of the most prevalent psychological disorders, causing sufferers severe distress as well as social, interpersonal, and occupational impairment [195]. Approximately one third of the population experience insomnia symptoms, with daytime sleepiness and dissatisfaction with their sleep [196], with prevalence rates reported to be higher in females compared to men [197]. It is thought that insomnia may have adverse implications for athletes and potentially affect performance [198].

A recent systematic review by Gupta and colleagues (2016) investigated sleep quality in athletes and reported that insomnia symptomatology is high among elite athletes [6]. However, there are no specific studies that have examined the effect of insomnia on athletic performance [199]. In non-athletic populations, exercise is often
a recommended treatment for insomnia [199]. It may be that the exercise or the activity improves insomnia, but in elite athletic populations sleep disturbances and pre-competition anxiety may be contributing factors for insomnia resulting in sleep loss.

Studies in athletic populations have used varying methodologies to determine the prevalence of insomnia. A sleep disorder questionnaire, validated against the Diagnostic and Statistical Manual of Mental Disorders-IV criteria for insomnia was administered in 103 Italian Olympic athletes [200] and revealed an insomnia prevalence rate of 4% [200]. Another study using home-based PSG and questionnaires in 107 elite ice hockey players reported an insomnia prevalence rate of 12% [174]. Yet another study using the validated Athens insomnia scale in 59 elite multi-sport athletes reported a mean score of 5 (scoring range 0-16) [201]. Whilst not reporting a prevalence rate, this study concluded that all athletes had serious insomnia symptoms with no clinical significance for insomnia in any athlete. Two studies using non-validated questionnaires that capture aspects of insomnia or sleep difficulties in athletes reported an insomnia prevalence rate between 60-80% [174, 178]. In elite female gymnasts prior to competition, 67% of athletes experienced daytime sleepiness [202], using the ESS, 77% experienced poor sleep quality using the PSQI and 19% experienced pre-competition anxiety.

In a study undertaken during the London 2012 Olympics, 53% of the athletes reported excessive daytime sleepiness [203]. This was attributed to 46% of the athletes being dissatisfied with their own sleep due to headaches, anxiety, snoring, leg cramps and leg movements. Similarly, in Chilean Para-Olympians, 28% had sleepiness when measured using the PSQI [204]. In wheelchair athletes, poor sleep quality and disturbance are reported with poor scores on the PSQI [205]. However, the reported
Sleep duration of 6 hrs 30 mins and sleep latency of 25 mins are similar to the sleep reported in other athletic groups [205].

### 2.6.6 Sleep disturbance in athletes

Prior to competition, sleep disturbances and poor sleep quality is more prevalent in individual athletes compared to all other pre-or post-competition nights [206]. Prior to a competition, athletes report only achieving 5 hrs 51 mins of sleep. This reduced sleep duration was attributed to pre-competition anxiety, ambient noise and awakenings to use the toilet. It is estimated that 80% of athletes experienced sleep onset insomnia, 77% experienced early morning wake insomnia due to nervousness and 76% with thoughts about a competition [178]. Such anxiety prior to a competition that reduced sleep duration was correlated with a poor physical performance in swimmers [207]. In another study investigating sleep disturbances in athletes, similar findings were reported with 64% of athletes reporting poor sleep in the nights prior to a competition with 82% finding it difficult to fall asleep due to nervousness and thoughts about competing [19].

Sleep disturbances are associated with the use of caffeine consumption in the hours prior to sleep, in particular by the consumption of energy drinks [122].

The prevalence of sleep disturbances in athletes can also be attributed to an increased training load placed upon athletes during training camps and or highly competitive periods [208]. It has been demonstrated that such periods of competition increase insomnia symptomology, as has been shown in elite Olympic athletes in whom 64% reported disturbed sleep in the nights prior to an important competition [19]. Elite Super Rugby union players also experienced a delay in time to fall asleep on the nights prior to a game and a delay in the time of sleep onset after a game [37].
During sustained periods of competition such as the in-season period, the prevalence of insomnia doubled in elite ice hockey players during the season [174].

Treatment for insomnia is varied and can be a challenge. Treatments include sleep restriction, cognitive behavioural therapy, and pharmacotherapy [209]. An increase in sleep duration and a reduction in insomnia symptoms [210] have been reported when practicing yoga, relaxation techniques, tai-chi, and or using relaxing music. Cognitive behavioural therapy often shows better results than medication [211]. Athletes may benefit from non-pharmacologic techniques for promoting sleep, including inverted posture, temperature control, sensory withdrawal, breathing techniques, and cognitive relaxation [211]. A novel approach to improving sleep as demonstrated in sub-elite soccer players was achieved using brainwave entrainment with binaural beats [212]. Additional actions to improve insomnia, and reduce disturbances include; sleep hygiene practices, such as a consistent time to bed, avoidance of caffeine within six hours of sleep onset and no stimulating activities (exercise, work or exposure to electronic devices) within one hour of sleep onset, as well as a focus on nutrition [213] and hydration prior to sleep [214].

2.6.7 Movement disorders in athletes

Periodic Leg Movements (PLMs) and Restless Legs Syndrome (RLS) are abnormal or unusual leg movements that affect sleep by causing disruptions, thus lowering sleep duration and sleep efficiency [215]. In the general population, the prevalence rates of RLS and PLMs using the criteria from International Classification of Sleep Disorders, were 3.9% and 5.5% for PLMs and RLS, respectively [216].

The International RLS Study Group (IRLSG) have developed a diagnostic criterion for restless legs syndrome [217]. The application of IRLSG criteria was used
in a study to quantify the prevalence of RLS in marathon runners during three marathons (42-kms) in Brazil. The study consisted of 61 subjects (47 males & 14 females) with 13% of the subjects meeting the criteria for RLS [218]. A study in elite ice hockey players using PSG and questionnaires reported a combined prevalence rate for RLS/PLMs of 4% [174]. These movement disorders have additional negative impacts to health [219], people with RLS have significantly lower perceptions of health and wellbeing. Depletion of magnesium and iron may exacerbate these movement disorders amongst athletes depending on their training load. The administration of iron supplementation [220] or a high dose of intravenous iron may be used in the treatment of subjects with RLS [221].

Overall there is a scarcity of research relating to the prevalence of sleep disorders in athletes and the potential effects of any such disorder on athletic performance. To date, most studies in this area have been conducted using methods such as questionnaires and portable PSG units. Such techniques have reduced capability and accuracy detecting sleep disorders compared to the gold standard laboratory-based PSG study. Indeed, to there have been studies published to date that have used in-laboratory based PSG to identify athletes that are potentially “at-risk” for the presence of a sleep disorder.

2.7 Sleep and athletic performance

2.7.1 Cognition testing in athletes related to sleep

Existing scientific reviews have highlighted the difficulty in assessing cognitive performance in athletes [170], mainly due to the fact that cognitive performance in athletic populations varies between sporting disciplines. These variations include specific game-related playing positions, time of day for training, competition and game
strategy. Whilst studies have investigated the effects of sleep loss on cognitive performance, there is still limited research investigating cognitive performance in athletic groups. To date, no standard measure exists for the assessment of cognitive performance in athletes. The tests currently used vary and range from questionnaires to memory-based recall, and in some instances, computer based reasoning or reaction time based assessment [222]. The use of the PVT has been the main modality for ascertaining the effect of sleep or sleep loss on cognitive performance by way of measuring reaction time and lapses in attention [223].

2.7.2 Physical testing in athletes related to sleep

Physical performance due to sleep loss or extension can be described and assessed in a number of ways, including strength, endurance, aerobic and anaerobic performance [224]. In addition, game or competition results may be used to determine the outcome of physical performance. Similar to testing for cognition, physical testing of athletes for the effects of the variation of sleep quantity and efficiency is not standardised. With the variation in different sports or skills, a standardised test is difficult to develop and replicate across all athletes.

To date, there is a great deal of variation in physical testing methodologies related to the effect of sleep. A commonly used test for physical performance is to measure the ability to ‘jump’ [225]. This is a key skill for many sports such as basketball, volleyball [225], rugby, and AFL. A variation on this is the use of a single leg hop (SLH) test. The SLH test is used with athletes to test for muscular function under conditions of muscular fatigue. The SLH tests were found to have acceptable test-retest reliability [226]. The mean number of hop-trials needed to obtain three successful hops at test and retest under non-muscular fatigued test conditions was 3.5 and 3.3 (range
3–5), with no significant differences between tests [226]. This test methodology has not been applied to subjects undergoing sleep loss or any intervention relating to sleep. In another study assessing the effects of red-light treatment and its effect on sleep and performance, researchers employed the Cooper 12-min run test. Participants were instructed to complete as many laps of a 400-m outdoor track as possible during a 12-min test period. Emphasis was placed on pacing oneself throughout the test [227].

To quantify the effect of sleep (deprivation or extension) on physical performance, a standardised battery of physical testing may be beneficial. This would facilitate the quantification of a baseline in performance relative to each athlete. Such an approach would help compare the results of studies within and between different sports, individual athletes, team-based athletes and even between playing positions.

2.8 Sleep loss and deprivation on athletic performance

2.8.1 Sleep loss of 24-hrs or more on athletic performance

Sleep loss of more than 24-hrs and the effect on performance is known in ultra-endurance athletes such as cycling [228, 229], sailing [230, 231], adventure racing [232] and military activities [5]. These studies have been primarily field based or during competition to reflect actual effects on performance. For example, ultra-endurance athletes were assessed during an adventure race over a distance of 411-km, whereby athletes were sleep deprived for a period of 96-125-hrs during the completion of the race. During this period of self-imposed sleep restriction, athletes’ power output was reduced by 30% in the first 24-hrs. However overall physical capability was only moderately affected over the course of the adventure race (411-km) of the race by 10-15% [232].

A study of 30-hrs of sleep deprivation resulted in a decline in VO\(_2\) max with no effect on endurance in 15 young healthy males [233]. Also, after 30-hrs of sleep
deprivation, team sports athletes demonstrated a reduction in sprint times and had slower pacing strategies where athletes were allowed to self-pace [234]. These negative effects on performance are most likely due to reduced muscle glycogen concentration and increased perceptual strain. The interaction between physical performance and sleep loss still remains unclear [234].

Anaerobic performance is not affected after 24-hrs of wakefulness with no sleep, however, when 36-hrs of wakefulness is experienced with no sleep, then anaerobic performance is impaired [235]. As hours of wakefulness increase, leading to cumulative sleep loss, so does an increase in the variation in performance. In particular, physical performance measures between morning and afternoon periods. In a study examining the effects of 24-hrs of sleep loss in soccer players, it was found that soccer skills such as a continuous kicking test was negatively affected after a prolonged period of wakefulness [236].

2.8.2 Sleep loss 24-hrs or less on athletic performance

Sleep loss of less than 24-hrs is more common in athletes than total sleep deprivation, wakefulness for more than 24-hrs. One night of sleep deprivation (8-hrs) results in reduced performance in running athletes during a self-paced 30-min treadmill test compared to a night of healthy sleep (8-hrs). Athletes in this study ran significantly shorter distance after one night of sleep deprivation, with athletes rating their effort as similar between both testing conditions (8-hrs of sleep vs no-sleep) [237]. One night of sleep deprivation also raised oxygen uptake and carbon dioxide production, although it did not result in any change to heart rate or VO₂ max during testing.

Sleep restriction of 3-hrs per night for three consecutive nights resulted in a reduction in strength performance with weight lifters [238]. This study may be more
representative of what athletes may experience, in particular on the night before a competition in individual athletes, or after a competition with team sport athletes [19]. Sleep loss in athletes either early in the night between 23:00-03:00 (hh:mm) or later in the night from 03:00-06:00 (hh:mm) affects aerobic performance [239]. Conversely, sleep loss during these periods does not affect anaerobic performance [239]. In the combat sport of judo, when partial sleep deprivation occurred at the end of the night between 03:00-06:00 (hh:mm), athletes had a reduction in muscle power as measured by the Wingate test [240]. Hand grip strength, which is at the core of judo, was not affected. Furthermore, sleep loss between 03:00-06:00 (hh:mm) resulted in more sleep disturbances for the athlete which may negatively affected individual athletes, more than team sports athletes, and is associated with pre-training fatigue levels [94]. In another combat sport, Taekwondo, athletes did not demonstrate any changes in aerobic performance when deprived of sleep between 23:00-03:00 (hh:mm) or 03:00-06:00 (hh:mm) [241]. Cognitive performance is also affected during these periods of sleep loss. Sleep deprivation during 23:00-03:00 (hh:mm) affects reaction time, whereas sleep deprivation between 03:00-06:00 (hh:mm) affects selective and constant attention [242].

Overall, it is difficult to ascertain the effect of sleep loss or sleep deprivation on performance in athletes. This is due to inherent many factors including variability of anthropometric factors, specific training and adaption and the lack of standardised testing. Much could potentially be learned from studies in disciplines such as ultra-running whereby athletes compete in remote, high altitude environments for periods ranging from 14-46 hrs, as such sports challenge sleep but require cognitive and physical performance to be maintained.
2.9 Sleep extension in athletes

Sleep extension or optimisation of sleep may be an effective strategy for improving performance, in particular when periods of sleep loss are anticipated. With numerous studies in athletic and non-athletic populations, including shift-workers and the military, it is surprising that only three studies exist in the current literature relating to sleep extension.

In a study with college varsity players, a sleep extension period of 2-hrs per night over a seven-night period resulted in reduced daytime sleepiness and increased serving accuracy of tennis players [243]. In basketball players, when sleep opportunity was increased to 10-hrs per night, sleep duration increased and subsequent improvements in reaction time on the PVT and in basketball shooting accuracy were evident [244]. However, smaller increases in sleep duration by 30-mins, from 7-hrs to 7.5-hrs, in female track athletes did not result in any improvements in performance. Furthermore, increases in sleep duration have been shown to improve overall mood in athletes [245]. This suggests that the magnitude of increase in sleep duration needs to be greater than the recommended 8-hrs of sleep per night to observe improvements in performance.

2.10 Summary

The number of studies investigating the role of sleep in athletic performance have significantly increased in recent years due to the importance placed on recovery and performance by athletic organisations and teams. Many of these studies to date have been conducted on the effects of sleep loss and sleep deprivation and the subsequent performance decrements. However, a scarcity of research relating to the potential benefits of sleep extension on performance still exists.
It would be beneficial to athletic organisations and researchers alike to employ gold standard PSG to identify and diagnose sleep disorders in elite athletes. Whilst prevalence rates of sleep disorders are well known in the general population and the impacts on long term health, a clear gap in the scientific knowledge base is the application of this methodology in athletic populations.

Generalisation of the effect of sleep (loss or extension) on cognitive and physical performance stills remains a challenge, as each sporting discipline will have specific outcome measures that are relevant to that discipline. Nonetheless, opportunities exist for the improvement of sleep in the nights leading into competition, in particular for individual athletes on the night before competition. In team-based sports, opportunities exist to improve post-competition sleep. Studies with specific intervention strategies may prove beneficial in improving sleep duration and sleep efficiency.

The use of biomathematical modelling to design training and recovery schedules may be of benefit to the coaching and athletic staff. This type of prediction modelling may aid in the design of training session timing to ensure optimal alertness for competition and to support recovery. In particular, modelling may be used to support optimal alertness during in-season periods, accounting for weekly games and or travel interstate or internationally.
2.11 References


43. Dement, W., The promise of sleep : a pioneer in sleep medicine explains the vital connection between health, happiness, and a good night's sleep. 1999.


175. Lang, C., et al., Increased self-reported and objectively assessed physical activity predict sleep quality among adolescents. Physiol Behav, 2013. 120: p. 46-53.


179. Economics, D.A., Asleep on the job, costs of inadequate sleep in Australia. 2017, Sleep Health Foundation


Chapter 3  Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults

Authors

Ian C Dunican1, Kevin Murray2, James A Slater1, Kathleen J Maddison1 Maddison J Jones3, Brian Dawson3, Leon M Straker4, John A Caldwell5, Shona L Halson6 and Peter R Eastwood1

Institutions

1Centre for Sleep Science, School of Human Sciences, The University of Western Australia, Crawley, Western Australia 6009, Australia.

2School of Population and Global Health, The University of Western Australia, Crawley, Western Australia 6009, Australia.

3School of Human Sciences, The University of Western Australia, Crawley, Western Australia 6009, Australia

4School of Physiotherapy and Exercise Science, Curtin University, Western Australia, Australia.

5Coastal Performance Consulting, Florida, United States.

6Department of Physiology, Australian Institute of Sport, Leverrier Street, Bruce, Australian Capital Territory, 2617, Australia.

Publication Status

Published in Sleep and Biological Rhythms

Dunican et al., “Laboratory and home comparison of wrist-activity monitors and polysomnography in middle aged adults” Sleep and Biological Rhythms, October 2017, doi:10.1007/s41105-017-0130-x.
3.1 Abstract

Accurate measurement of time at lights out is essential for calculation of several measures of sleep in wrist-activity monitors. While some devices use subjective reporting of time of lights out from a sleep diary, others utilise an automated proprietary scoring algorithm to calculate time at lights out, thereby negating the need for a sleep diary. This study aimed to compare sleep-measures from two such devices to polysomnography (PSG) measures (In-Laboratory) and against each other when worn at home (At-Home). Fifty middle-aged adults from the Raine Study underwent overnight PSG during which they wore an ActiGraph™ and a Readiband™. They also wore both devices at home for 7 nights. The Readiband uses an automated proprietary algorithm to determine time at lights out whereas the ActiGraph requires completion of a sleep diary noting this time. In laboratory, compared to PSG: Readiband underestimated time at lights out, sleep onset, and wake after sleep onset, overestimated sleep latency and duration (p<0.001 for all); while ActiGraph underestimated sleep latency and wake after sleep onset and overestimated sleep efficiency and duration (p<0.001 for all). Similar differences between devices were observed on the laboratory night and when at home. In conclusion, an automated algorithm such as the Readiband may be used in the same capacity as the ActiGraph for the collection of sleep measures including time at sleep onset, sleep duration and time at wake. However, Readiband and ActiGraph measures of sleep latency, efficiency and wake after sleep onset should be interpreted with caution.

Keywords: actigraphy, algorithm, validation, polysomnography, sleep, technology
3.2 Introduction

The gold standard method of measuring sleep is laboratory-based polysomnography (PSG) (1). This method requires the careful application of many recording sensors around the head and face to differentiate periods of sleep from wake and to determine the different stages of sleep. While providing a comprehensive set of sleep-related data, PSG is costly, requires setup and analysis by a trained sleep technician, therefore is unsuitable for repeated measurements in the same individual over many days especially in “real-world” settings (2).

Wrist-activity monitor that use accelerometers are becoming more widely used as an alternative to PSG to objectively distinguish periods of wake from sleep, within the period participants are in bed or at rest. Accelerometers measure movement and their general operating principle in sleep-measurement applications is to define sleep as periods of “no movement” and wake as periods of “movement” (3). A wrist-activity monitor permits long term, non-intrusive and cost effective assessment of sleep/wake patterns (4). Such devices have been used in a range of settings, including; in individuals who are shift workers, military personnel and athletes (5). Their ease of use has contributed to their popularity. Indeed, it is currently estimated that 69% of the United States population own and use a consumer-grade wrist activity monitor to assess their sleep and activity patterns (3).

Several algorithms have been developed to convert accelerometer-based measurements of movement into periods of wake and sleep (6, 7). In general, these algorithms have high sensitivity (i.e. they can accurately detect sleep periods within in the overall at rest period) but poor specificity (i.e. they cannot accurately detect periods of wakefulness during the overall at rest period) (8). To optimise the accuracy of these algorithms the American Academy of Sleep Medicine (AASM) recommends that
wrist-activity monitors be used in conjunction with a sleep diary (9) as a way to capture self-reported estimates of the time the individuals turned out their bedroom lights for the purpose of going to sleep (“time at lights out”). When combined with accelerometer-derived measurements of wake and sleep periods the measurement of lights out is necessary to calculate important sleep measurements such as sleep latency, sleep efficiency and time in bed.

The ActiGraph™ is one such wrist-activity monitor that has combined diary based information with accelerometer based data to objectively describe sleep in a wide range of health related and applied research projects (10-12). To calculate measures such as sleep efficiency, sleep latency and time in bed the ActiGraph software requires the user to enter the time of lights out from the sleep diary. However accurate assessment of these derived measures is critically dependent on the individual precisely recalling and recording the time they turned the lights out the previous night. This is potentially problematic given the reported variability between self-reported measures of sleep and actual sleep obtained (13).

In recent years, wrist-activity monitors us proprietary scoring algorithms to identify time of lights out, and therefore do not require input of subjective data from sleep diaries. One such device is the Readiband™ (14), a wrist-activity monitor developed for use in military environments unsuited to accurate and regular completion of a sleep diary. The Readiband has been used in a range of personnel and settings including police, physicians, mining, shift-workers, forestry industries (15-20) and in elite athletes (21-23) including the US National Football League. Currently, only one technical report has been conducted on the validity of the Readiband and this reported an overall accuracy of 93% when compared to PSG (14).
The aim of the present study was to compare measurements of sleep obtained from the ActiGraph and Readiband devices to measurements obtained from PSG in a sleep laboratory, and to compare both devices against each other when worn at home for 7 nights. We were also interested in determining the accuracy and influence of algorithm derived estimates of time at lights out (Readiband) and the subjective estimates of time at lights out (ActiGraph) on measurements of sleep latency and sleep efficiency.

3.3 Methods

3.3.1 Participants

A community sample of 50 middle-aged adults were recruited from the parents of participants in the 22-year follow-up study of the Western Australian Pregnancy Cohort (Raine) Study (24). Participants were recruited sequentially from September to December 2015 based upon their scheduled study night at the sleep laboratory. Inclusion for the study was agreement to wear the two wrist-activity monitors at home for the night of the sleep study and for an additional 7 nights. There were no exclusion criteria. Informed, written consent was obtained from each participant and ethical approval for the study was obtained from the University of Western Australia Human Research Ethics Committee.

3.3.2 Protocol

Each participant wore an ActiGraph and a Readiband on the same wrist (non-dominant) for eight successive nights. On the first night (Night 1) each participant slept at the University of Western Australia’s Centre for Sleep Science where they underwent simultaneous PSG (the “In-laboratory” condition). Subsequent nights (Nights 2-8) were spent at home (the “At-home” condition). Following Night 8 (i.e. Day 9) participants returned the devices to the research team.
3.3.3 Anthropometric measurements

Measurements of height (cm) and weight (kg) were collected on Night 1 when participants arrived at the sleep laboratory. Body Mass Index (BMI) was calculated from weight/height$^2$ (kg/m$^2$).

3.3.4 Sleep diaries

Participants were asked to complete a sleep diary every morning, noting the time they turned the lights out the previous evening (“time at lights out”).

3.3.5 Polysomnography

Participants attended the sleep laboratory for an overnight PSG assessment for the In-laboratory condition. All PSG studies were performed on a weeknight (Monday, Tuesday, Wednesday or Thursday). Each participant was instrumented by a trained sleep technician as per AASM recommendations (25, 26) and data were collected using the Compumedics Grael system (Compumedics, Victoria, Australia). As the focus of the study was PSG identification of wake and sleep periods, the following electrodes were placed to facilitate the staging of sleep: 6 electroencephalogram (EEG) sensors to the head utilising the 10/20 system (F3-M2, F4-M1, C3-M2, C4-M1, O1-M2, O2-M1); two electro-oculogram (EOG) sensors at the lower edge of the left eye and the upper edge of the right eye; and three submental electromyogram (EMG) electrodes were placed on the chin. Participants were awoken between 06:00-07:00 hr the following morning. The PSG data were scored by a sleep technician according to the AASM (2012) rules for the staging of sleep (25).
3.3.6 **Wrist-Activity Monitors**

ActiGraph recordings were performed using GT3X+ activity monitors (ActiGraph, FL, USA). This device has been shown to have good validity (overall accuracy of 82%) when compared to sleep/wake epochs against PSG (28). Data from the ActiGraph devices were downloaded and analyzed using the ActiLife™ software (ActiGraph 2012, ActiLife 6) and scored in one-minute epochs as awake or asleep as per the Cole-Kripke algorithm (7).

Readiband recordings were performed using the Readiband version 3 (Readiband, Fatigue Science Inc., Canada). To the best of our knowledge the current and previous versions of the Readiband are similar, and most changes between versions have been aesthetic changes to the wrist-activity monitor and its interface. This Readiband device has been shown to be valid (overall accuracy of 93%) when compared to sleep/wake epoch scoring against PSG (14) and has been approved by the US Federal Drug Administration for measurement of sleep (29). Data from the Readiband devices were downloaded and analysed using the automated proprietary scoring algorithm Readiband Sync™ software.

3.3.7 **Analyses**

Sleep measures output by each device and PSG included: time of lights out (for PSG, it is the time the sleep technician turned off the lights to initiate sleep, for ActiGraph, the participant self-reported time at lights out by way of diary and Readiband time at lights out utilized an automated proprietary scoring algorithm); sleep latency (number of minutes from time at lights out to time of sleep onset); time at sleep onset (time of the first epoch of sleep between lights out and lights on); sleep duration (number of minutes from time of sleep onset to time at wake, minus number of minutes awake);
wake after sleep onset (number of minutes awake after sleep onset); time at wake (the
time of wake from sleep with no further sleep duration); time in bed (the total time
spent in bed, from lights out until time at wake); and sleep efficiency (sleep duration
divided by time in bed multiplied by 100).

3.3.8 Statistical analysis

Linear mixed models were used to compare sleep measurements derived from PSG,
ActiGraph and Readiband for the In-laboratory condition and between ActiGraph and
Readiband for the At-home condition for the measurements of: time at lights out, sleep
latency, time at sleep onset, sleep duration, sleep efficiency, wake after sleep onset, time
at wake. Fixed effects of measurement device (PSG, ActiGraph or Readiband), time;
Night 1 (In-laboratory), Nights 2-8 (At-home) and their respective interaction terms (as
appropriate) were included in the model along with random individual effects. Sleep
latency and wake after sleep onset were transformed using a log transformation and
statistical analyses were performed on the transformed data. Sleep efficiency and sleep
period efficiency were transformed using an arcsine square root transformation. The
maximum likelihood estimation used in linear mixed-effects models effectively deals
with the problem of missing data, as opposed to alternative methods which employ case-
wise deletion should one individual have any observation missing.

Bland-Altman analyses were used to determine the agreement between devices
for each sleep measure and are presented as the magnitude of difference between
devices (bias) and the Limits of Agreement (LoA) (30). Data are presented as
mean±standard deviation (SD) or mean±LoA and p<0.05 was considered as
statistically significant for all tests. All statistical analyses were performed using the
R environment for statistical computing (31).
3.4 Results

A total of 50 participants (30 females, 20 males) volunteered for this study. Their mean age was 57±5 years (range 46-73 years), weight 76±13 kg (range 50-110 kg), height 167±10 cm (Range 134-186 cm) and BMI 27±5 kg/m² (Range 20-45).

Comparisons of sleep measures between PSG, ActiGraph and Readiband for the In-laboratory and At-home conditions are shown in Table 2 and summarised as follows:

Table 2 Wrist-Activity and PSG measures

<table>
<thead>
<tr>
<th>Sleep measure</th>
<th>Polysomnography</th>
<th>Readiband</th>
<th>ActiGraph</th>
<th>Readiband</th>
<th>ActiGraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time at Lights Out (hh:mm)</td>
<td>22:33±26</td>
<td>22:32±27</td>
<td>21:45±68†</td>
<td>22:40±54</td>
<td>21:55±77*</td>
</tr>
<tr>
<td>Sleep Latency (min)</td>
<td>18±18</td>
<td>4±4†</td>
<td>40±32†</td>
<td>5±4</td>
<td>27±18*</td>
</tr>
<tr>
<td>Sleep Duration (min)</td>
<td>335±61</td>
<td>339±40†</td>
<td>393±56†</td>
<td>413±39</td>
<td>451±49*</td>
</tr>
<tr>
<td>Wake After Sleep Onset (min)</td>
<td>84±51</td>
<td>36±29†</td>
<td>14±11†</td>
<td>46±24</td>
<td>14±8*</td>
</tr>
<tr>
<td>Time at Wake (hh:mm)</td>
<td>05:48±24</td>
<td>05:52±23</td>
<td>05:47±26</td>
<td>06:24±60</td>
<td>06:50±85</td>
</tr>
<tr>
<td>Time in Bed (min)</td>
<td>436±29</td>
<td>440±31</td>
<td>482±67†</td>
<td>464±38</td>
<td>528±62*</td>
</tr>
<tr>
<td>Sleep Efficiency</td>
<td>78±12</td>
<td>91±7†</td>
<td>79±11*</td>
<td>89±5</td>
<td>84±7*</td>
</tr>
</tbody>
</table>

Notes: “In-laboratory” and “At-home” conditions (n=50). Data are presented as means ± standard deviations, which for nights 2-8 are based on average data across all nights. *p<0.05 Readiband versus ActiGraph, †p<0.05 Readiband or ActiGraph versus Polysomnography on Night 1 only. Comparisons between ActiGraph and Readiband on Nights 2-8 are for aggregated difference across all nights.

3.4.1 Time at Lights Out

In the In-laboratory condition, compared to PSG, the time at lights out estimated by ActiGraph (i.e. from morning diary) (Table 1 and Figure 2) was not different (p=0.81), whereas the Readiband’s automated estimation of time of lights out occurred 48±136 min earlier (mean ±LoA) (p<0.001). However, a proportional bias (i.e. magnitude of difference related to the magnitude of measurements) was observed for Readiband vs PSG and ActiGraph vs Readiband. No difference was observed between ActiGraph vs PSG (p=0.48). In both the In-laboratory and At-home conditions the Readiband
automated estimation of time at lights out occurred earlier than ActiGraph, by 47±136 min and 45±108 min, respectively (p<0.001 for both).

Figure 2  Time at Lights Out (hours),

Notes: Bland Altman plots for time at lights out for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

### 3.4.2 Sleep Latency

In the In-laboratory condition (Table 2 and Figure 3), compared to PSG, ActiGraph sleep latency was underestimated by 14±35 min (p<0.05), while Readiband sleep latency was overestimated by 22±74 min (p<0.05). A proportional bias was observed for Readiband vs PSG, ActiGraph vs PSG and ActiGraph vs Readiband. In both the In-laboratory and At-home conditions the Readiband sleep latency was longer than ActiGraph, by 36±60 min (p<0.05) and 22±36 min (p<0.001), respectively.
Figure 3  
Sleep latency (Minutes)

Notes: Bland Altman plots for sleep latency for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.4.3  
Time at Sleep Onset

In the In-laboratory condition (Table 2 and Figure 4), compared to PSG, the ActiGraph was not different (p=0.17), while the Readiband was earlier by 27±96 min (p<0.05). A proportional bias was observed for Readiband vs PSG and ActiGraph vs Readiband. The estimated time at sleep onset was not different between the ActiGraph and Readiband for either the In-laboratory condition (p=0.37) or the At-home condition (p=0.13).
Figure 4  Time at sleep onset (hours),

Notes: Bland Altman plots for time at sleep onset for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.4.4  Sleep Duration

In the In-laboratory condition (Table 2 and Figure 5), compared to PSG, sleep duration was overestimated by both ActiGraph and Readiband, by 64±106 min and 58±122 min, respectively (p<0.001 for both). A proportional bias was observed for ActiGraph vs PSG and ActiGraph vs Readiband. Sleep duration was not different between the two devices for the In-laboratory condition (p=0.58), however for the At-home condition Readiband sleep duration was 38±61 min longer than the ActiGraph (p<0.001).
Figure 5  Sleep duration (minutes)

Notes: Bland Altman plots for sleep duration for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.4.5  Wake after Sleep Onset

In the In-laboratory condition (Table 2 and Figure 6), compared to PSG, the time spent awake after sleep onset was underestimated by both the ActiGraph and Readiband, by 48±85 min and 70±101 min, respectively (p<0.001 for both). A proportional bias was observed for Readiband vs PSG, ActiGraph vs PSG and ActiGraph vs Readiband. In both the In-laboratory and At-home conditions the Readiband estimated wake after sleep onset was less than ActiGraph, by 22±60 min and 32±52 min, respectively (p<0.001 for both).
Figure 6  
Wake after sleep onset (minutes)

Notes: Bland Altman plots for wake after sleep onset for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.4.6  
Time at Wake

In the In-laboratory condition (Table 2 and Figure 7), compared to PSG, there was no difference in the estimated time the participants woke for either the ActiGraph (p=0.67) or Readiband (p=0.99). The estimated time at wake was not different between the ActiGraph and Readiband for either the In-laboratory condition (p=0.66) or the At-home condition (p=0.16).
Figure 7  Time at wake (hours)

Notes: Bland Altman plots for time at wake for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.4.7  Sleep Efficiency

In the In-laboratory condition (Table 2 and Figure 8), compared to PSG, the ActiGraph overestimated sleep efficiency by 13±20 % (p<0.001) with no difference for the Readiband (p=0.45). A proportional bias was observed for ActiGraph vs PSG and ActiGraph vs Readiband. In both the In-laboratory and At-home conditions the Readiband estimated sleep efficiency was less than ActiGraph, by 12±20 % and 5±14 %, respectively (p<0.001 for both).
Figure 8  Sleep efficiency (%)

Notes: Bland Altman plots for sleep efficiency for (a) Readiband vs PSG (b) ActiGraph vs PSG (c) ActiGraph vs Readiband and (d) Box Plots PSG vs ActiGraph vs Readiband. Difference = Wrist Activity Monitor – PSG. Average = (Wrist Activity Monitor + PSG)/2. Solid line = mean of difference dashed lines (bias). Dashed line = ± 2SD. Perfect agreement is indicated by a mean difference of zero.

3.5 Discussion

This study compared measurements of sleep obtained from two wrist-activity monitors (the Readiband and ActiGraph), to the gold standard sleep assessment, laboratory-based PSG. In addition, these devices were compared against each other when worn at home for 7 consecutive nights. The major finding of the study was that the automated scoring algorithm estimation for time at lights out (as used by Readiband) was inaccurate compared to self-reported time at lights out (as used by ActiGraph) and technician reported time of lights out (as used by PSG). Sleep measurements that were
not reliant on this measurement (e.g. time at sleep onset, sleep duration and time at wake) were similar between devices when used in the laboratory.

Accelerometer-based measurements of sleep can be considered in terms of variables that are either ‘directly’ measured by the device or required to be inputted (e.g. time at lights out, time at sleep onset, wake after sleep onset and time at wake) or variables that are derived from these measures (e.g. sleep latency, sleep duration and sleep efficiency). The accuracy of the latter variables is entirely dependent on the accuracy of the former.

Currently, the main guidelines for use of wrist-activity monitors to assess sleep (9) recommend using a diary to enter a value for time at lights out, although new commercially available devices on the market have developed proprietary algorithms to automatically estimate time at lights out. A benefit of such an automated algorithm is that they are not reliant on the input of subjective data and thus not influenced by the potential variability associated with this (32). It is also recommended that accelerometry data be collected for at least seven nights to adequately represent sleep when using wrist-activity monitors (33, 34). Hence, a comparison of the behaviour of these devices against each other when worn at home for 7 nights in the current study, and against the results on the PSG night.

Accurate measurement of the time at lights out is essential for the calculation of sleep latency and sleep efficiency. On the PSG night, Readiband (Automated) underestimated time at lights out by 48 min (vs PSG) while the ActiGraph (Self-reported) was the same as PSG (within 1 minute). Similar differences in time at lights out were observed between the two devices when worn at home, suggesting that the underestimation by Readiband persisted during the At-home condition. Automatic measurement of time at lights out is challenging, and the precise algorithm used by the
Readiband is unknown. Other devices use a light sensor to identify time at lights out, however this is problematic as the measurement will be inaccurate when the device is worn under clothing or under bed covers (34). Other devices use an event marker for participants to identify time at lights out, however this too can be problematic as it requires an individual to remember to actuate this marker each night in order for accurate measurements of time at lights out to be obtained (34).

The time at sleep onset is used in the calculation of sleep latency and sleep duration. On the PSG night, the Readiband estimated time at sleep onset to occur 27 min earlier than PSG defined time at sleep onset while the ActiGraph was not statistically different. Similar differences in time at sleep onset were observed between the two devices when worn at home, suggesting that the earlier time at sleep onset recorded by Readiband, relative to the ActiGraph persisted during the home condition. While many wrist-activity monitors studies using wrist activity report measures such as sleep latency and sleep duration, (32, 35, 36) to date none have reported time at sleep onset against PSG.

The time at wake is used to signal the end of the sleep period and to calculate sleep duration. The Readiband and ActiGraph accurately estimated the time at wake against the PSG defined time at wake. In the home condition participants tended to wake later, however there was no difference between the Readiband and ActiGraph.

Generally, studies that compare wrist-activity monitor data to PSG or between actigraphy devices, in general do not report results relating time at wake or investigate the validity of such measures (32, 35, 36).

The time spent awake after sleep onset (WASO) is used to calculate sleep efficiency and is a commonly reported sleep measure in studies comparing wrist-activity monitors to PSG (8, 28, 37). In the present study both the Readiband and
ActiGraph devices significantly underestimated WASO by 70 and 48 minutes, respectively. It is likely that both devices continued to underestimate WASO in the home environment as the magnitudes of WASO and the differences between devices were similar when recorded in the laboratory and at home. These findings are consistent with many other studies that have reported that wrist-activity monitors are poor at correctly identifying periods of WASO (8), with some studies reporting overestimation of WASO compared to PSG (8, 38) and others reporting underestimation (39).

Sleep latency is defined as the time taken to fall asleep. Errors in the calculation of sleep latency can therefore result from inaccurate measurements of time at lights out or time at sleep onset. In this current study, compared to PSG, sleep latency was greater for the Readiband and less for the ActiGraph device. These differences were due to an earlier estimate of time at lights out and an earlier estimate of time at sleep onset for the Readiband; and an earlier estimate of time at sleep onset for the ActiGraph.

Previous studies have reported accelerometer-derived measures of sleep latency to be increased (37), decreased (8) or no different to PSG-derived measures (39, 40). While the reasons for these differences have not been explored in any previous studies, the findings of the present study highlight that errors in the estimations of times at lights out and/or time at sleep onset as potential sources of such variability in sleep latency (as sleep latency is calculated from these).

Sleep efficiency is a derived variable that is directly affected by the accuracy of the measurements of sleep latency and WASO. Specifically, WASO influences the measurement of sleep duration and sleep latency influences the measurement of time in bed. In the present study, the measurement of time in bed was affected by the significant underestimation of sleep latency using the self-reported method (ActiGraph) and significant overestimation by the automated scoring algorithm.
(Readiband). Both devices were poor at assessing WASO (underestimation by an average of 59 min compared to PSG) resulting in an overestimation of sleep duration, thereby affecting sleep efficiency. The overestimation of sleep efficiency by ActiGraph of 13% is likely to have continued in the home environment as the magnitude of sleep efficiency and the differences between devices were similar between the laboratory and home conditions.

Sleep duration is derived from time at sleep onset to time at wake minus any periods spent awake (WASO). Compared to PSG, both the Readiband and ActiGraph devices similarly overestimated sleep duration (by an average of 61 min). When used in the home setting sleep duration increased for both devices compared to sleep duration measured on the laboratory night. This was particularly the case for the Readiband which reported almost a one hour increase in sleep duration. There is probably no single reason for the difference in sleep duration between the two devices in the home setting as the Readiband reported an earlier time at sleep onset, later time at wake and decreased WASO compared to the ActiGraph, all of which could contribute to an increased sleep duration.

Previous studies comparing sleep duration when measured from wrist-activity monitors and PSG have reported both an underestimation (41) and overestimation (42) in sleep duration. Rupp and Balkin (43) suggested that such variability in sleep duration is mainly due to the inaccuracy of wrist-activity monitors to identify periods of wake during sleep. The similarity in the present study between the magnitude of underestimation of WASO and overestimation of sleep duration is consistent with the conclusions of Rupp and Balkin (43).

A strength of the current study is its use of an unbiased selection of the general population as the participants in this study (n=50) were part of the broader parent
cohort of participants in the Raine study (24), an internationally recognised and well-published birth cohort study. As such the findings of this study are generalizable to other studies using such devices in the general population.

3.5.1 Limitations

A limitation of this study is the potential inclusion of individuals with health issues such as sleep disorders and other comorbidities, which could influence accelerometry derived sleep variables. However, such a limitation will exist in any community-based study and therefore not influence the generalizability of the current findings. Further, each participant simultaneously wore both devices during the full laboratory-based PSG study, and as such served as their own control for this study when comparing measurements between devices. Another limitation of the study is the inability to access information regarding the proprietary algorithm used by the Readiband device. This is a problem common to many devices that contain automated scoring algorithms (e.g. FitBit, Jawbone, Garmin, Apple Watch). In the case of the Readiband the proprietary automated algorithm is owned by the United States military with Fatigue Science Inc., being the authorised distributor under license. To the best of our knowledge the underlying Readiband algorithm has not changed, with earlier versions of the device differing only in aesthetic changes to the watch and its interface.

3.5.2 Summary

The substantial challenges associated with automated measurement of time at lights out and sleep latency provide a strong reason for not including sleep latency in the calculation of time in bed and sleep efficiency. Similar issues regarding imprecise time in bed or rest interval period were found in another study using a default automated algorithm (44).
In such a scenario, both time in bed and sleep efficiency would be derived from a measurement of ‘sleep period time,’ being the time elapsed between the first onset of sleep and the final awakening (45). Indeed, such an approach is being applied to automated scoring algorithms of several consumer based wrist-activity monitors (32, 36), possibly in response to the substantial challenges in automatically determining time of lights out. However, a consequence of this approach is that such devices will provide higher values of sleep efficiency as well as not providing measures of sleep latency.

This study highlights the challenges of accurately measuring the time at lights out as the primary reason for differences in sleep measurements between the ActiGraph and Readiband devices. The use of an event marker for time at lights out may improve the accuracy of measurements of sleep latency, time in bed and sleep efficiency, however such a method is completely reliant on the wearer remembering to press the event marker each night, and to do this at the correct time. The accurate recall of time at lights out in the present study adds support for the potential use of an event marker or time stamp (44). However it must be noted that these data were obtained in the setting of a sleep laboratory and it remains unknown how accurate diaries or event markers are for measurement of lights out in applied settings such as shift workers, military or athletes (46).

3.5.3 Conclusion

In conclusion, this study has shown that the Readiband device may be used in the same capacity as other wrist-activity monitor devices such as the ActiGraph for the collection of sleep measures including time at sleep onset, sleep duration and time at wake. However, Readiband and ActiGraph measures of sleep latency, sleep efficiency and wake after sleep onset should be interpreted with caution.
3.5.4 Acknowledgements

We acknowledge and thank the Raine Study participants, their families Raine study team for cohort management and data collection. Many thanks to Fatigue Science, Vancouver, British Columbia for the supply of Readibands™.

3.6 Disclosure statement

The Raine Study 22 year follow up was supported by NHMRC project grants 10277449, 1021858, 1031617 and 1044840. Core funding for cohort management was provided by the University of Western Australia, the Telethon Institute for Child Health Research, Raine Medical Research Foundation, University of Western Australia Faculty of Medicine, Dentistry and Health, Women’s and Infant’s Research Foundation, Edith Cowan University and Curtin University. Professors Straker and Eastwood were funded by National Health and Medical Research Council of Australia (NHMRC) Senior Research Fellowships (1019980, 1042341).

3.7 Compliance with Ethical Standards

Conflict of Interest. Ian C Dunican and John A Caldwell have previously undertaken consultancy work for Fatigue Science, but neither are currently engaged in any capacity with the company.

Ethical approval. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study and ethical approval was obtained from the University of Western Australia Human Research Ethics Committee.
3.8 References


Chapter 4  The effects of the removal of electronic devices for 48 hours on sleep in elite judo athletes

Authors

Ian C Dunican¹, David T Martin², Shona L Halson², Reid Reale²,⁶, Brian Dawson³, John Caldwell⁵, Maddison J. Jones³ and Peter R Eastwood¹.

Institutions

¹ Centre for Sleep Science, School of Anatomy, Physiology and Human Biology, The University of Western Australia.

² The Australian Institute of Sport, Canberra, ACT, Australia.

³ School of Sports Science Exercise and Health, The University of Western Australia.

⁴ Coastal Performance Consulting, Florida, United States.

⁶ University of Sunshine Coast, Sippy Downs, Queensland, Australia

Publication Status

Published in the Journal of Strength and Conditioning Research

4.1 Abstract

This study examined the effects of evening use of electronic devices (i.e., smartphones, etc.) on sleep quality and next-day athletic and cognitive performance in elite Judo athletes. Over 6 consecutive days and nights, 23 elite Australian Judo athletes were monitored while attending a camp at the Australian Institute of Sport (AIS). In 14 athletes, all electronic devices were removed on days 3 & 4 (i.e. for 48 hours: the “device-restricted group”) while 9 were permitted to use their devices throughout the camp (the “control group”). All athletes wore an activity monitor (Readiband) continuously to provide measures of sleep quantity and quality. Other self-reported (diary) measures included time in bed, electronic device use, and rate of perceived exertion during training periods. Cognitive performance (Cogstate) and physical performance (single leg-triple hop test) were also measured. When considering Night 2 as a ‘baseline’ for each group, removal of electronic devices on Nights 3 & 4 (device-restricted group) resulted in no significant differences in any sleep-related measure between the groups. When comparing actigraphy-based measures of sleep to subjective measures, all athletes significantly overestimated sleep duration by 58±85 minutes (p=0.001) per night and underestimated time of sleep onset by 37±72 minutes (p=0.001) per night. No differences in physical or cognitive function were observed between the groups. This study has shown that the removal of electronic devices for a period of two nights (48 hours) during a judo camp does not affect sleep quality or quantity or influence athletic or cognitive performance.
4.2 Introduction

Elite athletes have busy schedules with commitments to training, competition, and media. Athletes are increasingly using electronic devices [1] to stay connected with family, friends and coaches. Whilst beneficial for communication, excessive late night use of electronic devices can result in decreased sleep duration and, potentially, athletic performance [2], as sleep is crucial for psychological functioning and daily performance of athletes [3]. Indeed, the high usage of electronic devices and potential negative effects on overnight sleep and subsequent next day performance were key factors in the imposition of a ‘tweeting ban’ on Australian athletes during the 2014 Sochi Winter Olympics [4].

A growing body of evidence indicates that use of electronic devices in the evening prior to sleep negatively affects the amount and quality of sleep obtained in young adults [2, 5, 6]. Specifically, electronic device usage prior to sleep has been shown to increase the severity of insomnia symptoms [5] and regular evening use of electronic devices can lead to an acute and/or a chronic sleep debt [2]. These negative effects appear to be particularly common in adolescents, with one in five reporting nightly bedtime delay and increased time taken to fall asleep as a consequence of electronic media use [6].

The main mechanism underlying the disruptive effects of electronic devices (smartphones, tablets, computers and televisions) on sleep is thought to be light emission from the device in the evening immediately prior to sleep. Early studies suggested that light intensity and/or brightness were responsible for these negative influences on sleep [7, 8]; however, more recent work indicates that the spectral distribution, or wavelength of the light may be of more importance than brightness [9]. Today’s electronic devices contain Light Emitting Diodes (LEDs) that emit a shorter wavelength light, making it more “blue” in appearance. Such light emissions can
affect sleep by disrupting normal circadian rhythms, particularly by suppressing the secretion of melatonin [9, 10], with resultant increased alertness and delayed time of sleep onset [10, 11]. These changes in alertness and time of sleep onset can lead to sleep loss and reduced sleep efficiency.

Sleep loss can have a negative impact on aspects of physical function known to be important for recovery and performance in competitive sports [12, 13]. For example, reduced muscle glycogen storage, increased perceived stress and reduced sprint performance have all been found to occur as a consequence of sleep loss [14]. Measurements of anaerobic power have been shown to be impaired after 36 hours without sleep [15] and both decreased sleep duration and increased sleep latency have been shown to negatively affect testosterone levels, hand grip strength and walking speed, all of which can impact physical performance [16].

Sleep loss also negatively affects cognitive performance and reaction time, both of which are important components of athletic performance. Restricting sleep to 4-5 hours per night, increases mood disturbances and the frequency and duration of Psychomotor Vigilance Test (PVT) lapses [17] whilst after 77 hours of wakefulness lapses significantly increase [18].

Therefore, the aim of this study was to determine the impact of the removal of electronic devices for a period of 48 hours on Judo athlete’s (Judokas) overnight sleep quantity and sleep quality, and the effect of any changes in sleep on subsequent physical and cognitive performance.
4.3 Methods

4.3.1 Experimental approach to the problem

The study was undertaken at the Australian Institute of Sport (AIS) Combat Centre. This study was conducted at an International Judo camp held at this facility over six consecutive days and nights in September 2014. All athletes travelled to Canberra from the eastern seaboard of Australia, therefore jetlag or circadian misalignment was not present.

The training camp required three training sessions per day. These occurred between the hours of 06:30-08:00, 10:00-12:00 and 16:00-18:00. On day seven the first training session was at 09:30 h, i.e. the athletes were provided an extended sleep opportunity on the previous night (Night six).

Meals and accommodation were provided at the AIS village. All athletes shared apartment style accommodation for the duration of the camp with 2 athletes per room. Shared sleeping environment was based on gender.

4.3.2 Subjects

Twenty-three athletes (12 males and 11 females) participated in this study. Their mean age was 18±2 years (range 16-24 years) and mean body mass was 66±10kg (48-81kg). Five participants in the device-restricted group (2 males, 3 females) were excluded from the final analyses due to their unanticipated self-reported use of electronic devices during the 48-hour restriction period. Specifically, these athletes watched television, accessed Facebook and sent text messages by obtaining electronic devices from the participants in the control group or from other persons at the AIS. Thus, final analyses were based on a total of 18 athletes, 9 in the device-restricted group (all males) and 9 in the control group (8 females, 1 male).
Information regarding the testing protocols and expected commitment to the study was provided to participants prior to obtaining their written consent and parent/guardian consent was obtained from any participants under 18 years of age. Ethical approval for the study was obtained from the Human Research Ethics Committees of the AIS and The University of Western Australia.

4.3.3 Procedure

This study was an observational/intervention design. On the evening of day 1 participants were asked to self-allocate to a control group or a device-restricted group. The device-restricted group (n=9) had all electronic devices (e.g. laptops, phones, tablets) removed for a period of 48 hours on days 3 and 4 (i.e. including nights 3 and 4). On the morning of day 5 electronic devices were returned to the device-restricted group. The control group (n=9) was permitted to use electronic devices ad libitum over the study period.

All athletes wore a wrist-activity monitor (Readiband™ Fatigue Science, Canada) continuously over the monitoring period to provide measures of sleep. Athletes also completed a diary each morning that included self-reported estimates of time in bed. Additional diary questions included daily electronic device use, daily caffeine use and the rating of perceived exertion (RPE) during all training periods.

Cognitive performance was measured on days 2 and 4 and physical performance was assessed on days 2, 3, 4, 5 and 6. At the commencement of the study, (evening of day 1), questionnaires were administered to collect general information including demographic and anthropometric data, sleep history, risk of insomnia, sleepiness and obstructive sleep apnea.
4.3.4 Specific Measurements

Actigraphy. An activity monitor and a sleep/training diary were issued to each athlete at 20:00 on the evening of Day 1 (Night 1) and retrieved on the morning of Day 7 (after Night 6). Activity monitors were worn on the non-dominant wrist throughout the monitoring period, including during training and sparring. These devices have been shown to accurately detect sleep/wake episodes (overall accuracy of 93%) in comparison to the gold standard of polysomnography (PSG)[19, 20].

Sleep related measures were derived from each device using the Readiband Sync software™. These included Sleep Duration (SD), Sleep Latency (SL), Time of Sleep Onset (SO), Wake After Sleep Onset (WASO), Sleep Efficiency (SE) and Time at Wake (WT).

Diary. Athletes were provided with a sleep/training diary, which they carried with them throughout the study period. The diary contained questions relating to their sleep, electronic device use, caffeine use, and training effort.

Electronic device use: Electronic device usage information included the duration of use in hours and minutes, the type of device/s used and the type of activity undertaken in the two hours prior to bed.

Caffeine Consumption: Quantity and type of caffeine consumption were recorded at the end of each day prior to sleep.

Training Effort: Rating of perceived exertion was recorded after each training session. The RPE scale is used to record the self-perceived exercise intensity and is strongly correlated with several other physiological measures of exertion [21].
Cognitive Performance. The Cogstate research tool (Cogstate Ltd, Australia) and Cogstate Research software were utilized to assess cognitive function. This computerized testing system has been shown to provide repeatable and sensitive measures of cognitive status [22] and has been used extensively in a range of applications including (but not limited to) sleep, cognitive performance and exercise [23]. Testing occurred in all participants between 13:00 and 16:00 on Days 2 and 4. The testing environment and testing stations were standardized for each session. The primary measure of cognitive performance was an identification task “speed of performance”, which measured reaction times for correct responses. A secondary measure was the total number of errors made in attempting to learn the same hidden pathway on five consecutive trials at a single session. For both tests a lower score indicated a better performance. Athletes conducted a familiarization test prior to each testing period on each day.

Physical Performance. A Single Leg -Three Hop Test (SL-THT) was used to assess physical performance, mainly due to its simplicity and relative ease of use for athletes. While jump tests and a ‘judo-specific test’ have been utilised in other judo studies [24, 25] these were deemed less relevant to the athletes in the current study given their different skill level (judo ranks) and demographic and anthropometric factors. The SL-THT was conducted on judo training mats each afternoon (Days 2 to 6) between 16:00 -16:30. The time of day was kept constant in order to control for any circadian variation in performance [26]. A 10-minute warm up was conducted prior to each testing session. This was facilitated and led by the Judo Australia training staff. The warm up was conducted on the tatami mats (approx. 25m x 25m) and consisted of jogging around the perimeter, 20m sprints, forward rolls, backward rolls over 20m, break falls and general mobility.
After a warm up, each athlete attempted to jump as far as possible on one leg, starting the test on one leg and finishing the test by landing on two feet with knees slightly flexed. A total of four tests were conducted on each occasion, with two attempts starting on each leg. The primary outcome measure was the sum of the greatest distances achieved when starting on the left and right leg. Athletes conducted a familiarization test prior to each testing period on each day.

*Anthropometric and demographic measurements.* Anthropometric measurements were collected on Day 2 of the training camp between 13:00-16:00, immediately prior to the cognitive performance tests. Measurements included height (cm), mass (kg) and neck circumference (cm). Body mass index (BMI) was calculated from weight/height$^2$ (kg.m$^2$).

*Sleep-Related Questionnaires.* Insomnia was assessed using the validated Insomnia Severity Index (ISI). The ISI consists of five separate questions that ask the participant to self-rate their own experience with insomnia, each with a scale of 0-4. The questions relate to severity, satisfaction, noticeability and worry or distress associated with their insomnia. Scores were aggregated and assessed against a criterion. A score greater than 15 indicates clinical insomnia [27].

*Daytime sleepiness* was assessed using the Epworth Sleepiness Scale (ESS). The ESS is a self-reported scale that asks how likely an individual is to doze off or fall asleep in common daytime situations. Scores in excess of 9 indicate excessive daytime sleepiness [28].

*Obstructive Sleep Apnoea (OSA)* risk was assessed using the Berlin questionnaire [29], which assigns risk of OSA based on the presence and frequency of snoring behaviour; wake time sleepiness or fatigue and a history of obesity and/or hypertension. A positive response to two or more of these categories indicates risk for OSA.
4.3.5 Statistical analysis

Night 1 was considered a familiarisation night and night 2 as the baseline night for all sleep-related measures. Nights 3 and 4 were considered the experimental nights for the device-restricted group, with night 5 considered as a return to baseline conditions. Night 6 was considered to be a recovery night, as athletes did not have a scheduled training session until 09:30 the following morning. A two-way repeated measures analysis of variance (ANOVA) was conducted on the raw data for all variables (device-restricted and control) over the 6 nights and 5 days (no data were collected on day 1) for sleep, electronic device use, and cognitive and physical performance data. An unpaired t-test was used to compare anthropometric data between groups, and between self-reported and actigraph measures of SD, WT and SO. Analyses were undertaken using SigmaStat version 13. Normality and equal variance were assessed using the Shapiro-Wilk and Brown Forsythe tests, respectively. Non-parametric data were compared using a Mann Whitney Rank Sum test and Fisher’s least significant difference test for post hoc testing. Data are presented as mean ± standard deviation (SD) for each group and p<0.05 was considered as statistically significant for all tests.

4.4 Results

Demographic, anthropometric and sleep-history data of participants are summarized in Table 3. Two athletes in the device-restricted group and one athlete in the control group reported sub-threshold insomnia (ISI score 8-14). Four athletes in the device-restricted group and one athlete in the control group reported having excessive daytime sleepiness (ESS score >10) and four athletes within the device-restricted group and three athletes within the control group were characterized as being at risk for OSA (Berlin questionnaire scores >2). All these athletes were included in subsequent analyses.
# Table 3 Descriptive characteristics of the sample population

<table>
<thead>
<tr>
<th></th>
<th>Device-restricted group N=9</th>
<th>Control group N=9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td><strong>Anthropometric data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>17.2±5.1</td>
<td>18.9±2.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.9±1.9</td>
<td>66.4±10.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176±10*</td>
<td>165±6</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>22.7±2.3*</td>
<td>24.2±2.8</td>
</tr>
<tr>
<td>Neck Size (cm)</td>
<td>37.8±2.2*</td>
<td>34.1±1.9</td>
</tr>
<tr>
<td>Time training Judo (months)</td>
<td>68±46</td>
<td>58±41</td>
</tr>
<tr>
<td>Alcohol use (score)</td>
<td>2±3</td>
<td>2±2</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Female</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td><strong>Sleep History</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep you feel you need each night (mins)</td>
<td>473±93</td>
<td>490±56</td>
</tr>
<tr>
<td>Sleep you get each night (mins)</td>
<td>441±58</td>
<td>416±60</td>
</tr>
<tr>
<td>Sleep you feel you need after training or competition (mins)</td>
<td>520±176</td>
<td>513±159</td>
</tr>
<tr>
<td>Sleep you get after training or competition (mins)</td>
<td>476±74</td>
<td>456±83</td>
</tr>
<tr>
<td>No of days disrupted sleep per week</td>
<td>1±1</td>
<td>2±3</td>
</tr>
<tr>
<td><strong>Sleep disorders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berlin questionnaire score</td>
<td>1±1</td>
<td>1±1.0</td>
</tr>
<tr>
<td>Epworth Sleepiness Scale</td>
<td>8±5</td>
<td>7±2</td>
</tr>
<tr>
<td>Insomnia Severity Index</td>
<td>5±4</td>
<td>6±3</td>
</tr>
<tr>
<td><strong>Competition weight classes (athlete distribution)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60(kg) Extra Lightweight</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>60-66(kg) Half Lightweight</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>66-73(kg) Lightweight</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>73-81(kg) Half Middleweight</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;48(kg) Extra Lightweight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>48-52(kg) Half Lightweight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>52-57(kg) Lightweight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>57-63(kg) Half Middleweight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>63-70(kg) Middleweight</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>70-78(kg) Half Heavyweight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Competition level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competed at International level</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Competed at National level</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C).

* P<0.05 vs the control group, -No representation at these competition weight classes.
4.4.1 Training and electronic device usage

All athletes attended (Figure 9) the same training sessions each day and trained for an average of 255 minutes per day. Athletes from both groups reported a RPE of 7±1 following all training sessions. Compared to Day 2 (baseline), electronic device decreased by 11 minutes on Night 3 (p<0.05) and increased by 18 minutes on Night 4 (p<0.05). As per the protocol, the device-restricted group did not use electronic devices on Days 3 and 4. On each of the 6 Nights, device use was greater in the control than device-restricted group (p<0.05).

![Graph showing electronic device usage between groups.](image)

**Figure 9** Electronic device usage between groups.

*Notes:* Data presented as mean minutes of use in the 2.0 hours before sleep. n = 9 for the device-restricted group and n = 9 for control group. DRG = device-restricted group.

4.4.2 Actigraphic sleep measures on night 2 vs. nights 3 & 4

When considering Night 2 data as a ‘baseline’ for each group, removal of electronic devices on Nights 3 and 4 (device-restricted group) resulted in no significant within-group or between-group differences in any sleep measure (Table 4).
4.4.3 Actigraphic sleep measures on night 6

Athletes were provided an extended sleep opportunity on Night 6, by virtue of a later next day training time (commencing at 09:30). Compared to Night 2, SD on Night 6 tended to increase in the device-restricted group by 30±51 minutes (p=0.32) and significantly increased in the control group by 46±35 minutes (p=0.03). SD on Night 6 was not significantly different between the groups (p=0.08).

4.4.4 Sleep diary measures

Data from all nights of self-reported sleep data were pooled from the device-restricted and control groups (n=18) and compared to actigraphy-derived measures.

Compared to actigraphy-based measures: subjective measures of SD were significantly overestimated by 58±85 minutes (490±66 minutes vs 432±63 minutes, respectively, p=0.001); subjective measures of WT were significantly greater by 4±57 minutes (06:12±61 minutes vs 06:08±42 minutes, respectively, p=0.001); and subjective measures of SO were significantly underestimated by 37±72 minutes per night (21:57±45 minutes vs 22:24±51 minutes, respectively, p=0.001).
### Table 4  Actigraphy data

<table>
<thead>
<tr>
<th>Treatment Group:</th>
<th>Pre device restriction</th>
<th>Device restriction period -48hrs</th>
<th>Post device restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Night 1</td>
<td>Night 2</td>
<td>Night 3</td>
</tr>
<tr>
<td><strong>Sleep Duration (mins)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>DR</td>
<td>386</td>
<td>±44</td>
<td>419</td>
</tr>
<tr>
<td>C</td>
<td>433</td>
<td>±47</td>
<td>445</td>
</tr>
<tr>
<td><strong>Sleep Efficiency (%)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>DR</td>
<td>81</td>
<td>±10</td>
<td>82</td>
</tr>
<tr>
<td>C</td>
<td>82</td>
<td>±9</td>
<td>89</td>
</tr>
<tr>
<td><strong>WASO (mins)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>DR</td>
<td>8</td>
<td>±6</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>±6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Time at Sleep Onset (hh:mm)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td><strong>Sleep Latency (mins)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>DR</td>
<td>42</td>
<td>±34</td>
<td>66</td>
</tr>
<tr>
<td>C</td>
<td>66</td>
<td>±45</td>
<td>26</td>
</tr>
<tr>
<td><strong>Time at Wake (hh:mm)</strong></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>DR</td>
<td>05:54</td>
<td>±10</td>
<td>06:14</td>
</tr>
<tr>
<td>C</td>
<td>05:53</td>
<td>±12</td>
<td>05:55</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C). * P<0.05 vs Night 2 (baseline night). † P<0.05 DR group vs. C group within the same night. Time at Wake & Time at Sleep Onset ± SD are expressed in minutes.
4.4.5 Cognitive and Physical Performance

Compared with day 2 (baseline), speed of performance and errors were unchanged on days 3 & 4 in the device-restricted and control group. There were no differences between groups in either speed of performance (p=0.47) or errors (p=0.13). Similarly, compared to day 2 (baseline), the distance jumped was unchanged on day 3 & 4 in the device-restricted and control group. There were no differences between groups for distance jumped (p=0.07).

4.5 Discussion

The major hypothesis of this study was that removal of all electronic devices from elite athletes midway through a training camp would provide an increased sleep opportunity and result in earlier time to sleep and increased sleep duration. We also hypothesised that these changes would result in improved cognitive and physical performance on the days following any nights with increased sleep duration.

While removal of electronic devices resulted in a tendency towards an earlier time of sleep onset, by 37 and 36 minutes on the two device-restricted nights, these changes were not significantly different from those in the control group, who also went to bed earlier on these same two nights by 7 and 22 minutes, respectively. Such findings highlight the importance of a control group when assessing the effects of any such interventions. It is highly likely that the lack of statistical significance in sleep duration between the groups in the present study is as a result of the athletes being required to awaken at a set time each morning (which prevented sleep extension) so that training could commence at 06:30 each day. In this regard it was notable that on Night 6 when the athletes were provided with an extended sleep opportunity, as training start time on
Day 7 was delayed until 09:30, the waking time was later, thus increasing sleep duration by 30 minutes in the device-restricted group and 46 minutes in the control group.

The lack of effect of electronic device-removal on sleep duration in this study contrasts with other studies in young children, preadolescent and adolescent cohorts that have reported an increase in sleep duration with device removal [30-32]. However, it is likely that such studies have limited relevance to the young elite athletes who participated in the current study, who will tend to have an “owl” chronotype, characterised by a delayed time of sleep onset and later evening use of electronic devices (i.e. after 21:00) with high social media use [33]. These biological and behavioural factors make it difficult to encourage athletes to go to bed earlier and increase their sleep duration in this way, whereas allowing athletes to sleep later the next morning might be a more productive strategy to increase sleep duration [34, 35].

The current study found no relationships between removal of electronic devices and changes in sleep or cognitive or physical performance. This is most likely due to the lack of effect of electronic device-removal on sleep duration in these athletes and due to the relatively low numbers of participants available. A selection bias was apparent in this study with males tending to self-select to the device-restricted group and females self-selecting to the control group. The tendency (p=0.07) for an increased distance to be jumped in the single hop jump test in the device-restricted group could be a consequence of the greater number of males in this group.

It is possible that alternative methods of extending sleep in athletes or longer periods of sleep extension are required to elicit cognitive or physical performance improvements. For example, studies of short-term sleep extension ranging from 2-4 days have shown no effect on athletic performance [36, 37], a study conducted in
college basketball athletes found that 5-7 weeks of sleep extension (athletes were instructed to try to achieve 10 hours sleep each night) was associated with improvements in anaerobic, skill-based and cognitive performance [38]. While small in number, these studies to date suggest that promotion of sleep extension in athletes requires an approach that is relevant to the athletic group based upon time of day for competition, training schedules and age [36-38]. Data from the current study support the notion that athletes can increase sleep duration if allowed a later waking time. Such a concept is consistent with the findings from previous studies in athletes and in the mining industry showing that early morning starts, truncate sleep opportunity and lead to sleep loss [39, 40]. However further studies are required to determine whether performance benefits can be elicited from shorter duration sleep extension opportunities, especially during training camps, as was the case in the current study.

This study utilised both actigraphy devices and sleep diaries to collect objective and subjective measures of sleep, respectively. It was notable that subjective estimates of sleep from the diary, overestimated objective sleep duration (actigraph) by 65 minutes per night. Such findings are consistent with those reported in earlier studies in adolescent populations [41] and highlight the importance of using objective measures of sleep (wherever possible) in any study of elite athletes.

A selection bias was apparent in this study with males tending to self-select to the device-restricted group and females self-selecting to the control group. Athletes were accommodated at the AIS athlete village. Males and females were allocated to apartment style accommodation and athletes shared a room with one other athlete. It is possible that this sleeping environment impacted the quality of sleep due to a change from home sleeping environment, however, these conditions are representative of the usual sleeping environment during training camps and international competition.
It was also noticeable that athletes who self-allocated to the control group were strongly opposed to surrendering their electronic devices at any stage of the camp, perhaps indicating an addictive relationship to electronic devices in those who self-allocated to the control group. Further support for the difficulty that elite athletes have in abstaining from the use of electronic devices during a training camp was seen in the five of the 12 athletes who self-allocated to the device-restricted group but had to be excluded from post-hoc analyses as they either watched television, or accessed Facebook or sent text messages by obtaining electronic devices from others. It was also notable that on the night immediately following return of the devices the device restricted group had reduced sleep duration (by 56 minutes) and sleep efficiency (by 12%) compared to the control group, perhaps reflecting a compensatory increased use in response to the loss of devices in the preceding 48 hours.

4.5.1 Practical applications

The data from this study indicates that removal of electronic devices for a period of 48 hours has little effect on time of sleep onset and sleep duration of elite athletes, at least under circumstances where training schedules precluded the athletes from delaying their next-morning wakeup. Further, the study demonstrates the difficulty in increasing sleep duration by providing an environment more conducive to sleep in the evening. In contrast, young adult athletes appear to be able to increase sleep duration by delaying wake time, but only when such an opportunity is presented, as was the case in the present study on the final day of the training camp. A practical recommendation of this study could be that daily training start times should be delayed until after 08:00 in young athletes (<21 years old). In more general terms, the scheduling of training camps should be designed to consider sleep and recovery in
order to support sleep-related optimisation and efficacy of the training and the consolidation of skills.

4.5.2 **Conclusion**

This research study has shown that the removal of electronic devices for a period of 48 hours during a judo camp does not affect sleep, cognition or physical performance. This study also suggests that an extended morning, rather than evening, sleep opportunity may be necessary to increase sleep duration in young elite athletes.

4.5.3 **Acknowledgments**

Many thanks to Fatigue Science, Vancouver, British Columbia for the supply of Readibands™ and Cogstate Ltd Research, Melbourne, Victoria. Many thanks also to the PhD scholars, staff at the AIS and Judo Australia.
4.6 References


4. Quinn, L., Tweeting ban on Australian Winter Olympic athletes, in The Australian. 2014: Australia


Chapter 5  Sleep is an important factor when considering rugby union player load

Authors

Ian C Dunican\textsuperscript{1} and Peter R Eastwood\textsuperscript{1}.

Institutions

\textsuperscript{1}Centre for Sleep Science, School of Anatomy, Physiology and Human Biology, The University of Western Australia, Crawley WA 6009.

Publication status

Letter to the Editor, published in the British Journal of Sports Medicine

Sleep is an important factor when considering rugby union player load

We read with great interest the paper by Dr Kenneth Quinnell et al. The paper provides an excellent summary of elite player physical demands, and the nature and measurement of the physical and non-physical loads that underpin these demands. However, we believe that the lack of acknowledgement of sleep as an important contributor to non-physical loads is an oversight. This is because sleep has been shown in many studies to be important for optimal athletic performance (physical and cognitive components) and is recognized as an essential component of recovery. Indeed, it is considered by some to be one of a number of universal risk factors for sports injuries.1

To date, only two studies have investigated sleep in rugby union players, one was undertaken in a small subgroup (n=10) of a team in the Southern Hemisphere’s Super Rugby competition2 and the other in all team players (n=28) in the UK’s Rugby League competition.3 Both reported a delayed time at sleep onset and decreased sleep duration on the night immediately following a match. Acknowledging the importance of the relationship between sleep and performance led the authors of these studies to recommend that postmatch sleep be prospectively arranged as part of the recovery process in order to optimize preparation for subsequent training days and performance.

Dr Quinnell and colleagues noted the deleterious effects of travel and in particular the non-physical loads such as jet lag and travel fatigue that are associated with international travel. Such loads are of particular concern in the Super Rugby competition as teams based in New Zealand, South Africa, Australia, South America, and Japan are required to travel extraordinary distances over the course of a season. The volume of international travel causes regular circadian desynchronization—a key characteristic of these circadian changes is impaired sleep on arrival at a new time zone. Such international travel causes athletes in many sports to commonly report experiencing fatigue during the day, an inability to sleep at night and overall sleep loss.4 Hence, travel-related sleep disturbance represents an important non-physical load to rugby union players.

Poor sleep as a consequence of sleep disorders could also represent a non-physical load to rugby union athletes, as such disorders can adversely affect physical and cognitive performance.5 While there has been no study examining the prevalence of sleep disorders in rugby union, it is notable that the prevalence of sleep-disordered breathing in 137 active National Football League athletes in North America was found to be 19%.6 The physical demands and anthropometric measurements of many NFL players are similar to rugby union athletes, thus it is possible that sleep disorders are also common in rugby union players.

In summary, poor sleep whether due to travel, sleep disorders, social factors or training schedules represents an important and potentially modifiable load to rugby union players. While more sport-specific studies are required, we believe that there is already sufficient information to justify considering sleep as an important contributor to non-physical loads in rugby union.

Ian C Dunican, Peter H Earwood
Centre for Sleep Science, School of Anatomy, Physiology and Human Biology, The University of Western Australia, Crawley, Western Australia, Australia
Correspondence to Ian C Dunican, ian.dunican@research.uwa.edu.au
Twitter Follow Ian Dunican at @sleepsuperstar
Competing interests None declared.
Prevention and poor review Not commissioned; externally peer reviewed.
To cite Dunican IC, Earwood PH. Br J Sports Med 2016;0:1–14. doi:10.1136/bjsports-2016-095172
Accepted 13 October 2016

REFERENCES
Dear Editor,

We read with great interest the recent review article by Dr Kenneth Quarrie et al entitled “Managing player load in professional rugby union: a review of current knowledge and practices.” The review provides an excellent summary of elite player physical demands, and the nature and measurement of the physical and non-physical loads that underpin these demands. However, we believe that the lack of acknowledgment of sleep as an important contributor to non-physical loads is an oversight. This is because sleep has been shown in many studies to be important for optimal athletic performance (both physical & cognitive components) and is recognized as an essential component of recovery [1]. Indeed, it is considered by some to be one of a number of universal risk factors for sports injuries [6].

To date only two studies have investigated sleep in Rugby Union players, one was undertaken in a small subgroup (n=10) of a team in the Southern Hemisphere’s Super Rugby competition [2] and the other in all team players (n=28) in the United Kingdom’s Celtic League competition [3]. Both reported a delayed time at sleep onset and decreased sleep duration on the night immediately following a match. Acknowledging the important relationship between sleep and performance led the authors of these studies to recommend that post-match sleep be proactively managed as part of the recovery process in order to optimise preparation for subsequent training days and/or performance.

Dr Quarrie and colleagues noted the deleterious effects of travel and in particular the non-physical loads such as jet lag and travel fatigue that are associated with international travel. Such loads are of particular concern in the Super Rugby competition as teams based in New Zealand, South Africa, Australia, South American
and Japan are required to travel extraordinary distances over the course of a season. This volume of international travel causes regular circadian desynchronization – a key characteristic of these circadian changes is impaired sleep on arrival at a new time zone. Such international travel causes athletes in many sports to commonly report experiencing fatigue during the day, an inability to sleep at night, and overall sleep loss [4]. Thus, travel-related sleep disturbance represents an important non-physical load to rugby union players.

Poor sleep as a consequence of sleep disorders could also represent a non-physical load to rugby union athletes; as such disorders can adversely affect both physical and cognitive performance [5]. While there has been no study examining the prevalence of sleep disorders in rugby union, it is notable that the prevalence of sleep disordered breathing (SDB) in 137 active National Football League athletes in North America was found to be 19% [6]. The physical demands and anthropometric measurements of many NFL players are similar to rugby union athletes, thus it is possible that sleep disorders are also common in rugby union players.

In summary, poor sleep whether due to travel, sleep disorders, social factors, or training schedules represents an important and potentially modifiable load to rugby union players. While more sport-specific studies are required, we believe that there is already sufficient information to justify considering sleep as an important contributor to non-physical loads in rugby union.
5.1 References


Chapter 6  Prevalence of sleep disorders and sleep problems in an elite super rugby union team

Authors

Ian C Dunican¹, Jennifer Walsh¹, Charles C Higgins², Maddison J Jones³, Kathleen Maddison¹, John A Caldwell⁴, David Hillman¹, and Peter R Eastwood¹.

Institutions

¹Centre for Sleep Science, School of Human Sciences, The University of Western Australia, Crawley, WA 6009.
²Western Force, Rugby Western Australia, Floreat WA 6014.
³School of Human Sciences, The University of Western Australia, Crawley, WA 6009
⁴Coastal Performance Consulting, Florida, United States.

Publication status

This chapter is currently in review with the Journal of Sports Science
6.1 Abstract

Objectives: (i) To determine the prevalence of sleep disorders in an elite rugby union team using in-laboratory polysomnography (PSG) and sleep questionnaires and (ii) investigate differences in prevalence of sleep disorders between players with different anthropometric characteristics.

Methods: 25 elite rugby union players, aged 25±4 years with a mean mass of 104±10 kg underwent a night of PSG during the “off season” of the Super Rugby competition. Of interest were measurements that detected the presence of obstructive sleep apnea (OSA; apnea hypopnea index >5 events/hr) and the presence of moderate-severe periodic leg movements during sleep (PLMs; >15 events/hr). Players also completed sleep-related questionnaires to assess daytime sleepiness, perception of insomnia (insomnia severity index (ISI)), risk of OSA, and the presence of restless legs syndrome (RLS) as well as undergoing basic anthropometric assessments including body mass index (BMI) and neck circumference.

Results: OSA was present in 24% (n=6) of players and PLMs>15 events/hr in 12% (n=3). Questionnaire responses showed that all players had ISI-defined subthreshold insomnia and excessive daytime sleepiness, two players were identified as being at risk for OSA and none were classified as having RLS. No anthropometric measures were associated with the severity of OSA, number of PLMs or any questionnaire-related measure of sleepiness, insomnia, risk of OSA or RLS.

Conclusion: Sleep disorders and excessive sleepiness are very common in elite rugby union players. A process to identify and manage sleep disorders should be considered by teams to optimise their physical recovery, athletic performance and to safeguard their health.
### 6.2 Introduction

It is estimated that approximately one third of the general population will experience a sleep disorder at some time during their life [1]. Currently over 80 recognised sleep disorders are listed in the international classification of sleep disorders (3rd Ed)[2]. In the general population the most common sleep disorders are obstructive sleep apnea (OSA), insomnia, and restless legs syndrome (RLS)[3]. They are associated with many adverse short and long-term health consequences [4]. Despite the potential for sleep disorders to negatively affect athletic performance there is very little information in the sports science and medicine literature on the prevalence of sleep disorders in elite athletes [5].

Obstructive sleep apnea is characterised as repeated events of partial or complete obstruction of the upper airway during sleep. To date, four studies have assessed the prevalence of OSA in athletes and have been conducted primarily with contact athletes in American football and ice hockey with a prevalence of OSA reported ranging from 8-19% [6-9]. The first study used a single channel, home based, unattended, portable, sleep apnea monitor in 137 National Football League (NFL) players and reported that 19% of players had mild OSA, defined as an apnea hypopnea index (AHI) >5 events/hr [6]. A second study used a questionnaire and a single-channel (finger pulse oximetry) photo-plethysmography device in 51 collegiate football players, and reported that 8% of players had OSA, as defined as an AHI>5 events/hr [7]. In a third study, 302 players from eight professional football teams in the NFL completed specific sleep related questionnaires including the Epworth sleepiness scale (ESS) and the Stanford sleepiness scale. Players were stratified into risk categories based upon the scores from these questionnaires and a multivariable apnea prediction index developed that included questions about the frequency of symptoms from OSA, body mass index
(BMI), age and gender. Based on this approach 73 players were identified as being at high risk of OSA and 229 players at low risk. Random sampling from both groups resulted in 52 players identified to undergo PSG. The study reported that 14% of professional football players had OSA (AHI>10 events/hr) [8] and that there was no differences in the prevalence of OSA between players with different anthropometric characteristics (e.g. between linesman and non-linesman). A fourth study assessed 107 ice hockey players for the prevalence of sleep disorders using sleep related questionnaires. Based upon the questionnaire scores, those players suspected of having a sleep disorder underwent a home-based PSG study. The study reported that 13% (n=14) of the 107 athletes screened for a potential sleep disorder had OSA [9].

Insomnia is characterised by a difficulty falling asleep, staying asleep and/or waking too early. Causes of insomnia reported by athletes are mainly as a result of nervousness and thoughts about competition or games in the nights leading up to competition [10, 11]. To date few studies have used validated insomnia questionnaires to determine the prevalence of insomnia in athletes. One study used a sleep disorders questionnaire which had been validated against Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria for insomnia in 103 Italian Olympic athletes and reported a prevalence rate of 4% for insomnia [12]. A more recent study used a questionnaire and home-based PSG study in 107 ice hockey players and reported a prevalence rate of insomnia of 12% [9]. Another study using the validated Athens insomnia scale (AIS) in 59 elite multi-sport athletes resulted in a mean score of 5 (range 0-16) [13]. While not reporting prevalence, the study concluded that athletes had serious insomnia symptoms but not at a score of 6 or more indicating clinical significance for insomnia. Two studies using non-validated questionnaires that capture
aspects of insomnia or sleep difficulties in athletes report a prevalence of insomnia of between 60 and 80% [9, 10].

Restless legs syndrome is characterised by an urge to move the legs due to unpleasant sensations which are often due to inactivity and may be worse in the evening [14]. Whilst RLS occurs during waking hours, it is also associated with the occurrence of periodic leg movements (PLMs) during sleep [14]. To date, only two studies have determined the prevalence of RLS in athletes. Using the international restless leg study group (IRLSG) criteria to diagnose RLS [15], Fagundes et al., studied 60 marathon runners and reported a RLS prevalence rate of 13% [16]. Tuomilehto et al., used PSG and questionnaires to study 107 professional ice hockey players and reported a prevalence rate of RLS/PLMs of 4% [9].

This current study sought to determine, for the first time, the prevalence of sleep disorders in an elite rugby union team using a combination of the gold standard, comprehensive in-laboratory PSG and sleep-related questionnaires. Due to the known association of some sleep disorders and anthropometric characteristics, particularly BMI and neck circumference in the case of OSA[17], we also determined the prevalence rates in each of the two positional playing groups: ‘forwards’ and ‘backs,’ as forwards typically have a larger body mass and a greater neck circumference for scrummaging and rucking.

Therefore, the aims of this study were to: (i) determine the prevalence of sleep disorders in an elite rugby union team using in-laboratory PSG and questionnaires; and (ii) investigate the prevalence of sleep disorders in forwards versus backs.
6.3 Methods

6.3.1 Subjects

All participants were contracted elite rugby union players from a single professional Super Rugby team based in Australia. Data were collected over ten separate nights between the 6th of August and the 27th of September 2015 during the ‘off-season’ of the Super Rugby championship. Informed, written consent was obtained from each player and approval for the study was obtained from the University of Western Australia Human Research Ethics Committee (RA/4/1/7235).

6.3.2 Protocol

After completing a series of sleep-related questionnaires and undergoing basic anthropometric assessments (height, weight, neck circumference), players underwent an overnight PSG study at the Centre for Sleep Science, University of Western Australia. Players arrived at the sleep laboratory between 18:30 and 21:00 hrs and were instrumented by a sleep technician. Once set-up, they were asked to follow their normal pre-bedtime routine as much as possible before lights out. They were woken between 06:00 and 07:00 hrs the following morning.

6.3.3 Polysomnography

Sleep studies were performed as per American Academy of Sleep Medicine (AASM) recommendations [18]. Electroencephalogram (EEG), electrooculogram (EOG) and chin electromyogram (EMG) were measured using surface electrodes. Respiration was monitored with nasal prongs, an oronasal thermistor and thoracic and abdominal respiratory bands. Blood oxygen saturation (SaO2) and heart rate were monitored continuously from a pulse oximeter on the index finger and Electrocardiography
Leg movements were monitored by EMG electrodes placed over the tibialis anterior muscle. A position sensor, microphone and a live video feed via an infrared camera were used to monitor body position and snoring. A sleep technician monitored the recordings and video in each room for the duration of the study. Data were acquired using Compumedics Grael (Compumedics, Victoria, Australia) system and scored by an experienced sleep technician using Profusion (PSG4) software according to the AASM 2012 version 2.0 rules for the scoring of sleep and associated events [19].

Sleep Behaviour was determined from the scored PSG studies and included measurements of: time in bed (the total time spent in bed, from lights out until time at wake); total sleep time (number of minutes from time of sleep onset to time at wake, minus number of minutes awake); sleep efficiency (SE) (total sleep time divided by time in bed multiplied by 100); sleep onset latency (SOL) (number of minutes from time at lights out to time of sleep onset); rapid eye movement (REM) latency (number of minutes from sleep onset until the first epoch of REM sleep) and time awake after sleep onset (WASO; number of minutes awake after sleep onset).

Sleep Architecture was determined from the scored overnight study and defined in terms of wake (W), light sleep (stages N1 and N2), deep slow wave sleep (SWS) (stage N3) and rapid eye movement sleep (stage REM). Each sleep stage was expressed as a percentage of total sleep time (TST).

Obstructive Sleep Apnea was determined from the number of apneas and hypopneas events/hr. An apnea was defined as a >90% decrease in airflow from a pre-event baseline that lasted for >10 secs and a hypopnea was defined as a >30% decrease in airflow from a pre-event baseline that lasted >10 secs, with both accompanied by either a >3% decrease in SaO2 or EEG evidence of an arousal. The AHI was calculated as
the total of all apneas and hypopneas divided by the TST. Severity of OSA was defined as mild (AHI 5-15 events/hr), moderate (AHI between 15-30 events/hr) or severe (AHI > 30 events/hr) [19].

Periodic leg movements (PLMs) were determined from the total number of periodic leg movements, scored according to standard criteria [19]. Specifically, a PLM was defined based upon the duration of an event (0.5-10 secs) with a minimum amplitude of the event is an 8 µV increase in EMG voltage above resting rate. PLMs were not scored unless they occurred in a series of four or more consecutive leg movements within 5-90 secs of each other. Movement on two different legs were scored as a single leg movement if they occurred less than five secs apart. The periodic leg movement index (PLMI) was calculated as the total number of events divided by TST; PLMI event/hr scores between 15-25 events are classified as mild, between 26-50 as moderate and >50 as being severe [19].

6.3.4 Questionnaires

Insomnia was assessed using the insomnia severity index (ISI) [20]. The ISI consists of five separate questions that ask the participant to self-rate their own experience with insomnia from a scale of 0-4. An aggregate score of 8-14 is indicative of sub-threshold insomnia, a score greater than 14 indicates clinical insomnia [20].

Daytime sleepiness was assessed using the Epworth sleepiness scale (ESS) which is a self-report scale that asks how likely an individual is to doze off or fall asleep in common daytime situations [21]. Scores >9 indicates excessive daytime sleepiness.

Risk of obstructive sleep apnea was assessed using the Berlin questionnaire [22] which assigns the risk of OSA based on the presence and frequency of snoring behaviour;
wake time sleepiness or fatigue and a history of obesity and/or hypertension. A positive response in two or more of these categories indicates elevated risk for OSA.

Restless legs syndrome (RLS) was assessed using the validated IRLSG questionnaire [23] that used six questions relating to the timing, frequency and symptoms of RLS. Scores are aggregated and severity of symptoms are calculated from the scores of 6 questions. Questions one to four (mild <4; moderate= 4-8; severe =8-12; very severe= 12-16) and questions five and six use a positive or negative response.

6.3.5 Statistical Analysis

Descriptive statistics were conducted on the entire group and comparative statistics were conducted based upon positional playing groups (i.e. forwards and backs). AHI data were transformed using a square root transformation and analyses were performed on the transformed data. Students t-test was used for between group comparisons using SigmaStat (Version 13). Normality and equal variance were assessed using the Shapiro-Wilk and Brown Forsythe tests, respectively. Non-parametric data were compared using a Mann Whitney Rank Sum test. Correlations were performed to assess relationships between PSG derived sleep measures, sleep related questionnaires as well as anthropometric factors. Data are presented as mean ± standard deviation for each group and p<0.05 was considered as statistically significant for all tests.

6.4 Results

Of the squad of 36 players, 11 were unavailable due to being selected to play in the Rugby World Cup 2015, or competing in other international and domestic rugby competitions in Japan and New Zealand. All available players (n=25) took part in this study. One player from the ‘backs’ group experienced technical issues with acquiring
flow signal with nasal prongs and or oronasal thermistor for scoring of breathing, and or snoring, however data for sleep stages and movement from this player were included. Players had a mean age of 25±4 years (range 20-31 years) and mean mass of 104±10 kg (range 83-122 kg). Demographic and anthropometric data are summarised in Table 5 by the whole group (n=25) and by backs (n=11) and forwards (n=14). As expected, forwards were heavier and had a greater BMI than the backs (P<0.05). Although there were no differences between forwards and backs, the mean neck circumference for the group overall and for forwards and backs was above the threshold risk for OSA (>42cm) (Table 5) [24].

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Demographic and Anthropometric Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total n=25</td>
</tr>
<tr>
<td>Age (years)</td>
<td>25±4</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>104±10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>186±7</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>30±3</td>
</tr>
<tr>
<td>Neck circumference (cm)</td>
<td>43±4</td>
</tr>
</tbody>
</table>

Notes: Data presented as means and standard deviations (±SD). *p<0.05 for Backs versus Forwards.

6.4.1 Sleep Behaviour and Sleep Architecture

Players slept for an average of 6.5 hours and fell asleep within 13 min (Table 6). Once asleep they were awake for a total of 39 min (or 12% of the night), resulting in an overall sleep efficiency of 88%. The majority of sleep time (61%) was spent in light sleep (stages N1 and N2), while 19% was spent in SWS and 20% in REM sleep. This pattern of sleep stages was similar in backs and forwards. There were no significant relationships between any measure of sleep behaviour or architecture and any anthropometric measure.
Table 6  Sleep Data-Polysomnography

<table>
<thead>
<tr>
<th></th>
<th>Total n=25</th>
<th>Backs n=11</th>
<th>Forwards n=14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sleep Behaviour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study duration (mins)</td>
<td>540±52</td>
<td>538±54</td>
<td>542±52</td>
</tr>
<tr>
<td>Time in bed (mins)</td>
<td>447±30</td>
<td>448±26</td>
<td>447±33</td>
</tr>
<tr>
<td>Total sleep time (mins)</td>
<td>394±32</td>
<td>391±34</td>
<td>396±31</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>88±6</td>
<td>87±6</td>
<td>89±7</td>
</tr>
<tr>
<td>Sleep onset latency (mins)</td>
<td>13±11</td>
<td>13±9</td>
<td>14±13</td>
</tr>
<tr>
<td>Rapid eye movement latency (mins)</td>
<td>123±68</td>
<td>108±42</td>
<td>135±83</td>
</tr>
<tr>
<td>Wake after sleep onset (mins)</td>
<td>39±28</td>
<td>42±24</td>
<td>37±31</td>
</tr>
<tr>
<td><strong>Sleep Architecture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage N1 (%)</td>
<td>15±10</td>
<td>12±7</td>
<td>16±11</td>
</tr>
<tr>
<td>Stage N2 (%)</td>
<td>46±6</td>
<td>47±6</td>
<td>46±6</td>
</tr>
<tr>
<td>Stage N3 (%)</td>
<td>19±6</td>
<td>21±5</td>
<td>18±6</td>
</tr>
<tr>
<td>Stage REM (%)</td>
<td>20±7</td>
<td>19±5</td>
<td>20±9</td>
</tr>
<tr>
<td><strong>Breathing, Arousals, Movement, and Snoring</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apnea hypopnea index (events/hour)</td>
<td>4±3</td>
<td>3±4</td>
<td>4±3</td>
</tr>
<tr>
<td>Arousals index (events/hour)</td>
<td>15±8</td>
<td>14±6</td>
<td>15±5</td>
</tr>
<tr>
<td>Desaturation index &gt;3% (events/hour)</td>
<td>3±3</td>
<td>2±2</td>
<td>4±3</td>
</tr>
<tr>
<td>Periodic limb movement index (events/hour)</td>
<td>9±10</td>
<td>5±9</td>
<td>9±11</td>
</tr>
<tr>
<td>Total snoring duration (mins)</td>
<td>14±16</td>
<td>9±9</td>
<td>19±20</td>
</tr>
<tr>
<td>Average snore during sleep (dB)</td>
<td>45±12</td>
<td>46±4</td>
<td>43±16</td>
</tr>
<tr>
<td>Loudest snore during sleep (dB)</td>
<td>71±18</td>
<td>75±12</td>
<td>66±22</td>
</tr>
</tbody>
</table>

**Notes**: Data presented as means and standard deviations (±SD)

6.4.2  Breathing, arousals, snoring and movement during sleep

The mean AHI for all players was 4±3 events/hr (Table 6), however six players (24%) had an AHI between 5-15 events/hr, indicating mild OSA. Two of these players were backs and four were forwards. The mean number of arousals/hour for all players was 15±8 and was not different between backs and forwards. In those players with OSA (n=6) compared to those without OSA (n=18) (Table 7) AHI, arousals, and desaturations >3% were greater and PLMI was less (p<0.05 for all). There were no differences in snoring duration or intensity between players with and without OSA (Table 7).
### Table 7  OSA vs Non OSA

<table>
<thead>
<tr>
<th>Sleep Behaviour</th>
<th>Total n=24</th>
<th>OSA n=6</th>
<th>Non-OSA n=18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study duration (mins)</td>
<td>540±52</td>
<td>538±54</td>
<td>530±46</td>
</tr>
<tr>
<td>Time in bed (mins)</td>
<td>447±30</td>
<td>458±25</td>
<td>444±31</td>
</tr>
<tr>
<td>Total sleep time (mins)</td>
<td>394±32</td>
<td>396±21</td>
<td>393±34</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>88±6</td>
<td>87±4</td>
<td>89±7</td>
</tr>
<tr>
<td>Sleep onset latency (mins)</td>
<td>13±11</td>
<td>15±4</td>
<td>13±11</td>
</tr>
<tr>
<td>Rapid eye movement latency (mins)</td>
<td>123±68</td>
<td>141±83</td>
<td>118±64</td>
</tr>
<tr>
<td>Wake after sleep onset (mins)</td>
<td>39±28</td>
<td>46±22</td>
<td>37±30</td>
</tr>
</tbody>
</table>

### Sleep Architecture

<table>
<thead>
<tr>
<th></th>
<th>Stage N1 (%)</th>
<th>Stage N2 (%)</th>
<th>Stage N3 (%)</th>
<th>Stage REM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15±10</td>
<td>46±6</td>
<td>19±6</td>
<td>20±7</td>
</tr>
</tbody>
</table>

### Breathing, Arousals, Movement, and Snoring

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Apnea hypopnea index (events/hour)</td>
<td>4±3</td>
<td>9±2*</td>
<td>2±2</td>
</tr>
<tr>
<td>Arousals index (events/hour)</td>
<td>15±8</td>
<td>19±3*</td>
<td>13±5</td>
</tr>
<tr>
<td>Desaturation index &gt;3% (events/hour)</td>
<td>3±3</td>
<td>6±4*</td>
<td>2±2</td>
</tr>
<tr>
<td>Periodic limb movement index (events/hour)</td>
<td>9±10</td>
<td>0±1*</td>
<td>9±10</td>
</tr>
<tr>
<td>Total snoring duration (mins)</td>
<td>14±16</td>
<td>9±8</td>
<td>16±18</td>
</tr>
<tr>
<td>Average snore during sleep (dB)</td>
<td>45±12</td>
<td>40±20</td>
<td>44±14</td>
</tr>
<tr>
<td>Loudest snore during sleep (dB)</td>
<td>71±18</td>
<td>67±34</td>
<td>68±20</td>
</tr>
</tbody>
</table>

**Notes:** Data presented as means and standard deviations (±SD). *p<0.05 OSA vs Non-OSA. One player removed from Non-OSA group due to no respiratory data.

The mean PLMI for all players was 4±8 events/hr with no differences found between backs and forwards (Table 6). Two backs had a mild PLMI (between 15-25 events/hr) and one forward had a moderate PLMI (26-50 events/hr). In players with a PLMI>15 events/hr (n=3) compared to those with a PLMI<15 events/hr (n=22) (Table 8); SOL decreased and PLMI increased (p<0.05 for all). There were no relationships between any measure of breathing, arousal, or movement and any anthropometric measure.
Table 8  PLM vs Non-PLM

<table>
<thead>
<tr>
<th>Sleep Behaviour</th>
<th>Total n=25</th>
<th>PLMI &gt;15 n=3</th>
<th>PLMI &lt;15 n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study duration (mins)</td>
<td>540±52</td>
<td>539±35</td>
<td>540±46</td>
</tr>
<tr>
<td>Time in bed (TIB) (mins)</td>
<td>447±30</td>
<td>441±47</td>
<td>448±28</td>
</tr>
<tr>
<td>Total sleep time (TST) (mins)</td>
<td>394±32</td>
<td>401±17</td>
<td>392±33</td>
</tr>
<tr>
<td>Sleep efficiency (SE) (%)</td>
<td>88±6</td>
<td>91±8</td>
<td>88±6</td>
</tr>
<tr>
<td>Sleep onset latency (SOL) (mins)</td>
<td>13±11</td>
<td>5±3*</td>
<td>14±11</td>
</tr>
<tr>
<td>Rapid eye movement (REM) Latency (mins)</td>
<td>123±68</td>
<td>119±85</td>
<td>123±67</td>
</tr>
<tr>
<td>Wake after sleep onset (WASO) (mins)</td>
<td>39±28</td>
<td>35±41</td>
<td>40±28</td>
</tr>
</tbody>
</table>

Sleep Architecture

| Stage N1 (%)                                        | 15±10      | 15±10        | 15±10        |
| Stage N2 (%)                                        | 46±6       | 42±10        | 47±6         |
| Stage N3 (%)                                        | 19±6       | 19±3         | 19±6         |
| Stage REM (%)                                       | 20±7       | 24±5         | 19±6         |

Breathing, Arousals, Movement and Snoring

| Apnea hypopnea index (events/hour)                  | 4±3        | 3±2          | 4±3          |
| Arousal index (events/hour)                         | 15±8       | 17±3         | 14±5         |
| Desaturation index >3% (events/hour)                | 3±3        | 2±1          | 3±3          |
| Periodic limb movement index (events/hour)          | 9±10       | 23±6*        | 1±2          |
| Total snoring duration (mins)                       | 14±16      | 4±5          | 13±16        |
| Average snore during sleep (dB)                     | 45±12      | 53±16        | 35±20        |
| Loudest snore during sleep (dB)                     | 71±18      | 81±12        | 56±32        |

Notes: Data presented as means and standard deviations (±SD). *p<0.05 PLMI>15 events/hr v PLMI <15 events/hr.

6.4.3  Sleep-related questionnaires

All players reported subthreshold insomnia (ISI score 8-14) and excessive daytime sleepiness (ESS score >10) (Table 9). Two players were identified as being at risk for OSA (i.e. Berlin questionnaire positive in 2 or more categories). No player scored positive for RLS. In players with OSA (n=6) compared to those without OSA (n=19), ESS scores increased and ISI scores decreased (p<0.05). There were no differences in scores on the Berlin, ESS, ISI, RLS questionnaires between players with a PLMI>15
(n=3) compared to those with a PLMI<15. There were no relationships between scores on any of the questionnaires and any anthropometric measure.

### Table 9 Sleep related questionnaire data

<table>
<thead>
<tr>
<th></th>
<th>Total n=25</th>
<th>Backs n=11</th>
<th>Forwards n=14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Backs v Forwards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berlin questionnaire (positive)</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Epworth sleepiness scale</td>
<td>15±3</td>
<td>14±3</td>
<td>16±2</td>
</tr>
<tr>
<td>Insomnia severity index</td>
<td>11±2</td>
<td>11±2</td>
<td>11±3</td>
</tr>
<tr>
<td>Restless legs syndrome</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total n=24</th>
<th>OSA n=6</th>
<th>Non-OSA n=18</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OSA v Non-OSA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berlin questionnaire (positive)</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Epworth sleepiness scale</td>
<td>15±3</td>
<td>17±3*</td>
<td>14±3</td>
</tr>
<tr>
<td>Insomnia severity index</td>
<td>11±2</td>
<td>9±1*</td>
<td>11±2</td>
</tr>
<tr>
<td>Restless legs syndrome</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total n=25</th>
<th>PLM&gt;15 n=3</th>
<th>PLM&lt;15 n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PLM&gt;15 vs PLM&lt;15</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berlin questionnaire (positive)</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Epworth sleepiness scale</td>
<td>15±3</td>
<td>16±2</td>
<td>15±3</td>
</tr>
<tr>
<td>Insomnia severity index</td>
<td>11±2</td>
<td>11±2</td>
<td>11±3</td>
</tr>
<tr>
<td>Restless legs syndrome</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Notes:** Data presented as means and standard deviations (±SD). *p<0.05 OSA vs Non-OSA

### 6.5 Discussion

This study aimed to determine the prevalence of sleep disorders in a team of 25 elite rugby union players using in-laboratory PSG and sleep questionnaires. The major findings were that OSA was present in 24% of players, PLMs>15/hr in 12% of players, and subthreshold insomnia and excessive daytime sleepiness in all players. There were no associations between the severities of any of these disorders and any anthropometric measure, and there was no difference in the prevalence rates between backs and forwards.
Sleep behaviour and sleep architecture. The 6.5 hours of sleep obtained in these athletes is less than the recommended adult sleep duration of 7-9 hrs [3]. However, this is not abnormal in the context of this study given that a night of sleep in a laboratory is often of less duration than at home due to the change in sleeping environment and the intrusive nature of a PSG study. Further, the studies were stopped and/or players woken between 06:00-07:00, which would have decreased sleep duration in some. Notably, sleep efficiency was high, being 88%, indicating that the quality of the sleep was good during the laboratory-based studies. The players spent 61%, 19% and 20% in light sleep, deep slow wave sleep, and REM sleep, respectively. Such a pattern is similar to the sleep architecture reported in 21-30 year old adults from the general population [25].

Obstructive sleep apnea, defined as an AHI>5 events/hr during a PSG, was present in 24% of rugby players. This is marginally higher than reports from studies in NFL players, whereby prevalence rates of OSA were 14% [8] and 19% [6]. It is likely that the use of different sleep scoring criteria contributes to the variability in prevalence estimates between studies. Specifically, some studies have defined OSA as an AHI>10 events/hr [8] while others, including the present study, used an AHI>5 [6, 7]. Another study that assessed OSA prevalence was undertaken in collegiate football players. The relatively low prevalence rate of 8% reported in that study [7] was likely due to the simplified sleep analysis device used (a single-channel finger pulse oximetry photoplethysmography device) and the known tendency of such devices to underestimate severity of OSA [26]. Prevalence estimates of OSA in similarly aged men in the general population are scarce. While data from the Wisconsin Sleep Cohort Study, published in 1993, estimated that 17% of men aged 30-39 years have an AHI ≥ 5 events/hr [27] a more recent study reported that 4% of Australians aged 25-34 years
self-reported “pauses in breathing in sleep” to occur “at least a few times a month”, with a slightly greater prevalence in males than females [28].

Despite a difference in BMI between forwards and backs in the present study, these two player groups did not differ in the prevalence of any sleep disorder. A similar finding was reported by Rice et al [6] who showed that although NFL linemen weighed more and had a greater body fat percentage, waist circumference and neck circumference compared with non-linemen, there was no difference in prevalence estimates of OSA between the groups. The findings of these studies indicate that the normal predictors of OSA such as body mass and neck circumference may not be applicable to elite rugby union or NFL players. This is probably due to the systematic difference in physical characteristics of these elite athletes compared to the general population (in whom normal predictors have been generated). Specifically, all the athletes tended to have a high BMI (30 kg/m²) and neck circumference (43cm).

Due to their ease of administration, many studies have used questionnaires to estimate the prevalence of OSA and snoring in athletic populations. Such studies have produced variable estimates of OSA prevalence, ranging from 10% in ice hockey players to 38% in rugby players [9, 30]. In the current study, using the Berlin questionnaire, only 8% of players were categorised as being at high risk for OSA compared to 24% assessed by PSG. A similar lack of specificity is seen when using self-reported questionnaire-based estimates of snoring prevalence, which range from 9% in hockey players [9] to 38% in rugby players [30]. In the current study 64% of players reported themselves as snorers in one of the questions in the Berlin questionnaire. As such, caution should be taken when attempting to use questionnaires to identify sleep disorders, and PSG should remain the gold standard method.
A surprising finding in the present study was that every player reported excessive daytime sleepiness using the ESS. Such a prevalence (100%) is significantly higher than previous reports of daytime sleepiness of 28% in rugby players [30], and 20% [8] and 24% in NFL players [6]. It is possible that the ESS, which was originally developed and validated for use in patients with a range of sleep disorders [31], may not be appropriate in an athletic population. This is likely given that factors other than sleep disorders could affect daytime sleepiness in athletes such as training load, travel, and disturbed sleep associated with competition. The newly developed Athlete Sleep Screening Questionnaire (ASSQ), a subjective, self-report, sleep-screening questionnaire, is a potentially useful tool for assessing sleep disturbance in athletes as it takes athlete-specific factors into account [32].

**Periodic leg movements and restless legs syndrome.** The best method of determining PLMs is with comprehensive laboratory-based PSG, whereas RLS (which occurs during the day) is assessed using a validated questionnaire such as the IRLSG criteria [23]. Both were used to determine the presence of PLMs and RLS in the rugby players in the current study. While no player reported positive for RLS, 12% had PLMs >15 events/hr. PLMs and RLS are often associated with each other [14], the causes of both are thought to be attributable to a brain iron deficiency with abnormal dopaminergic function [33] Regardless of the underlying mechanism, the presence of the PLMs in the three players did not affect their sleep, as a measure of their sleep behaviour, architecture, AHI, and snoring were not different to those players without a high number of PLMs.

**Insomnia** is broadly categorised by an inability to fall asleep or to maintain sleep or to early waking and can lead to daytime sleepiness, irritability, and difficulty in maintaining vigilance. The ISI captures an individual’s perception of their insomnia.
and has been validated as an outcome measure for insomnia research [20]. Questions asked in the ISI relate to severity, satisfaction, interference with daily activities, noticeability and a how distressed a person is about their perceived insomnia. When scores are aggregated they can be assigned to a category including no clinically significant insomnia, subthreshold insomnia, moderate clinical insomnia and severe clinical insomnia [20].

No players in the current study were categorised as having moderate or severe insomnia, however all (100%) were categorised as having subthreshold insomnia. These results are similar to a study using the validated Athens insomnia scale [13] which concluded that many athletes had serious insomnia symptoms but not at a level indicating clinical significance for insomnia. The prevalence estimates of subthreshold of insomnia in the current study are, however, greater than those reported in some other studies conducted in elite athletes, which have estimated insomnia to be experienced in 10% of ice hockey players [9] and 4% of Italian Olympic athletes [12]. While the prevalence of insomnia symptomatology in athletes is generally thought to be high [34] there are many reasons for difference in prevalence estimates between studies and populations of athletes. For example, the data in the current study were collected during the non-competitive ‘off-season’ period of the Super Rugby season. A previous study in elite ice hockey players reported that the prevalence of insomnia, assessed using questions relating to duration of sleep latency and number of awakenings, doubled during the playing season [9]. Competition can also affect insomnia symptomatology, as has been shown in elite Olympic athletes in whom 64% report disturbed sleep in the nights prior to an important competition [11] and in rugby union players who experience a delay in time to fall asleep on the nights prior to a game and a delay in the time of sleep onset after a game [35].
In conclusion, this study has shown that sleep disorders and excessive daytime sleepiness are common in elite rugby union players. These findings indicate the need for a more proactive approach in the management of sleep and its disorders in professional rugby union. Such a process, whereby sleep disorders and poor sleep habits are identified, diagnosed, and managed could serve to optimise the players' physical recovery and athletic performance. In addition, it can safeguard the long-term health of players, since sleep disruptions have been associated with cardiovascular disease, diabetes, obesity, cancer, and early mortality [4].
6.6 References


Chapter 7  Sleep behaviour in an elite Super Rugby team during game week

Authors

Ian C Dunican¹, Charles C Higgins ², Kevin Murray³, Maddison J Jones ⁴, Brian Dawson⁴, John A Caldwell⁵, Shona L Halson⁶ and Peter R Eastwood¹

Institutions

¹Centre for Sleep Science, School of Human Sciences, The University of Western Australia, Crawley, WA 6009, Australia.

²Western Force, Rugby Western Australia, Floreat WA 6014, Australia.

³School of Population and Global Health, The University of Western Australia, Crawley, WA 6009, Australia.

⁴School of Human Sciences, The University of Western Australia, Crawley, WA 6009, Australia.

⁵Coastal Performance Consulting, Florida, United States.

⁶Department of Physiology, Australian Institute of Sport, Leverrier Street, Bruce, ACT, 2617, Australia.

Publication Status

This chapter is currently in review with the Journal of Human Kinetics
7.1 Abstract

Sleep is a vital component of preparation, performance and recovery for a Super Rugby game. The purpose of this study was to quantify sleep behaviours and alertness of professional rugby union players during training and a game. Thirty-six rugby union players from a Super Rugby team wore a wrist-activity device (Readiband™) to measure sleep for 3 days before, 3 days after and on the night of an evening game. Players were separated into those selected to play the game (n=23) and those who were not (n=13). Alertness was assessed for all training and game times using biometrical modelling. Alertness measures <90% are considered to reflect impaired reaction time. Those selected to play in the game progressively increased sleep duration over the nights prior to the game (by 92 min p<0.05) by delaying wake time. Players went to bed later after the game (02:20±114 min vs 22:57±60 min; p<0.001) which resulted in decreased sleep duration on game night compared to pre-game nights (296±179 min vs 459±78 min; p<0.05). Four players did not achieve any sleep on game night. Sleep duration appeared to be truncated by early morning training sessions (before 08:00) on the second and third mornings after the game. Alertness was >90% for all training and game times for all players. In conclusion, in the days leading into a Super Rugby game, players delay morning time at wake and consequently increase sleep duration with post-game sleep reduced in some.

Keywords: alertness, recovery, actigraphy, athletes
7.2 Introduction

A rugby union game lasts for 80 min and is cognitively and physically demanding. Throughout the game effective decision making and execution of game specific strategies are required [1]. Previously, most rugby (union and league) studies have examined how to optimise player performance by focusing on improving position-dependent physical attributes, such as mass and body fat, endocrine levels and power output [2-4]. However, sleep is vital in the recovery and performance of athletes [5]. Studies in other team sports such as rugby league [6] and soccer [7] highlight this importance, yet little is known about sleep behaviours of elite rugby players [8]. To date, only two studies have reported the effects of training and game time on sleep in rugby union players; both utilised wrist-activity monitors to assess sleep on the nights before, the night of and nights after a game, reporting increases in player sleep duration in the nights prior to a game, and delayed sleep onset time and decreased sleep duration on the night of the game [9, 10].

The present study used wrist-activity monitors to assess sleep in elite rugby players as they minimally interfere with normal training and sleep in athletes [11]. This study also estimated alertness during training and game time via a three process biomathematical model [12], the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model [13]. This approach is common in military, aviation and railroad operations in the design of work and rest patterns to maximise alertness and to minimise risk [14, 15]. To date, no studies have investigated the use of such biomathematical modelling in athletic populations to assess alertness.

Typically, during the week of a Super Rugby game, a team of 23 players (15 to start the game, plus 8 substitutes) will be selected from a squad of 36 players three days prior to a game. The remaining players (13) will continue to train with the team up to the day
before the game. These circumstances provide a unique opportunity to investigate the sleep habits of those selected (and not selected) to play the game and thereby understand more about the sleep behaviours of elite rugby players before and after training and game periods. Such information could be beneficial to coaches and researchers in understanding pre-game, game and post-game sleep behaviours that may be used to support the scheduling of training times to optimise recovery and alertness.

Therefore, the aims of this study were to: (i) quantify the differences in sleep behaviours in players who played the game and those from the greater squad who did not play during the week of a Super Rugby home game; and (ii) estimate alertness for players in both groups for training and game time.

7.3 Methods

7.3.1 Participants

Thirty-six elite contracted male rugby union players from a Super Rugby team based in Perth, Western Australia participated in this study. Players age was 26±3 years (21-34 years) and mass 102±11 kg (80-122 kg). Demographic information, health status and sleep history were collected from players via a paper based survey. Ethics approval was obtained from the University of Western Australia and informed consent received from all athletes prior to participation. This study was conducted in compliance with the Declaration of Helsinki for human experimentation.

7.3.2 Measures

Measures of sleep were obtained from a wrist-activity monitor, the Readiband™ (v3, analysed using Readiband Sync™) (Fatigue Science Inc., Canada). The wrist-activity monitor was issued to each player at 17:00 on the Wednesday; three days before the
game and collected at 08:00 on the Wednesday; four days after the game. These were continuously worn on the non-dominant wrist throughout the 7-day period. The Readiband has good validity (overall accuracy of 93%) when compared to sleep/wake epochs against polysomnography [16], has undergone in-field validation in Australian Rules Football [17] and has been approved by the US Federal Drug Administration (FDA) [18] as a device for measurement of physical activity and sleep data.

The monitors were downloaded and analysed using the automated Readiband Sync software and its proprietary algorithm. Sleep measures derived included: time at sleep onset (the time the person initiated sleep), sleep latency (time between lights out and sleep onset), sleep duration (time between sleep onset and wake, minus any time awake during this period), wake after sleep onset (WASO) (time spent awake after sleep onset and before final waking time), time at wake (time of final waking, not followed by any additional sleep) and sleep efficiency (percentage of time spent asleep whilst in bed: sleep duration/time in bed minus sleep latency and WASO).

Measures of alertness were calculated using the SAFTE algorithm (Figure 10). SAFTE incorporates a homeostatic sleep reservoir, circadian oscillator and sleep inertia function [19] to generate a measure of alertness [13]. The algorithm allows input of variables such as geographical location (longitude and latitude) for calculation of natural light and dark cycles, duration of training sessions, sleep variables from activity monitors and any subjective sleep-related measures such as sleep onset and wake times [20]. Measures of alertness derived from the SAFTE algorithm have been correlated with and validated against the psychomotor-vigilance test (PVT) ($R^2=0.88$, $p<0.001$) (Roma et al., 2012; [20], such that the greater the alertness score the less the likelihood of lapses in reaction time. In our study, the SAFTE model was used to generate a continuous estimate (scale from 0-100%) of alertness for each player across
7 days. Ideally, individuals and teams should be training and competing when alertness is maximal (Figure 10).

Figure 10  Example of SAFTE graphical output of alertness

Notes: The measure of alertness is graphically depicted as a continuous oscillating line, running left to right. The measure of alertness is determined by the time of day, circadian oscillation, hours of wakefulness and the amount of sleep obtained in the past 24, 48 and 72 hours. The oscillating line is presented in different colours to represent specific periods of time: the blue line represents periods of sleep (e.g. Point 1); the thin black line represents periods of wake (e.g. Point 2); and the thick black line represents periods of training or competition/game (e.g. Point 3). The magnitude of alertness (y-axis, 0-100%) is depicted as a function of time (x-axis, six-hour epochs). The x-axis also contains: light grey bars representing periods of natural darkness (night); white bars representing periods of natural light (day); blue bars representing periods of sleep; and black bars representing periods of training or competition/game. Two dips in alertness are apparent over each 24-hr period, each being related to the cyclic nature of the circadian oscillator. The first dip occurs during daylight hours (13:00-16:00) (e.g. Point 4) and the second dip occurs in the early hours of the morning (03:00-06:00) (e.g. Point 5). Note the rapid and marked decrease in alertness in the evening (i.e. after 16 hours of wakefulness) and its rapid recovery with sleep. Ideally, individuals and teams should be training and competing when alertness is maximal.

This study was based around an evening home game (19:00-21:00) in the Super Rugby competition during April 2015. This game was selected as no travel occurred for 13 days prior to, or 10 days after the game. Consequently, players had access to their usual home sleeping environment and performance was unaffected by travel across time zones. Continuous sleep measurements were obtained on each player over
a 7-night period: pre-game (Wednesday, Thursday and Friday), the night of the game (Saturday) and post-game (Sunday, Monday, Tuesday). For data analysis, the 36 players were separated into those selected to play in the game (Game-Group, n=23) and those not selected (Non-Game Group, n=13). Selection by the Head Coach was made on the Thursday prior to the game, and all players in the Non-Game Group attended the game as spectators.

7.3.3 Statistical analysis

Comparisons of demographics and sleep history measures were made between the two groups (Game-Group vs Non-Game Group) using two sample t-tests. The 7-day study period was separated into pre-game nights (1, 2 and 3), game night, and post-game nights (1, 2 and 3). Linear mixed models were used to compare wrist-activity monitor sleep measures between the two groups (Game-Group vs Non-Game Group) over the 7 nights of the study. The models included fixed effects of group (Game-Group vs Non-Game Group) and night (1 to 7), their interaction and random effect of the individual. Differences in least squares means were used to determine statistically significant differences after observing significant fixed effects and estimates of these differences along with 95% confidence intervals are provided. Data are presented as mean±standard deviation (SD) unless otherwise stated with p<0.05 considered statistically significant for all tests. All analyses were carried out using the R environment for statistical computing [21].

7.4 Results

In the Game-Group, 3 players were excluded from the final analyses due to their failure to consistently wear the wrist-activity monitor, meaning data from 33 players were analysed (Game-Group, 20; Non-Game Group, 13).
7.4.1 Demographic information and sleep history

Demographic, anthropometric measures and sleep history were similar between groups (Table 10). The number of days with disrupted sleep during the week was greater in the Non-Game Group by 2±1 days compared to the Game-Group (p<0.05).

Table 10 Descriptive characteristics of Game vs Non-Game Group

<table>
<thead>
<tr>
<th></th>
<th>Game (n=20)</th>
<th>Non-Game (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographic information</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>26±3</td>
<td>25±3</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>102±12</td>
<td>102±10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>185±7</td>
<td>185±8</td>
</tr>
<tr>
<td>Body Mass Index (BMI)</td>
<td>30±3</td>
<td>30±2</td>
</tr>
<tr>
<td>Neck size (cm)</td>
<td>41±6</td>
<td>45±2</td>
</tr>
<tr>
<td><strong>Sleep history</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep you feel you need each night (min)</td>
<td>433±52</td>
<td>431±56</td>
</tr>
<tr>
<td>Sleep you get each night (min)</td>
<td>426±60</td>
<td>420±58</td>
</tr>
<tr>
<td>Sleep you feel you need after training or competition (mins)</td>
<td>465±92</td>
<td>474±72</td>
</tr>
<tr>
<td>Sleep you get after training or competition (mins)</td>
<td>348±118</td>
<td>370±122</td>
</tr>
<tr>
<td>Number of days disrupted sleep per week (count)</td>
<td>2±2*</td>
<td>4±1</td>
</tr>
<tr>
<td>Number of times sleep is disrupted each night (count)</td>
<td>2±1</td>
<td>1±1</td>
</tr>
<tr>
<td><strong>How would you rate the importance of sleep on your recovery (count of response)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not important at all</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Somewhat important</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Important</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Extremely important</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td><strong>Self-reported health status (count of response)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Very Good</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Good</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Martial and family status (count of response)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Single</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Living with partner</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Number of players with children under 18 (living at home)</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Notes:** Anthropometric data and sleep related responses from the survey instrument. Data are presented as means and standard deviations (SD). * p<0.05 for Game-Group v Non-Game Group.
7.4.2 Overall sleep measures (both groups)

Considering the entire squad (n=33) there was: a later time of sleep onset (~3hrs) on the night of the game relative to all nights before and after the game; a tendency to progressively wake later leading up to a game (~2 hrs); and a progressive increase in sleep duration on the days leading up to a game (~1.5 hrs).

7.4.3 Measures of sleep within the Game-Group

Compared to game night (Figure 11), sleep latency was increased by 30 min on pre-game night 1 (estimated difference 27 min 95% CI 8-46 min, p=0.005), time at sleep onset was earlier (difference ranged from 182 to 211 min, all p<0.05) and sleep duration was greater on all pre-game and post-game nights (difference ranges from 128 to 219 min, all p<0.05). There was increased WASO on post-game night 1 (estimated difference 10 min 95% CI 3.2-16.8 min, p=0.004) and decreased sleep efficiency on game night compared to other nights (difference ranges from 16.2 to 21.5 percent, all p<0.05). Additionally, time at wake (were earlier on pre-game nights 1 and 2 and post-game nights 1, 2 and 3 (all p<0.05). Notably, four players in the Game-Group did not achieve any sleep after the game until post-game night 1.
Figure 11  Measures of Sleep, Game vs Non-Game Group

Notes: Sleep Measures (a-f): Measures of sleep on pre-game 1 (Pre-1), pre-game 2 (Pre-2) and pre-game 3 (Pre-3) day of the game (Game) (transparent box) and post-game 1 (Post-1), post-game 2 (Post-2) and post-game 3 (Post-3) in the Game Group (solid black line, n=20) and the Non-Game Group (grey line, n=13). Data presented as mean ±SD with n=20 for the Game Group and n=13 for the Non-Game Group, * P<0.05 v Game Night, † P<0.05 Game v Non-Game Group within the same night.
7.4.4 Measures of sleep within the Non-Game Group

Compared to game night sleep latency was greater on pre-game 3 (difference to game night ranged from 0 to 48 min), time at sleep onset was earlier on all pre-game and post-game nights (difference to game night ranged from 102 to 150 min, all p<0.05) and wake times were earlier on pre-game nights 1 and 2 and post-game nights 1, 2 and 3 (all p<0.05).

7.4.5 Comparing measures of sleep between the Game vs Non-Game Group

In the Game-Group compared to the Non-Game Group sleep latency was increased by 26 mins on pre-game 2 (95% CI 3-50 min, p=0.028) and decreased by 25 min on pre-game 3 (95% CI 1-48 min, p=0.039). Sleep duration was greater in the Non-Game Group by 144 min on game night (95% CI 74-214 min, p<0.001) and greater in the Game-Group by 82 min on pre-game 2 (95% CI 13-150 min, p=0.019) and by 64 min on pre-game 3 (95% CI 1-133 min, p=0.065), with the latter not being statistically significant but displaying the same general trend. Sleep efficiency was also significantly lower on game night for the Game-Group with a difference of 20 percent (95% CI 11-30 percent, p<0.001).

7.4.6 Alertness

Alertness was bio-mathematically modelled over the study period for both groups and continuous data are shown in Figure 12. During all pre- and post-game training sessions, alertness was greater than 90%. On game night, the Game-Group had an average alertness of 100% during the game and the Non-Game Group had an average of 97%. 
Figure 12  Measures of Alertness

Notes: Figure 12 (a-b): Measures of alertness on pre-game 1 pre-game 2 and pre-game 3, night of the game (Game) (transparent box) and post-game 1, post-game 2 and post-game 3 for both the Game Group (a) and the Non-Game Group (b).
7.5 Discussion

This study found that professional rugby players progressively increased sleep duration in the nights leading into an evening game, in those who were selected to play (compared to those not selected but who still attended the game). Those who played went to bed 3 hrs later on the night of the game (02:00 vs 23:00 hrs on other nights), with a resultant decrease in sleep duration of ~2.5 hrs on this night. These changes in sleep did not affect the modelled estimate of alertness, which remained above 93% of maximum during the game and all training sessions.

The progressive increase in sleep duration seen in the nights leading into an evening game has also been reported in two other rugby studies [9, 10] and may represent an intentional pre-game strategy by athletes to optimise game performance. Our study shows that such sleep behaviours occurs only in those players selected to play, and not in unselected players who attended the game as spectators. While the precise performance benefits of increases in sleep duration remain unclear, a previous study of prolonged periods of sleep extension in collegiate basketball players has resulted in improved sprint times, shooting accuracy, reaction time and levels of daytime sleepiness [22]. Similar sleep prolongation strategies are employed in military special operations by the intentional provision of extended sleep opportunities prior to deployment on missions [23].

In contrast to the nights leading into a game, which were characterised by a progressive increase in sleep duration, on game night, those who played the game had a 2.5-hr decrease in sleep duration. This was primarily due to a 3-hr delay in sleep onset time compared to all other nights. Such findings are consistent with results from other studies conducted in rugby union and the Australian Football League; after evening games, sleep onset time was delayed and sleep duration reduced compared to
pre-game nights [10, 24, 25]. The delay in time to sleep following a game could be due to several factors, including media commitments, recovery sessions, socialising, persisting game-related increases in cortisol levels and mood disturbances, both of which can occur for 12-36 hrs after a rugby game [26] and up to 48 hrs following a rugby league game [27]. The mechanisms underlying the significant increase in time at sleep onset following an evening game still remain unclear but could include the potentially detrimental effects of pre-game ergogenic caffeine ingestion on sleep.

The nights following the game were characterised by a gradual return to pre-game sleep patterns. On the second and third nights, post-game wake times were constrained by scheduled early morning training sessions (commencing before 08:00). These early morning training sessions truncate the opportunity for sleep, thus reducing sleep duration [28].

As previously noted, the measure of alertness used in this study has been validated against the PVT ($R^2=0.88$, $p<0.001$) [19, 29]. A test of sustained attention that is sensitive to sleep loss [30] and circadian misalignment and which provides a surrogate measure of behavioural alertness [29]. The alertness algorithm and association with PVT have been validated in the aviation and rail transportation industries (Hursh et al., 2006; Roma et al., 2012) such that values of alertness <90% are considered to reflect impaired in reaction times. Indeed, alertness values between 80-90% have been associated with an 18% decrease in reaction time based upon PVT results and an alertness score of 77% has been shown to be accompanied by a 34% reduction in reaction time (Hursh et al., 2006; Roma et al., 2012) a decreases in reaction time that is equivalent to that occurring with blood alcohol concentration of 0.05% or after 17 hrs of sustained wakefulness [30]. While there are no published reports of alertness
being used in athletic populations, such information may be useful for identifying periods of cognitive impairment, which may result in suboptimal performance.

In the present study for Game and Non-Group players; alertness remained above 90% during all training sessions and above 95% during the game. The tendency for game alertness to increase could be attributed to increased sleep in the days before the game, particularly in those players who were selected to participate in the evening game. Potentially, substantial differences in alertness could occur with international travel, which occurs regularly with Super Rugby teams. By adjusting for changes in time zones, the SAFTE model used in this study (Hursh et al., 2004) and other bio-mathematical models could be used to predict optimal travel and training times for travelling teams.

7.5.1 Limitations

The sample size in this study was limited by squad numbers (n=36), as this was the only team based within the State. However, the data collected reflect the responses of the whole team, thus the findings are representative of sleep in elite rugby players within a Super Rugby team. Also, the results relate to a single Super Rugby home game with no interstate or international travel in the week before or after, as such it not known how representative they are of other teams, especially following travel to away games.

7.5.2 Conclusion

Those professional rugby players who have been selected during the week to play in an evening game on the weekend showed a progressive increase in sleep duration in the days leading up to the game. It is possible that such behaviour is an attempt by the player to maximise alertness for training and game time, which were high in the Game-Group. However, it was notable that high levels of alertness were also observed in those players who were not selected to play in the weekend game, suggesting that they
might be prepared, at least in terms of alertness, for last minute inclusion in the team on game day if needed. The finding of a significant delay in time of sleep onset and reduction in sleep duration after a game in all players should be of interest to coaches, who could consider delaying post-game training sessions in order to allow for optimal recovery. Bio-mathematical modelling of alertness, as used in this study, might represent a useful tool for coaching and performance staff for development of objective performance decisions related to training and recovery periods. Such modelling could, for example, be used to assist with scheduling of travel.

7.5.3 Acknowledgements

Many thanks to Fatigue Science, Vancouver, British Columbia for the supply of Readiband™ and SAFTE™ software. Also to the staff and players at the Western Force. Peter R Eastwood is supported by a NHMRC Senior Research Fellowship (No. 513704).

7.5.4 Conflict of Interest statement

Both Ian C. Dunican and John A. Caldwell have previously undertaken consultancy work for Fatigue Science, but neither are currently engaged in any capacity with the company.
### References


Chapter 8  Caffeine use in a Super Rugby game and its relationship to post-game sleep

Authors:

Ian C Duncan¹, Charles C Higgins², Maddison J Jones³, Michael W Clarke⁴, Kevin Murray⁵, Brian Dawson³, John A Caldwell⁶, Shona L Halson⁷ and Peter R Eastwood¹

Institutions

¹Centre for Sleep Science, School of Human Sciences, The University of Western Australia. 35 Stirling Hwy, Crawley, Western Australia 6009, Australia.

²Western Force, Floreat, Rugby WA, Western Australia 6014, Australia.

³School of Human Sciences, The University of Western Australia. 35 Stirling Hwy, Crawley, Western Australia 6009, Australia.

⁴Centre for Microscopy, Characterisation and Analysis, The University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia 6009, Australia.

⁵School of Population and Global Health, The University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia 6009, Australia.

⁶Coastal Performance Consulting, Key West, Florida, United States.

⁷Department of Physiology, The Australian Institute of Sport, Canberra, ACT, Australia.

Publication Status

Published in the European Journal of Sport Science

8.1 Abstract

**Objective:** To examine the relationship between regular game-related caffeine consumption on sleep after an evening Super Rugby game.

**Methods:** 20 elite rugby union players wore a wrist-activity monitor to measure sleep for three days before, three days after and on the night of an evening Super Rugby game (19:00-21:00). Players ingested caffeine as they would normally (i.e. before and sometimes during a game) and saliva samples were collected before (17:00) and after (21:30) the game for caffeine concentration.

**Results:** Compared to the nights leading up to the game, on the night of the game, players went to bed 3 h later (23:08±66 mins vs 02:11±114 mins; p<0.001) and had 1.5 h less sleep (296±179 mins vs 472±84 mins; p<0.05) and 4 players did not sleep after the game. Post-game caffeine saliva concentration was greater than pre-game levels in 17 players (Pre-Game 0.40µg/ml vs Post-Game 2.77µg/ml; p<0.001). The increase in caffeine saliva concentration was moderately associated with an increase in sleep latency (p<0.05), a decrease in sleep efficiency (p<0.05), and a trend for a decrease in sleep duration (p=0.06) on game night.

**Conclusion:** Caffeine consumption before a Super Rugby game markedly increases post-game saliva caffeine levels. This may contribute to the observed 3.5 hr delay in time at sleep onset and the 1.5 hr reduction in sleep duration on the night of the game. This study highlights the need for a strategic approach to the use of caffeine within a Super Rugby team considering the potential effect on post-game sleep.
8.2 Introduction

In the southern hemisphere, the Super Rugby championship is contested across five countries with 18 teams from Australia, South Africa, New Zealand, Japan, and Argentina. A Super Rugby team will play 15 games in a season (Home & Away) with games generally played at night, between the hours of 18:00-22:00, at a time of the day when the drive for sleep is increasing [1]. The requirement to compete at this time of day for 80 mins in a contact sport that places high demands on players from a strength, aerobic, and anaerobic capacity [2] may negatively affect sleep after such games.

Sleep is an important process for recovery in athletes [3]. This is especially true following intense competitive events or training regimes since fatigue, staleness, and soreness is associated with insufficient recovery and contributes to poorer performance in subsequent competitions (Hooper et al., 1995). Unfortunately, in team sports such as soccer, perceived recovery and sleep often is reduced following a night game [4]. Similarly, Sargent & Roach (2016) report shortened sleep attributable to delayed sleep onset following an Australian Rules Football (AFL) night game. Such sleep loss leads to decrements in physical [5] and cognitive performance in athletes [6].

When sleep loss occurs after a contact game such as rugby union it negatively affects reaction time, physical performance and subjective perceptions of muscle soreness [7]. Sleep loss due to a post-game delay in sleep onset has been reported in several studies of rugby union athletes [8, 9], although the specific factors contributing to these sleep-related changes were unclear. It is speculated that these sleep-related changes may include the arousing effects of an evening game, an elevated body temperature [10], alcohol consumption [11, 12] and pre-game ingestion of caffeine [8].
From the standpoint of gaining a competitive edge, athletes often rely on pre-game caffeine ingestion as an ergogenic aid [13, 14]. Such a strategy appears warranted considering that consumption of 2-9 mg/kg of caffeine has been shown to increase the sprint speed, power and passing accuracy of rugby players during training [15, 16]. Similar doses have been shown to improve reaction time in Taekwondo athletes [17].

Unfortunately, while caffeine exerts a number of beneficial effects on waking performance, the late-day or evening consumption of caffeine can impair subsequent sleep [18]. Once ingested, caffeine typically reaches peak plasma levels in 60 minutes and takes about four to six hours to metabolise half of the initial dose [19]. Caffeine consumed shortly before bedtime will decrease sleep duration and sleep efficiency [18]. The adverse effect of caffeine on sleep duration is primarily due to an increase in the time it takes to fall asleep (sleep latency) which due to lifestyle factors or other demands is not offset by a delayed wake-up time the next day [20]. The adverse effect of caffeine on sleep efficiency is attributable the tendency for caffeine to increase the number of times an individual wakes transiently during the sleep period [21], which also reduces overall sleep duration.

As noted previously, it has been hypothesised that the sleep problems previously reported among rugby players may in part be due to the pre-game usage of caffeine as an ergogenic aid. However, to date, no studies have assessed caffeine consumption (self-reported or objectively quantified) and its potential impact on sleep in rugby or other team sport athletes participating in evening or night-time competitions. Anecdotally, elite rugby union players report ingesting caffeine before night games, but objective confirmation of such reports have not been published.
The aim of this study was to; (i) quantify the caffeine concentration levels of professional rugby union players before and after an evening Super Rugby game and (ii) determine any relationships between caffeine concentration levels and post-game sleep. Measures of caffeine concentration were obtained relatively non-obtrusively via saliva assays (which have been shown to reliably reflect blood plasma levels—see Zylber-Katz, Granit, & Levy, 1984), and sleep measures were obtained via wrist actigraphy (which has been to closely approximate sleep assessments made via polysomnography (Dunican et al, 2017). We hypothesised that an increase in caffeine levels after an evening game would be related to a reduction in the sleep quantity and sleep efficiency of post-game sleep.

8.3 Methods

All participants were contracted players from a single professional Super Rugby team based in Perth, Western Australia. The mean age of the players was 26±3 years (21-34 years) with a mean mass of 102±12 kg (80-122 kg) (Table 11). Ethical approval for the study was obtained from the Human Research Ethics Office of the University of Western Australia (RA/4/1/7235) and written informed consent were obtained from all players before their participation.

8.3.1 Experimental overview

The study was undertaken during the week of a Super Rugby home game in April 2015. This game was selected as no travel occurred for 13 days before the game or for ten days after the game, thus ensuring that players had access to their usual sleep environment and completed all training within a standard time zone. Wrist-activity monitors were continually worn on each of the three days before (Wednesday, Thursday, and Friday) and after (Sunday, Monday, Tuesday) a Saturday evening game
(19:00-21:00 h). Saliva samples were collected three hrs before the game (16:00-17:00 h) and within 30 min after the game (21:00-21:30 h) to assess caffeine concentration.

8.3.2 Demographic and anthropometric measurements

The team’s athletic performance support staff provided measurements of each athlete’s height (cm), competition weight (kg), and Body Mass Index (BMI), calculated from weight/height$^2$ (kg/m$^2$). Data were collected on each player's regular caffeine consumption in relation to the seven days prior to this Super Rugby game.

8.3.3 Sleep measures-wrist activity monitor

To obtain measures of sleep in this study, wrist-activity monitors were used as they are ideal to monitor sleep in athletes since they minimally interfere with normal training and sleep opportunities [22]; [23]. The wrist-activity monitor used in this study, the Readiband™ (v3, Fatigue Science Inc., Canada), was issued to each player at 17:00 h on the Wednesday before the game and collected at 08:00 h on the Wednesday after the game. The wrist-activity monitors were worn on the non-dominant wrist throughout the 7-day period, including during training sessions.

These devices have been shown to compare favourably both to in-laboratory polysomnography (PSG) and another widely used and validated wrist-activity monitor, the ActiGraph (Duncan et al., 2017). In addition, Readiband wrist monitors have been shown to have an epoch-to-epoch sleep/wake scoring accuracy of 82%, sensitivity of 88% and specificity of 55% in comparison to gold standard in-laboratory PSG [24]. The Readiband has been used in a number of sports related research studies [25-27], has undergone an infield validation in Australian Rules Football [28] and has been approved by the Federal Drug Administration [29] for measurement of physical activity and sleep.
8.3.4  **Sleep analysis-wrist activity monitor**

A single trained scientist downloaded Readiband™ data and analysed these data using the automated Readiband Sync™ software. Sleep measures included: sleep latency (number of mins from time of trying to initiate sleep to time of sleep onset); time at sleep onset (time of the first epoch of sleep between time of trying to initiate sleep and time at wake up); sleep duration (number of mins from time of sleep onset to time at wake, minus number of mins awake); wake after sleep onset (number of mins awake after sleep onset); time at wake (the time of wake from sleep with no further sleep duration); and sleep efficiency (sleep duration divided by time in bed multiplied by 100).

8.3.5  **Sleep & Training Diary**

Players were provided with a sleep and training diary, which they carried with them throughout the seven days. The diary contained questions relating to their sleep patterns and training effort and included questions relating to the time players went to bed the previous night and the time they woke up.

8.3.6  **Caffeine measures**

Saliva samples were collected from each participant under the supervision of the research team twice on game night. A pre-game sample was collected three hrs before the game (16:00-17:00 h) and a post-game sample was collected within 30 mins after the end of the game (21:00-21:30 h). Players were given a pre-labelled blue cap Salivette® (ref. 51.1534.500) with a unique identification code. The Salivette® contained a cotton swab. Players removed the cotton swab, placed it in their mouth and chewed on it for 45 s to stimulate salivation. The cotton swab was then placed back into the Salivette® and sealed with a stopper. When completed, the player handed
the Salivette® containing the saliva sample to a member of the research team. Samples were immediately placed in a portable ice container and were placed in a freezer later that night (at 22:30 h). The following day at 09:00 h, the samples were transported to the University of Western Australia (UWA) laboratory and stored at -20°Celsius.

8.3.7 Caffeine analysis

Caffeine saliva samples were analysed using an HPLC column (Phenomenex Biphenyl 150mm x 3mm, 2.6µm). Synthetic saliva was from LGC (OraFlx negative-synthetic saliva), LCMS grade water from Thermofisher, LCMS grade methanol from Burdich and Jackson, Formic acid from Merck and pure caffeine and 13C3 caffeine standards from Sigma-Aldrich. Assay samples were defrosted, and 100µL of saliva was spiked with 50µL labelled caffeine (5µg/mL), vortexed briefly then extracted by 1mL of Ethyl Acetate. This was vortexed for 60s, then 900 µL was dried down by evaporation. The dried extract was reconstituted in 70µL of 50:50 Methanol: Water, then 5µL was injected onto an Agilent 6460 LC-MS/MS. The solvents were A (water + 0.1% formic acid), B (Methanol + 0.1% formic acid) and the following gradient was applied, 0 mins 50% B, 7 mins 98% B, 8 mins 50% B, 9 mins 50% B. The transitions monitored for caffeine and 13C3 caffeine were 195.1>137.9 and 197.9>139.9 and the retention time was 3.3 mins. Assay calibration was achieved by spiking synthetic saliva (LGC) with known amounts of caffeine. A typical calibration curve showed an $R^2 = 0.999$. Assay precision, indicating instrument accuracy, was assessed by running a test sample in triplicate. The coefficient of variation of these measures was 0.7% at 0.152 µg/ml.

8.3.8 Statistical analysis

Linear mixed models were used to compare wrist-activity monitor derived sleep measures over the course of the study. For measures that were taken by both wrist-
activity monitor and sleep diary, fixed effects of measurement type (sleep measures
taken from the wrist-activity monitor or sleep diary), night (pre-game nights 1, 2, 3,
game night, post-game nights 1, 2, 3), along with their interactions were included, in
addition to appropriate random effects of the individual. For the measures that were
taken by wrist-activity monitor only, fixed effect of night and random individual
effects were included. Differences in least squares means were used to assess
significant differences and are presented along with 95% confidence intervals for
differences. In instances where the model assumptions were violated, a transformation
(square root) was performed. Paired t-tests were used to compare pre-game versus
post-game caffeine levels, and a series of bivariate correlational analyses were used to
examine the association between changes in caffeine against measures of sleep. Data
are presented as mean± standard deviation (SD) and p<0.05 was considered as
statistically significant for all tests. All analyses were carried out using SAS software
(SAS Institute Inc., Cary, NC, USA).

8.4 Results

Of the 23 elite rugby union players who were enrolled in the study, three were excluded
from the final analyses due to their failure to wear the wrist-activity monitor as per
instructions. Therefore, data from a total of 20 players were analysed.

8.4.1 Sleep measures- wrist activity monitor

In general, sleep latency (Figure 13) was longer on all nights compared to the night of
the game with statistically significant differences occurring on pre–game 1 with mean
differences of 27 mins (95% CI 1,4 mins), pre-game 2 of 17 mins (95% CI 0, 3 mins),
and post-game 1 of 17 mins (95% CI 0, 3 mins) (p<0.05 for all). Time at sleep onset
was different on game night compared to all other nights with a minimum difference
of 3 hrs 6 mins on pre-game 1 (95% CI 2:18, 3:42 hh:mm) and maximum difference of 3 hrs 30 mins on post-game 1 (95% CI 2:42, 4:06 hh:mm) (p<0.05 for all). Sleep duration was significantly longer on all nights compared to game night with a range of mean differences over the nights 128 mins (95% CI 66, 189 mins) to 219 mins (95% CI 158, 280 mins) (p<0.001 for all). Wake after sleep onset was only significantly different on post-game 1 compared to game night with a significantly smaller time (95% CI 1, 3 mins) (p<0.05). Time at wake was different for all nights when compared to game night except night pre-game 3 (the morning of the game). The average difference ranged from 48 mins (95% CI 0:12,1:24 hh:mm) on pre-game 2 to 2 hrs 12 mins (95% CI 1:36, 2:48 hh:mm) on post-game 2 (p<0.05 for all). Sleep efficiency was much lower on game night compared to all other nights (p<0.001) with a range for the differences from 16% (95% CI 7, 26 %) on pre-game 2 to 22% on post-game night 3 (95% CI 12, 32%).
Figure 13  Measures of objective sleep vs self-reported sleep

Notes: (Pre-1), pre-game 2 (Pre-2) and pre-game3 (Pre-3) day of the game (Game) (transparent box) and post-game 1 (Post-1), post-game 2 (Post-2) and post-game 3 (Post-3). Wrist Activity Monitor data (solid black line) and the Sleep Diary data (grey line) presented as mean ±SD, * Indicates P<0.05 for within measure comparison v Game Night. † Indicates P<0.05 for between measures (Wrist-activity vs Diary data) within the same night.
8.4.2 **Sleep measures - self-reported**

Time at sleep onset (Figure 13) was different on game night compared to all nights with a minimum difference of 2 hrs 12 mins on pre-game 3 (95% CI 1:30,2:48 hh:mm) and maximum difference of 2 hrs 48 mins on post-game 3 (95% CI 2:12, 3:36 hh:mm) (p<0.05 for all). Sleep duration was recorded as longer on all nights compared to game night with statistically significant differences on pre-game 1 with mean difference of 72 mins (95% CI 10, 133 mins), pre-game night 2 mean difference of 74 mins (95% CI 13, 135 mins), and post-game night 2 with mean difference 73 mins (95% CI 10, 134 mins) (p<0.05 for all). Time at wake was statistically significantly different on pre-game night 1 and post-game nights 1-3, with the differences ranging from 54 mins on post-game night 3 (95% CI 0:18, 1:30 hh:mm) (p<0.05) to 1 hr 33 mins on post-game night 2 (95% CI 0:54, 2:06 hh:mm) (p<0.001).

8.4.3 **Associations between self-reported and wrist-activity monitor measures of sleep**

Sleep diary based measurements for time at sleep onset were similar to measures derived from the wrist-activity monitor except for the night of the game in which the sleep diary estimates of sleep were earlier by 60 mins (95% CI 0:17, 102 mins), than those obtained via the wrist-activity monitor (Figure 13) (p<0.05). This resulted in self-reported sleep duration being overestimated by 148 mins on game night (95% CI 87, 209 mins) (p<0.001) and on all other pre-and post-game nights were consistently overestimated by an average of 60 mins per night (p<0.05). Time at wake was not significantly different between sleep diary and wrist-activity monitor measurements for any of the nights.
8.4.4 Caffeine saliva concentrations

Post-game caffeine saliva concentrations (Figure 14) increased in 17 of the 20 players and decreased in 3 players. When considered as a group, caffeine saliva concentrations increased by 2.35±2.07 μg/ml, from 0.42±0.52 μg/ml before the game (16:00-17:00) to 2.77±2.27 μg/ml following the game (21:00-21:30) (p<0.001).

![Bar graph showing caffeine concentration before and after the game](image)

**Figure 14** Pre-Game vs Post-Game caffeine consumption

8.4.5 Self-reported caffeine consumption

On average, players reported consuming two caffeinated drinks per day in the seven days prior to the commencement of the study (Table 11). Nine of the 20 players reported that when playing a game that they consume caffeine for performance, on average these players consumed caffeine 49±61mins before the commencement of a game.
Table 11  Demographic and self-reported caffeine consumption (n=20)

<table>
<thead>
<tr>
<th>Demographic information (mean±SD)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26±3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>102±12</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>185±7</td>
</tr>
<tr>
<td>Body Mass Index (BMI)</td>
<td>30±3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Self-reported caffeine consumption (mean)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffeinated drinks consumed per day, per player</td>
<td>2</td>
</tr>
<tr>
<td>(count of drinks)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sources of caffeine consumption in the past 7 days (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Home brew coffee</td>
<td>13%</td>
</tr>
<tr>
<td>Cappuccino/Latte/Flat white</td>
<td>31%</td>
</tr>
<tr>
<td>Tea</td>
<td>28%</td>
</tr>
<tr>
<td>Energy drinks</td>
<td>3%</td>
</tr>
<tr>
<td>Cola drinks</td>
<td>25%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time of day when MOST of caffeine is consumed (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>06:00-12:00</td>
<td>67%</td>
</tr>
<tr>
<td>12:00-18:00</td>
<td>27%</td>
</tr>
<tr>
<td>18:00-00:00</td>
<td>6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Self-reported caffeine use prior to a Super Rugby game</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of players who take caffeine prior to a</td>
<td>9</td>
</tr>
<tr>
<td>competitive game (count)</td>
<td></td>
</tr>
<tr>
<td>Time of consumption prior to a competitive game (mins</td>
<td>49±61</td>
</tr>
<tr>
<td>(mean±SD)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sources of caffeine consumption prior to a Super Rugby game (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Home brew coffee</td>
<td>3%</td>
</tr>
<tr>
<td>Cappuccino/Latte/Flat white</td>
<td>13%</td>
</tr>
<tr>
<td>Tea</td>
<td>32%</td>
</tr>
<tr>
<td>Cola drinks</td>
<td>28%</td>
</tr>
<tr>
<td>No Doze tablets</td>
<td>21%</td>
</tr>
<tr>
<td>Chocolate</td>
<td>3%</td>
</tr>
</tbody>
</table>

8.4.6  Associations between sleep and caffeine

On game night, changes in caffeine saliva concentrations from before to after the game were moderately related to an increase in sleep latency (r=0.53, p=0.03) and a decrease in sleep efficiency (r=0.52, p=0.03) in post-game sleep (Figure 15). The size of the game-related increase in caffeine tended to be related to a decrease in sleep duration after the game (r=0.44, p=0.06). Changes in caffeine concentration were not related to any other measure of sleep.
Figure 14 (a): Change in sleep latency vs change in caffeine

Figure 14 (b): Change in sleep efficiency vs change in caffeine

Figure 14 (c): Change in sleep duration vs change in caffeine

Figure 15  Associations between sleep and caffeine

Notes: Figure 15 (a and b) n=16 due to n=4 players not achieving sleep on game night. Figure 15 (c) n=20 inclusive of those that did not sleep (n=4). Overlapping data points have been offset for the purpose of the figure depiction.
8.5 Discussion

The aim of this study was to examine the relationships between caffeine consumption and a variety of actigraphy-derived sleep measures collected after an evening Super Rugby game. The main findings were that: (i) caffeine consumption was common before the game; (ii) this resulted in markedly increased post-game saliva caffeine levels in most players; and (iii) the increase in caffeine concentrations was moderately associated with an increase in sleep latency, a decrease in sleep efficiency, and a tendency toward decreased sleep duration.

Our results revealed a significant delay in the time of sleep onset and the duration of sleep after the game compared to what was observed each night leading up to the game and each night following the game. These results are similar to those found in other studies of rugby players in Australia and Wales, in which the athletes slept significantly less after a game [9, 30]. One of these studies (conducted in another Super Rugby team based in Australia), reported an average post-game sleep duration of 4hrs 45 mins and an average sleep onset time of 02:24 h [9], while in our study players achieved an average sleep duration of 4hrs 56min and fell asleep at 02:12 h. A study conducted on the Celtic League in Wales, indicated that players achieved slightly more post-game sleep (i.e., 6 hrs), most likely because they fell asleep earlier (at 00:49 h) and awakened later the next day (at 08:56 h) [8].

It was of interest that in this study 20% of players did not achieve any sleep after the game. Post data-collection discussions with those specific players confirmed the actigraphy-based findings. The main self-reported mechanism responsible for the complete absence of post-game sleep was continued post-game arousal, the stress of having lost that game, and engagement in post-game socialising with team members.
It is important to acknowledge these and other factors that can play a role in delayed sleep times in athletes, including the general arousing effects of an evening game, an elevated body temperature [10], alcohol consumption [11, 12] and/or the requirement to attend a post-game press conference, post-game recovery sessions and/or post-game medical evaluations. Any or all of these can negatively affect bedtime, sleep duration and sleep efficiency in athletes [4]. Our current findings within the context of an evening game in combination of those from other assessments of contact sports such as rugby and AFL suggest that greater emphasis should be placed on the importance of post-game recovery sleep for teams preparing for an additional game the following week (one that may require the additional sleep-disrupting complications of interstate or international travel).

It is surprising that players in the present investigation did not compensate for the increase in sleep latency and the delayed time of post-game sleep onset by delaying the wakeup time the next morning since there were no scheduled team events which would have prohibited this adjustment. Perhaps the players attempted to sleep later the next day but were unable to do so because of an increase in perceived muscle soreness and/or an increase in creatine-kinase levels since both of these have been reported in rugby league players [7]. In addition, post-game alcohol consumption may have affected the sleep/wake timing [31]. These factors were not evaluated in our investigation, but should be considered in future studies of athlete sleep characteristics.

In general, the measures of self-reported sleep from players agreed with those obtained via the wrist-activity monitors, but the athletes nevertheless tended to overestimate their sleep duration by an average of 1-hr. Such a discrepancy is not surprising since it is difficult for humans to be cognisant of overnight awakenings and the cumulative effect of such awakenings on total sleep time. For this reason,
actigraphy-based measures tend to be superior to self-ratings. Also actigraphy-based sleep measures are more accurate than those derived from sleep diaries because they are less likely to suffer from participants’ failures to complete the reports on a daily basis or to correctly recall sleep times upon next-day reflection [32]. The Readiband wrist-activity monitor used in the present study proved to be popular amongst the players due to its robust, non-intrusive nature and the ability to collect data continuously over the period of the study. The fact that there were differences between the Readiband data and the sleep-dairy reports in this study suggests that coaches and athletic staff should interpret self-reported sleep with caution.

Our results indicated that saliva caffeine levels increased by 2.37 µg/ml from pre-game to post-game testing. This would equate to a dose of 2.37 mg/kg of BW as the average mass of players was 100 kg, [33, 34]. It is difficult to know with our data if this is within normal levels of consumption for rugby players first study to quantify caffeine consumption and the effect on sleep in rugby players.

Caffeine is beneficial for physical performance when taken at doses of 3 mg/kg BW [35]. In rugby union players, a dose of 3 mg/kg BW has been shown to improve movement patterns during a simulated game [14]. At a dose of 5 mg/kg BW, caffeine can lead to a faster reaction time in taekwondo athletes [17]. Thus, it is not surprising the players assessed in our evaluation would ingest caffeine thinking that such a practice would serve an ergogenic function. Unfortunately, they may not have considered the effects of caffeine on subsequent post-game recovery sleep.

It is well known that caffeine has negative effects on sleep, even with consumption as low as 1 mg/kg BW [18]. These effects include; increase in sleep latency, increase in arousals and awakenings, decreased sleep duration and a decrease in sleep efficiency
To date there is no available data or information on the precise effects of caffeine on the recovery sleep of rugby players. Indeed, there are very few studies investigating the effects of caffeine on sleep in athletic populations. It was notable in our study that the changes in caffeine levels were moderately related to an increase in sleep latency, lower sleep efficiency and a trend to decrease sleep duration. These findings suggest that players who ingested more caffeine before the game had worse sleep after the game.

Of the limited data on caffeine and sleep in athletes, caffeine consumption of 3 mg/kg BW in male cyclists in the late afternoon significantly prolongs sleep latency and decreases sleep efficiency [36]. A similar dose of caffeine, ingested by male and female athletes in the afternoon increases symptoms of insomnia by way of an increase in the number of awakenings, increasing wake after sleep onset which leads to sleep loss overnight in athletes [37].

It is of interest in our study that that time of sleep onset (02:12, hh:mm) does not occur until the half-life of caffeine (4-6 hrs) has passed, some five hrs after the post-game saliva sampling [19]. This is consistent with the existing research; sleep can be negatively affected when caffeine is consumed within six hrs of the proposed time to bed [38]. It is unlikely that caffeine played a role in the relatively early time at wake on the morning following a game, as the proposed the caffeine plasma levels would be negligible.

To ascertain if caffeine played a role in affecting the time at sleep onset, sleep duration and time at wake, it is worth considering the probable caffeine pharmacokinetics (Supplementary figure 8, p.267). Our generated caffeine concentration curve was developed by utilising known caffeine levels from saliva samples (pre and post-game saliva samples), wrist-activity monitor based measures of
sleep and wake times as collected by the Readiband, self-reported caffeine consumption and estimated levels of caffeine levels from published pharmacokinetics [34].

Self-reported consumption of caffeine on the game night was very different to the measured changes in caffeine from the saliva samples. Specifically, only nine players reported consuming caffeine for ergogenic benefit, however 17 players had increased saliva caffeine concentrations from pre-to post-game. Such a finding highlights the caution that needs to be applied to self-reported measures of caffeine consumption. It is possible that knowledge of caffeine sources is not well understood, even by professional athletes. Consistent with this, several players commented after the study that they were unaware that the supplement commonly referred to as “pre-workout” or the caffeine tablets contained caffeine.

8.5.1 Limitations

There are several potential limitations of this study. Firstly, the study used wrist-activity monitors to measure sleep behaviours over a 7-day period in 20 athletes. The gold-standard measurement of sleep is polysomnography; however such an approach would not be practical or acceptable to professional sporting teams during the season. Secondly, the focus of this study was one Super Rugby home game and it is unknown how representative the sleep and caffeine data obtained from this game is of other games in a season. Finally, we were limited to measuring caffeine saliva to only two time-points, pre- and post-game. Additional sampling on the days leading up to a game, and even during a game, would provide a better understanding of within- and between-individual variability in saliva concentrations, however such measurements would be challenging to obtain in an elite professional sporting team.
8.5.2 Conclusion

Caffeine consumption before and during a Super Rugby game resulted in markedly increased saliva caffeine levels. The magnitude of the increase in caffeine was related to poorer sleep immediately following the game. This study highlights the need for a strategic approach to the use of caffeine within a Super Rugby team. In particular, a player education program regarding sources of caffeine, timing, and the potential effect on sleep.
8.6 References


Chapter 9  Discussion

9.1  Overview and summary of thesis

The field and laboratory studies in this thesis have evaluated the importance of sleep for recovery and performance in elite athletes. In the Literature Review (Chapter 2), the general scarcity of studies on this topic was highlighted. However, it also was noted that the few studies that have been published appeared to have occurred primarily in the past decade. This highlights the fact that scientific interest in “sleep research” is a relatively recent phenomenon.

This thesis consists of a series of scientific studies that 1) fills gaps identified in the Literature Review regarding the importance of sleep for recovery and performance in athletes, and 2) focused on sleep and performance issues that are considered to be of priority to elite athletic organisations. Specifically, these studies investigated the current factors that affect sleep in elite combat (judo) and contact athletes (rugby union). They focussed on; (i) validity of a currently used wrist-activity monitor (Readiband) that provides automated measures of sleep for use with contact and combat sports such as the rugby union and judo; (ii) the potential effects of the removal of electronic devices on physical and cognitive performance during an elite judo training camp at the AIS for a period of 48-hrs; (iii) the prevalence of sleep disorders and sleep problems in elite Super Rugby players; (iv) sleep behaviours such as sleep obtained before and after a home Super Rugby game; and (v) the effects of ergogenic aids such as caffeine on post-game sleep by determining whether a dose-response relationship exists between caffeine consumption around the time of a Super Rugby game and the subsequent sleep of the athletes.
The studies in this thesis were conducted on three sample groups. The first were Australian Institute of Sport (AIS) combat athletes. The AIS has established a combat centre in Canberra, Australian Capital Territory that is focused on the identification and development of talent in combat sports. Its aim is to improve Australia’s performance at an international level, specifically at the Commonwealth and Olympic Games. The second were contact sport athletes from the Western Force rugby union team based in Perth, Western Australia. During the studies on these athletes, the Western Force competed in the Super Rugby competition. This competition occurs from February to July each year and games are played in South Africa, Australia, Japan, Argentina and New Zealand. The third group of volunteers evaluated were the parents of the participants in the 22-year follow-up of the Western Australian Pregnancy Cohort (Raine) Study.

9.2 Study population-elite combat and contact athletes

Three of the studies were conducted in a ‘field setting’ (Chapters 4, 7 and 8) and two in the laboratory setting (Chapters 3 and 6). The number of participants in these exceeds the sample sizes of many previous studies in this area. From combat sport, there were 23 judo athletes (Chapter 4); from contact sport, there were 37 rugby union players (Chapters 6, 7 and 8); and from the community-based study, there were 50 middle-aged adults (the Raine study parent cohort supported the in-laboratory and at-home validation of the Readiband wrist-activity monitor) (Chapter 3). Thus, a total of 110 participants were included in all studies combined.

All athletes involved in the studies were competing at an elite level. Of the judo athletes (Chapter 4), 67% had competed at an international level for Australia and the remaining 33% at a national level for their respective states in Australia. The rugby
union players described in Chapters 6, 7 and 8 were all participating in the highly respected Super Rugby competition. This is an elite rugby union competition spanning five countries (Australia, New Zealand, South Africa, Japan and Argentina) with 35% of study participants having previously or currently representing Australia, New Zealand, Tonga or the United States in an international rugby union test game.

9.3 Participation rates in these studies

The participation rates, levels of commitment and involvement of the elite athletes in the studies were extremely high. In the study determining the impact of the removal of electronic devices for a period of 48-hrs on judo athletes’ overnight sleep quantity and sleep quality and the effect of any changes in sleep on subsequent physical and cognitive performance (Chapter 4), the 23 elite judo athletes who agreed to participate represented 100% of the potential subjects available.

A professional Super Rugby team consists of a squad of approximately 36-40 players for a game that requires 15 players and eight substitutes, thus 23 players are required for a game. Over an 11-month period, a total of 37 players were available to participate in the studies described in Chapters 6, 7 and 8. Again, 100% of the players available for potential inclusion in these studies volunteered to participate. An overview of the participation numbers and characteristics of the Western Force Super Rugby team members and their allocation to each study is shown in Figure 16, below.
The 100% participation rates in these studies reflect the importance that elite athletes place upon their own sleep, recovery and performance. It was notable that at the conclusion of the studies many athletes asked to keep their personal sleep data. They regularly sought specific advice on personal sleep strategies for training and travel, as well as requesting general discussions around the importance of sleep for their own health and wellbeing.

9.4 Sleep behaviours in elite athletes

A total of 815 nights of sleep-related data were obtained in this thesis. This consisted of: 75 nights of in-laboratory PSG assessment (50 nights in a middle-aged community sample for the validation of a wrist-activity monitor and 25 nights in elite rugby union players to determine the prevalence of sleep disorders and sleep problems); and 740 nights of field-based sleep measures collected using the Readiband wrist-activity monitors. The wrist monitor provided multiple measures of sleep for each day/night during which it was worn. Included in this was sleep latency, time at sleep onset, sleep
duration, wake after sleep onset, time at wake and sleep efficiency. These measurements provided an objective basis on which to characterise the sleep behaviours of each participant in the studies within this thesis.

Age is known to affect sleep behaviour, and it was notable that the judo athletes (Chapter 4) were on average 18 years old and the rugby union players (Chapters 6, 7 and 8) were 25 years old, respectively (Table 12). This is on average a seven-year difference between the two respective study participant groups (combat sport vs contact sports). It may be thought that such an age difference would have resulted in different sleep behaviours, as 18 year olds are thought to predominantly have an “owl” chronotype, characterised by a delayed time of sleep onset and a later time of wake the next day [1], whereas, the 25 year olds are thought to have an average or normal sleep period (i.e. 23:00-07:00) [2]. The studies described in this thesis found the opposite; the judo athletes went to sleep at approximately 22:00 (hh:mm), whilst the rugby union players went to sleep at 23:40 (hh:mm). Such a finding suggests that previous notions of age-related differences in chronotype (i.e. ‘owls’ in younger adults) may not be applicable to elite athletes. However, care needs to be taken with such a conclusion, as the studies were not designed to compare sleep between these groups, and many additional factors, uncontrolled in the current studies, are known to influence an individual’s chronotype including external influences such as light/dark cycles, external time cues, and work or training schedules.

The most likely reason for the differences in sleep between these groups is the imposition of scheduled training start times, being 06:30 (hh:mm) for the judo athletes during a training camp and 08:00 (hh:mm) for the rugby union players. Such speculation is supported by the Readiband showing that a delay in training start time to 10:00 (hh:mm) (as occurred on the morning of day seven during the judo camp)
resulted in increased sleep duration, later time of sleep onset and a later time of wake in the judo athletes. Thus, the imposed training schedules had a significant effect on the times that these young adults went to bed and woke the following morning.

Other measures of sleep were similar between the judo athletes and rugby union players. Sleep latency in both groups tended to be greater than the standard normal ranges of 10-20 mins (as stated by the AASM). The observation that measures of sleep latency were longer than expected for judo athletes, rugby union players and the community based sample (Table 12) was likely to be due, in part, to the fact that the Readiband tends to overestimate sleep latency when compared to PSG (Chapter 3). Indeed, when sleep latencies were assessed via PSG, as was the case for the 25 rugby union players (Chapter 6), the average sleep latency of 13 minutes was within the normal range, as were the majority of individual data points (range 2-24 mins).

The sleep durations found in the present studies was similar between the judo athletes and rugby union players (Table 12), but longer relative to the durations reported in previous studies. For instance, one prior study reported that team sport athletes achieved 6 hrs 50 min per night [3], and two other prior studies indicated that athletes from individual sports achieved 6 hrs 30 min per night [3, 4]. It is possible that the increased sleep duration in more recent studies is a reflection of an increased awareness and focus on the importance of sleep for recovery and performance by athletic organisations. Such increased information can be seen in both the lay public press and in the scientific literature.
Table 12  Comparison of sleep measures from studies

<table>
<thead>
<tr>
<th>Sleep measures</th>
<th>Judo athletes n=23</th>
<th>Rugby union players n=37</th>
<th>Community sample n=50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>18</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Sleep latency (mins)</td>
<td>30</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>Time at sleep onset (hh:mm)</td>
<td>21:57</td>
<td>23:40</td>
<td>22:23</td>
</tr>
<tr>
<td>Sleep duration (mins)</td>
<td>07:09</td>
<td>07:12</td>
<td>07:31</td>
</tr>
<tr>
<td>Wake after sleep onset (mins)</td>
<td>9</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Time at wake (hh:mm)</td>
<td>06:09</td>
<td>07:35</td>
<td>06:50</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>85</td>
<td>80</td>
<td>84</td>
</tr>
<tr>
<td>Sleep athletes feel they need each night (hh:mm)</td>
<td>07:53</td>
<td>07:12</td>
<td>-</td>
</tr>
<tr>
<td>Sleep athletes feel they need get night (hh:mm)</td>
<td>07:21</td>
<td>07:03</td>
<td>-</td>
</tr>
</tbody>
</table>

All measures of sleep were collected using the Readiband (wrist-activity monitor), with additional information collected via a survey instrument (i.e., age, sleep they feel they need and get).

9.5  Measuring sleep in elite athletes

In general, the research conducted on the athletes revealed they were good at identifying the sleep duration that they achieved each night via a self-reported survey instrument which was completed at the commencement of a study. However, (as discussed in Chapters 4 and 8) when athletes completed a daily sleep diary they overestimated their sleep duration by approximately 1-hr each night compared to the objective measures from the Readiband during the week of a game (rugby union players) and during the week of a training camp (judo athletes).

This overestimation of sleep duration using the sleep diary in comparison to the Readiband is an interesting finding within these athletes. Many studies within athletic populations utilise a sleep diary or a self-reported daily sleep measure to examine sleep. These data highlights that such an approach can be problematic and potentially misrepresent the real sleep obtained in athletes.

In the past 15 years, an increase in the validity and use of wrist-activity monitors has allowed the collection of data in field-based settings for shiftworkers, military personnel, and other industrial and/or high-risk occupations. This has led to, and
supported, an increase in the use of this methodological approach in athletic populations, and in elite athletes in particular. Wrist monitors are preferred for sleep evaluations in elite athletes mainly because the devices minimally interfere with training. In fact, the device used in the thesis studies reported here (the Readiband) is presently being used by several teams and organizations including the Chicago Cubs, the Australian Institute of Sport, the Seattle Seahawks and by the Australian Rugby Union team as a result of the research in this thesis. In addition, use of the Readiband device is proving to be popular in elite sports as well as within industrial settings. This is mainly due to its unique robust design; encased in a rubber housing to protect the device and to reduce harm during contact, a quick release strap for the safety of the wearer and the device is water resistant.

In general, for studying sleep duration, wrist monitors are recommended because they provide a superior set of validated sleep measures in comparison to self-reported sleep, and they are far more practical than daily PSG assessments. The Readiband used in this thesis was shown to have good agreement when compared to PSG and the ActiGraph (Chapter 3).

9.6 Sleep disorders and problems in rugby union players

The study described in Chapter 6 revealed a high prevalence of sleep related disorders and problems in elite rugby union players. One in three rugby union players was found to be experiencing a sleep disorder. This compares to one in five Australians in the general population. The most common sleep disorders found among the athletes studied were sleep-related breathing disorders such as OSA and movement disorders during sleep such as PLMs. These findings are novel and potentially important, as there are few studies that have comprehensively assessed sleep disorder in elite
athletes. The negative effects of such disorders on the health of the general population are well known, however little information exists on the effects of such disorders on both physical and cognitive performance in athletic applications.

Validated sleep questionnaires are widely used to assess the probability of an individual having a sleep disorder. While such an approach may be useful in the general population, the study in Chapter 6 found that questionnaires such as the Epworth Sleepiness Scale, the Berlin and the Insomnia Severity Index were not suited to athletes. The reasons for this are multiple, and include a lack of specific questions related to training load, game time and travel (international and national), all of which apply to elite athletes and could affect sleep behaviour and potentially the risk of developing a sleep disorder (such as insomnia). As such, athletic organisations should use these questionnaires with caution. A useful recommendation would be that such questionnaires be only used in conjunction with anthropometric data such as body mass, neck circumference, objective sleep data, athlete performance data, and most importantly in conjunction with an athlete interview designed to gain feedback on each individual’s sleep and any specific problems that they may be experiencing. Such a battery of measurements could be collected when an athlete first joins an organisation, and ideally such assessments should be repeated annually, at a time prior to the start of a competitive season or a period of intense competition.

9.7 Biomathematical modelling for alertness in elite athletes

Biomathematical modelling is widely used in aviation, rail operations, military and the mining industry for the design of shifts and rosters or to assess alertness for on-duty periods. Whilst beneficial in these industrial, transportation and military applications, no known athletic organisation or research study on athletes has used biomathematical
modelling to design training or travel schedules. Biomathematical modelling was used in Chapter 7 to estimate alertness in rugby union players participating in a Super Rugby home game. The analyses revealed that on game night, during game time (19:00-21:00), the average levels of player alertness were high (>90%) and thus at a level which would not be expected to negatively impact reaction time. Such high alertness scores were mainly attributed to adequate sleep having been obtained on the night before the game as well as the fact that the game was played at an optimal time of day (both of these factors are primary input parameters for alertness prediction models). Whilst the use of biomathematical modelling in the present thesis work could be considered a ‘proof of concept’, the results were encouraging since the model was found to be easily used when measures of sleep and training information was readily available for input. As such, biomathematical model may play an important future role in planning optimal sleep, training, and travel schedules for upcoming competitive seasons.

9.8 External influences on sleep - Electronic devices, caffeine and post-game behaviour

Studies on the effects of electronic device usage on sleep in the general population have increased in number over recent years, using both in-laboratory studies and surveys with children or adolescents in home environments [6, 7]. However, little is known about the effects of electronic device usage on sleep in elite or highly trained athletes. In fact, less than five studies on athletes have been published to date.

The data in Chapter 4 relates to the removal of electronic devices (laptops, smartphones, tablets etc.) in nine athletes (device-restricted group) for a period of 48-hrs during an elite judo training camp at the AIS, Australia. Whilst it was hypothesised that the removal of such devices would increase sleep duration, and results in improved next day physical cognitive and physical performance, no significant findings were
noted. Whilst the results of this study were surprising, they were similar to studies on athletes conducted by others in which electronic devices were removed or restricted in a laboratory setting [9] or during training [10] and/or competition [11].

More research is required on the impact of electronic devices among athletes and sleep. However, when taken together, the studies to date suggest that they do not affect sleep and subsequent performance to the same extent as they do in the general population. Future studies could investigate the effects of these devices in more high-stress environments such as during actual or simulated competitions such as Super Rugby, Olympics or the Commonwealth games. During such circumstances media commitments and social media interaction will also increase beyond normal daily usage, thus providing a more realistic environment for measuring the effects of electronic device usage on sleep.

Another important finding from Chapter 8 was that a significant amount of caffeine was consumed prior to a Super Rugby game, mainly in the form of a pre-workout supplementation (Pre-Game 0.40µg/ml vs Post-Game 2.77µg/ml; p<0.001). This increase in caffeine saliva concentration was moderately associated with an increase in sleep latency, a decrease in sleep efficiency, and a trend for a decrease in sleep duration on game night.

Given that caffeine was used so heavily, it was surprising that there was little knowledge amongst rugby union players as to the quantity of caffeine in a recommended dose; that there was an unregulated, self-serving approach to caffeine prior to a game; that there was an absence of a caffeine consumption strategy prior to a game; and that there was a general lack of knowledge amongst the players relating to sources of caffeine. The results and information from the present work have been used by the
Western Force to develop a specific pre-game caffeine consumption strategy that does not exceed 3mg/kg BW of caffeine per person, consumed within 60-mins of the game start time. This strategy was used during Super Rugby games in the 2017 season and was associated with an increase in sleep duration by an average of 35-mins each night, with an earlier time at sleep onset each night by an average of 1-hr.

An alarming finding in the thesis (Chapter 7 and 8) was the post-game sleep behaviour in the rugby union players, in particular the extremely delayed sleep onset immediately following a game and a complete lack of sleep in some players. Although caffeine may be a contributing factor in the delay in time of sleep onset and reduction in sleep duration, it is likely that other factors contributed to these decrements in sleep. In particular, post evening games in rugby union often result in alcohol consumption. Indeed, rugby union players have been reported as having at-risk drinking behaviour after a game [14, 15]. This, coupled with an elevated creatine kinase levels, muscle blood flow and protein synthesis after a contact sport game could negatively affect the recovery of the skeletal muscle system [16]. Large quantities of alcohol consumption may also affect next day hydration levels.

9.9 Limitations/ Challenges

A strength of the studies in this thesis is their ecological validity and the use of objective sleep data in athletes at the elite levels of judo and rugby union. The studies also have several limitations. Firstly, the study population is specific and may not be generalisable to other athletic disciplines. For example, the age of the athletes ranges from 18-25 years and may not represent developing athletes 14-18 years or indeed older athletes >30 years. Additionally, the numbers of female athletes being approximately 20% and from judo the judo study, was low. Secondly, the studies
focussed on contact and combat sports athletes, as such the results might not be applicable to other sports. Thirdly, it is possible that external influences could have affected the measures of sleep collected with these athletes. These include individual variation in sleeping environment, such as sharing of rooms at home or during a training camp, geographical location of a person’s home and an unfamiliar training camp environment. However, controlling such factors is extremely difficult in the applied setting where a balance needs to be achieved between the need to collect such measures in elite athletes but to do so without interfering with their regular training practices or game preparation. The success of such studies requires a respectful, collaborative effort between the researcher, the coaching and athletic staff and the athletes themselves. Indeed, the high participation rates of athletes and successful completion of studies in this thesis reflect the development of strong relationships between the researcher, staff and athletes in each of the studies.

9.10  **Practical recommendations**

A number of practical recommendations arise from the studies in this thesis. Such recommendations may assist coaches, performance staff and researchers to improve sleep, recovery and performance in combat and contact athletes. Four such recommendations are as follows:

1. The selection and deployment of wrist-worn actigraphy to ascertain measures of sleep in athletes is strongly encouraged. As discussed within this thesis and indeed from other research studies, athletes overestimate sleep duration, underestimate time to fall asleep and tend to over report sleep problems such as insomnia and daytime sleepiness. The use of objective data from wrist-worn actigraphy would provide superior measures of sleep. As validated in chapter three, the Readiband device may be more appropriate for use in
combat and contact athletes. This is due to its robust design, encased in rubber to minimise damage due to impact, water resistant and a quick release strap to ensure safety of the wearer. Since the publication of chapter three, this device has been upgraded by the company so that it now has the capability to synchronise to a smartphone in order to provide the wearer with instantaneous measures of sleep and alertness through the biomathematical model of alertness SAFTE (as described in chapter seven).

2. A process whereby athletes are periodically screened for the prevalence of sleep disorders and sleep problems would assist in the improvement of sleep and thereby support subsequent recovery and performance. Such a process should incorporate pre-test probability testing using appropriate questionnaire-based methods such as the ASSQ, skinfold thickness using DXA scan or clipper method, wrist-worn actigraphy measures of sleep and athlete feedback. Such processes would allow performance and medical staff to identify any athlete at risk of a potential sleep related disorder. This could lead to a referral to a sleep physician to undergo the appropriate clinical testing, including PSG studies. Once identified, performance and medical staff can monitor treatment with the identified at-risk athlete. Organisations and teams should consider such an approach when a new athlete joins an organisation or team and each year prior to the commencement of a competitive season and or before competitive events such as the Olympics or the Commonwealth games.

3. A caffeine strategy that factors in the ergogenic requirement and the post-competition sleep and recovery for athletes should be considered by all coaching staff. Based upon known pharmacokinetics of caffeine, athletes
should consume 3mg/kg of BW of caffeine approximately 60-90 minutes prior to a competitive event. Depending on the duration of the event, caffeine may not need to be consumed again as the ergogenic benefit will not be attained until after the competitive event. For example, in a rugby union game lasting 80-mins, consumption of caffeine may negatively affect the onset of sleep by 4-8 hours as observed in chapter 8 of this thesis. It is also recommended that performance staff consult a dietician when developing a caffeine strategy in order to ascertain the sources of caffeine that athletes may consume such as coffee, pre-workout supplementation, caffeine tablets, caffeine gum or energy drinks.

4. When designing training and travel schedules in preparation for a competitive event or for an entire season, the use of biomathematical modelling might represent a useful tool for coaching and performance staff. Biomathematical modelling of alertness, as used in chapter seven provides objective performance decisions related to training and recovery periods. Such an approach may be used to assist with the scheduling of international or interstate travel as certain models can identify periods of low alertness on arrival to a new time zone that may inform performance staff as to the intensity of training and support circadian adaptation.

9.11 Future Studies

The questions asked in this thesis, and the results of the studies have led to many additional questions, all of which could be addressed in future studies. Several important research directions include the following:
• Ascertain individual responses to caffeine to assist in the development of a tailored caffeine response profiles that could be used in a caffeine strategy or to override the negative effects of jet-lag.

• Better understand the prevalence and consequences of sleep disorders in combat and contact athletes using PSG studies and also skinfold thickness with methods such as DXA scans.

• Utilise biomathematical modelling to assess the potential alertness of athletes across a season or competitive period with objective sleep inputs from wrist-worn actigraphy. This could allow for the deployment of specific intervention strategies to improve alertness for specific time periods such as training or competition.

9.12 Summary Statement

The importance of optimising sleep to maximise human performance is becoming more widely accepted by athletes and coaches. The findings from the studies in this thesis could be used by coaches and athletic staff to guide strategies to improve sleep in elite athletes. Specific recommendations from the studies in this thesis include: considering assessing players for the presence of sleep disorders; delaying post-game training sessions to allow for preparation for competition and optimal recovery; and developing a caffeine consumption strategy for game performance to maximise its ergogenic effects but minimise its impact on post-game sleep.
9.13 References


Appendix A   Ethics approval letter
(for Chapter 3)

P-amendment review
Western Australian Pregnancy Cohort (Raine) Study

Project amendment approval response (P-amendment review form): Response from Raine Study to a request to amend an existing approved project.

Please note that commencement of the project is subject to the receipt of a copy of the appropriate Human Research Ethics Committee approval by the Raine Study secretariat.

<table>
<thead>
<tr>
<th>Project title:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessing sleep using actigraphy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P form reference number: To be used in all correspondence regarding this project</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSEL1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead investigator: Name, institution, position,</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Chief Investigator) Peter Eastwood, School of Anatomy, Physiology &amp; Human Biology, UWA</td>
</tr>
<tr>
<td>(Co-investigator) Leon Straker, School of Physiotherapy, Curtin University</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Co-investigator(s): Title, name, position, institution</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Student(s): Name, institution, student status (e.g. Honours, Masters, PhD), supervisor(s), specific role in project</th>
</tr>
</thead>
</table>

Date: 27 July 2015
The above project application was reviewed by the Raine Study Secretariat.
Approval was granted.

Kind regards,

Jenny Mountain
Raine Study Manager
Appendix B  Supplementary tables
(for Chapter 4)

Table S1  (Supp Chapter 4) Training and electronic device use (self-reported)

<table>
<thead>
<tr>
<th>Experimental Phase:</th>
<th>Pre-device-restriction</th>
<th>Device-restriction period -48 hours</th>
<th>Post device-restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 2</td>
<td>Day 3</td>
<td>Day 4</td>
</tr>
<tr>
<td>Treatment Group:</td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>Training time (mins)</td>
<td>186 ±66</td>
<td>286 ±106</td>
<td>248 ±106</td>
</tr>
<tr>
<td></td>
<td>187 ±71</td>
<td>246 ±97</td>
<td>278 ±42</td>
</tr>
<tr>
<td>Rate of Perceived Exertion (1-10)</td>
<td>7 ±1</td>
<td>8 ±1</td>
<td>8 ±1</td>
</tr>
<tr>
<td></td>
<td>8 ±1</td>
<td>8 ±1</td>
<td>8 ±1</td>
</tr>
<tr>
<td>Electronic device duration of use prior to sleep (mins)</td>
<td>39† ±27</td>
<td>0*† ±106</td>
<td>0*† ±106</td>
</tr>
<tr>
<td></td>
<td>60 ±41</td>
<td>49* ±45</td>
<td>76* ±53</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C).

* P<0.05 vs Night 2 (baseline night). † P<0.05 DR group vs. C group within the same night.
### Table S2 (Supp Chapter 4) Sleep diary-data (self-reported)

<table>
<thead>
<tr>
<th>Experimental Phase:</th>
<th>Pre-device restriction</th>
<th>Device restriction period -48 hours</th>
<th>Post device restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day:</td>
<td>Night 1</td>
<td>Night 2</td>
<td>Night 3</td>
</tr>
<tr>
<td>Treatment Group:</td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>Sleep Duration (Mins)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>437 ± 70</td>
<td>465 ± 46</td>
<td>478 ± 32</td>
</tr>
<tr>
<td>Time of Wake (hh mm)</td>
<td>05:47 ± 56</td>
<td>6:13 ± 19</td>
<td>06:04 ± 10</td>
</tr>
<tr>
<td>Sleep Quality (1-5)</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
<td>3 ± 1</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C).

* P=<0.05 on night relative to night 2 (baseline night)

Time of Wake± SD are expressed in minutes
### Table S3  (Supp Chapter 4) Cognitive Performance

<table>
<thead>
<tr>
<th>Experimental Phase:</th>
<th>Pre-device restriction</th>
<th>Device restriction period 48 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day:</td>
<td>Day 2</td>
<td>Day 4</td>
</tr>
<tr>
<td>Treatment Group:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DR</td>
<td>C</td>
</tr>
<tr>
<td>Detection Speed</td>
<td>2.40</td>
<td>2.38</td>
</tr>
<tr>
<td>(secs)</td>
<td>± 0.05</td>
<td>± 0.26</td>
</tr>
<tr>
<td>Detection Accuracy</td>
<td>1.44</td>
<td>1.23</td>
</tr>
<tr>
<td>(count)</td>
<td>± 0.10</td>
<td>± 0.34</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C).

There were no significant differences for any measure.

### Table S4  (Supp Chapter 4) Physical Performance

<table>
<thead>
<tr>
<th>Experimental Phase:</th>
<th>Pre-device restriction</th>
<th>Device restriction period 48 hours</th>
<th>Post device restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day:</td>
<td>Day 2</td>
<td>Day 3</td>
<td>Day 4</td>
</tr>
<tr>
<td>Treatment Group:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DR</td>
<td>C</td>
<td>DR</td>
</tr>
<tr>
<td>Single Leg –Triple Hop Test (metres)</td>
<td>4.8</td>
<td>7.9</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>±3.0</td>
<td>±1.2</td>
<td>±2.7</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD with n=9 for the device-restricted (DR) group and n=9 for control group (C).

There were no significant differences for any measure.
Appendix C  Ethics approval letter
(for Chapter 4)

Our Ref: RA/4/1/7121  15 September 2014

Winthrop Professor Peter Eastwood
School of Anatomy, Physiology and Human Biology
MBDP: M569

Dear Professor Eastwood

HUMAN RESEARCH ETHICS OFFICE – RECOGNITION OF ETHICS APPROVAL FROM ANOTHER HUMAN RESEARCH ETHICS COMMITTEE

Project: Monitoring Athletes’ Sleep Habits, Quality & Quantity via Actical Activity Monitors - Recognition Australian Institute of Sport HREC Approval 20130466

Thank you for your correspondence enclosing the necessary documents to facilitate recognition of the ethics approval for the above project granted by an external Human Research Ethics Committee (HREC) registered with the National Health and Medical Research Council (NHMRC).

It is noted that you have ethics approval from Australian Institute of Sport Ethics Committee, approval number 20130466. The UWA students and researchers identified as working on this project are:

UWA Researchers:

<table>
<thead>
<tr>
<th>Name</th>
<th>Faculty / School</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winthrop Professor Peter Eastwood</td>
<td>School of Anatomy, Physiology and Human Biology</td>
<td>Chief Investigator</td>
</tr>
</tbody>
</table>

Student(s): Ian Duncan

Although The University of Western Australia reserves the right to subject any research involving its staff and students to its own ethics review process, in this case, the Human Research Ethics Office has recognised the existing approval of the external HREC. The project is exempt from ethics review at UWA and the involvement of the above-listed researchers has been authorised. Any conditions for the recognition of the external HREC’s existing approval are listed below.

Special Conditions

1. Approving HREC to receive annual reports, amendments and notification of adverse events

You are reminded that it will be the responsibility of the approving HREC to ensure compliance with all ethics requirements and to monitor and report on the project. However, should any relevant ethics issues arise during the course of the project, you should inform the Human Research Ethics Office of The University of Western Australia.

If you have any queries, please contact the HSO at humanethics@uwa.edu.au.

Please ensure that you quote the file reference – RA/4/1/7121 – and the associated project title in all future correspondence.

Yours sincerely,
Appendix D  Information to participants
(for Chapter 4)

Information To Participants

Title
Monitoring athletes’ sleep habits, quality and quantity via activity monitors.

Researchers
Ian Duniam, Dr. David Martin, Dr. Sharae Hudson and Professor Peter Eastwood.

Background
Sleep is often considered the best recovery tool available to elite athletes. To date, limited literature exists examining sleep habits, quality and quantity in elite athletes. Preliminary results of an AIS questionnaire on the sleep habits of Australian athletes prior to competitions indicate greater than 60% of athletes experience disrupted or fragmented sleep prior to competition. Furthermore, greater than 80% find it difficult to fall asleep and approximately 50% indicate increased daytime sleepiness and not feeling refreshed the following day. This data complements previous AIS research that concluded athletes averaged 6.72 hours of sleep per night, which is less than recommended. Sleep deprivation is recognised to have a negative influence on cognitive performance, decision-making skills, mood, motivation, immune and hormonal function and exercise performance.

Significance
For the reasons above, athletes’ sleep habits are monitored as part of routine servicing and they are provided with individualised advice to improve sleep. However, due to the limited literature on athletes’ sleep, normative values are difficult to obtain. This study will provide a greater understanding of athletes’ sleep habits and performance.

Aim
To assess the relationship between sleep and electronic devices use in Australian Judo athletes and the effect on subsequent day athletic performance.

Participation
This study has no exclusion criteria. You will be fully informed of your involvement in this study and have the opportunity to clarify any matters that are unclear. You will then be asked to sign an “Informed Consent Form”.

Protocol
Your sleep/wake patterns will be monitored for 1 to 6 days using the Releasable actigraphy monitors and by completing a sleep diary. After use, the data will be downloaded and analysed using sleep software in conjunction with the sleep diary to produce a individual sleep report containing the following information: bed time, wake-up time, time to fall asleep (sleep latency), sleep per night, sleep efficiency, subjective sleep quality, and naps. Physical performance measures will be collected during the warm up phase of randomised and on three cognitive reaction test will be conducted on three separate days. You will subsequently be provided with a sleep report and individual feedback on how to improve your sleep. The data will also be grouped to obtain normative sleep data for different athlete groups.

Right of Withdrawal
You should understand that your participation in this study is completely voluntary. You may choose to withdraw from the study at any time for any reason, without prejudice. If you choose to do so, there will be no compromise in the relationship between you and the investigators. By signing the informed consent you are indicating that the texts and procedures of this study have been explained to you and understood by you.

Confidentiality
Your involvement in this study will be confidential, only the researchers and where appropriate your coach and referring Sport Science, Sports Medicine staff will have access to your results, except as required by law. A report of the study may be submitted for publication, but individual participants will not be identifiable.

Enquiries
Any inquiries regarding this study are encouraged. Please contact the investigator if you have any questions.
Ian Duniam
Dr. David Martin

The Australian Institute of Sport ethics committee has approved this study. If you have any concerns with respect to the conduct of this study, you may contact the AIS Ethics Committee on (Helena Rushby) 02 6214 1577.
Appendix E  Informed consent form – minor
(for Chapter 4)

‘INFORMED CONSENT’ FORM (Minor)

Project Title: Monitoring athletes’ sleep habits, quality and quantity via activity monitors

Principal Researchers: Ian Duncan and David Martin

This is to certify that I, hereby agree to give permission to have my child participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of .

The investigation and my child’s part in the investigation have been defined and fully explained to me by and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions my child or myself may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that my child is free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that my child is free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage.
- I understand that my child is free to withdraw his/her data from analysis without disadvantage.
- I understand that any data or answers to questions will remain confidential with regard to my child’s identity.
- I certify to the best of my knowledge and belief, my child has no physical or mental illness or weakness that would increase the risk to me (him/her) of participating in this investigation.
- My child is participating in this project of my (his/her) own free will and My child has not been coerced in any way to participate.

Privacy Statement: The information submitted will be managed in accordance with the ASC Privacy Policy.

☐ I consent to the ASC keeping my personal information.

Signature of Participant: ___________________________ Date: __/__/__

Signature of Parent or Guardian of minor: (under 18 years) ___________________________ Date: __/__/__

I, the undersigned, was present when the study was explained to the subject’s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ___________________________ Date: __/__/__
Appendix F  Sleep and Training Diary
(used in Chapters 4,6,7 and 8)

Sleep and Training Diary

Name

Readiband number:

Date commenced Day ___ Month ___ Year ___

Email

Contact Number

Contacts:
Ian Dunican
University of Western Australia
Ph.: [removed]
Email: [removed]
Keeping a Sleep Diary

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

Instructions
1. Complete a single line of the diary for every sleep period or training session. Use extra lines for naps and additional training sessions if needed.
2. Date – the date that you go to bed.
3. Training/Game start time – Record the time you started training/game.
4. Training/Game duration - Record the length of time you trained for.
5. Training/Game RPE – Your overall rating of perceived exertion for the session, see the attached scale.
6. Time of Last Caffeine Intake - Record the time of your last caffeine intake (coffee, red bull, coke, etc)
7. Pre-Sleep Arousal Level – Record your arousal level prior to sleep.
8. Bed Time – the time that you start attempting to sleep. Don’t include time spent reading, watching TV.
9. Get Up Time – the time that you stop attempting to sleep. Don’t include time spent reading, watching TV, etc.
10. Sleep Quality – the quality of your sleep compared to a ‘normal’ sleep period.
11. Please complete the diary straight after every sleep period to aid accuracy. This will have a big influence on the quality of the data that we collect.

Rated Perceived Exertion (RPE) Scale

The RPE scale is used to measure the intensity of your exercise. The RPE scale runs from 0 – 10. The numbers below relate to phrases used to rate how easy or difficult you find an activity. For example, 0 (nothing at all) would be how you feel when sitting in a chair; 10 (very, very heavy) is how you feel at the end of an exercise stress test or after a very difficult activity.

0 – Nothing at all
0.5 – Just noticeable
1 – Very light
2 – Light
3 – Moderate
4 – Somewhat heavy
5 – Heavy
6
7 – Very heavy
8
9
10 – Very, very heavy
What will your data look like?

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

- The figure represents 7 days of data.
- Each line represents a day of data, from midnight to midnight.
- The blue represent sleep times we will get from the Readiband.
- The black vertical bars represent the level of activity we will get from your Readiband.
- At the end of this, you will get a report about your sleep/wake patterns that will include a figure like the one above.
<table>
<thead>
<tr>
<th>Date</th>
<th>Training/ Game Duration min</th>
<th>Caffeine Intake Amount &amp; Time</th>
<th>Did you watch or use any of the following devices within 2 hrs prior to sleep? Please circle/highlight</th>
<th>Duration of total use hh:mm</th>
<th>Main activity of use Please circle/highlight</th>
<th>Bed Time hh:mm</th>
<th>Get-up Time hh:mm</th>
<th>Sleep Quality Please circle/highlight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
<td>Game console</td>
<td>E reader</td>
</tr>
</tbody>
</table>

222
<table>
<thead>
<tr>
<th>Date</th>
<th>Training/ Game Duration min</th>
<th>Training/ Game RPE 1-10</th>
<th>Caffeine Intake Amount &amp; Time</th>
<th>Did you watch or use any of the following devices within 2 hrs prior to sleep? Please circle/highlight</th>
<th>Duration of total use hh:mm</th>
<th>Main activity of use Please circle/highlight</th>
<th>Bed Time hh:mm</th>
<th>Get-up Time hh:mm</th>
<th>Sleep Quality Please circle/highlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone Computer</td>
<td>Game console</td>
<td>E-reader</td>
<td>TV shows</td>
<td>Emails</td>
<td>Gaming</td>
<td>Facebook</td>
<td>Text/Instant messaging</td>
</tr>
<tr>
<td>Date</td>
<td>Training/ Game</td>
<td>Duration min</td>
<td>Training/ Game RPE</td>
<td>Caffeine Intake</td>
<td>Amount &amp; Time</td>
<td>Did you watch or use any of the following devices within 2 hrs prior to sleep? <em>Please circle/highlight</em></td>
<td>Duration of total use hh:mm</td>
<td>Main activity of use <em>Please circle/highlight</em></td>
<td>Bed Time hh:mm</td>
</tr>
<tr>
<td>------</td>
<td>----------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>----------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TV</td>
<td>Tablet</td>
<td>Smartphone</td>
<td>Computer</td>
</tr>
</tbody>
</table>

224
Appendix G  Ethics approval letter
(for Chapters 6,7 and 8)

Our Ref: RA/4/17235

09 December 2014

Winthrop Professor Peter Eastwood
School of Anatomy, Physiology and Human Biology
MBDP M309

Dear Professor Eastwood

HUMAN RESEARCH ETHICS APPROVAL - THE UNIVERSITY OF WESTERN AUSTRALIA
Assessing an Elite Rugby Team for Sleep Disorders & the Effect of Caffeine on Game Performance and Subsequent Day Sleep & Recovery

Student(s): Ian Dunican - Phd - 21546342

Ethics approval for the above project has been granted in accordance with the requirements of the National Statements on Ethical Conduct in Human Research (National Statement) and the policies and procedures of The University of Western Australia. Please note that the period of ethics approval for this project is five (5) years from the date of this notification. However, ethics approval is conditional upon the submission of satisfactory progress reports by the designated renewal date. Therefore initial approval has been granted from 09 December 2014 to 01 December 2015.

You are reminded of the following requirements:

1. The application and all supporting documentation form the basis of the ethics approval and you must not depart from the research protocol that has been approved.
2. The Human Ethics office must be approached for approval in advance for any requested amendments to the approved research protocol.
3. The Chief Investigator is required to report immediately to the Human Ethics office any adverse or unexpected event or any other event that may impact on the ethics approval for the project.
4. The Chief Investigator must submit a final report upon project completion, even if a research project is discontinued before the anticipated date of completion.

Any conditions of ethics approval that have been imposed are listed below:

Special Conditions
None specified

The University of Western Australia is bound by the National Statement to monitor the progress of all approved projects until completion to ensure continued compliance with ethical principles.

The Human Ethics office will forward a request for a Progress Report approximately 30 days before the due date.

If you have any queries please contact the Human Ethics office at humanethics@uwa.edu.au.

Please ensure that you quote the file reference – RA/4/17235 – and the associated project title in all future correspondence.

Yours sincerely,
Appendix H  Information to participants  
(for Chapters 6, 7 and 8)

PARTICIPANT CONSENT FORM

Information To Participants

Title: Assessing an elite rugby team for sleep disorders and the effect of caffeine on game performance and subsequent day sleep and recovery

Researchers: W/W/Prof Peter Eastwood, Ian Duncan, Charlie Higgins and David Joyce

Background
Sleep is often considered the best recovery tool available to elite athletes. To date, limited literature exists examining sleep habits, quality and quantity in elite athletes. Acute sleep deprivation related to caffeine consumption is recognised to have a negative influence on cognitive performance, decision-making skills, mood, motivation, immune and hormonal function and exercise performance.

Aim
This research project will assess 23-35 elite rugby players for sleep disorders. This will be achieved using overnight Polysomnography (PSG) or sleep screening at the Centre for Sleep Science at UWA. A sleep watch (actigraphy) will also be used during the overnight screening and during the week prior, during and post an elite rugby game in Perth, WA. The objective of the research project is to assess elite rugby players for sleep disorders and to quantify the effect of caffeine consumption on game performance and post game recovery sleep.

Participation
This study has no exclusion criteria. You will be fully informed of your involvement in this study and have the opportunity to clarify any matters that are unclear. You will then be asked to sign a Participant Consent Form.

Protocol
You will undergo one night of sleep screening/PSG at the Centre for Sleep Science at UWA. The PSG will be recorded according to the laboratory procedures in accordance with the ASA and AASM. The PSG will provide measures relating to Total Sleep Time (TST), Sleep latency, time in different sleep stages, sleep efficiency and potential sleep disorders.

The overnight PSG consists of the application of EEG, EOG, EMG this is used to determine sleep staging, ECG, thermocouple, SaO2, oxygen and abdominal and thorax band to measure respiratory effort. Leg EMG to measure leg movement. In addition microphones and a video camera will be present in the room to support the data collected and allow the sleep scientist score and analyse the data effectively.

Please note NS refers to the NEHRM "National Statement" for the ethical conduct of research. For further information please go to http://www.nhmrc.gov.au and follow the links.
During the early phase of the Super 15 Rugby Season you will be administered a sleep watch (actigraphy) to measure your sleep and wake patterns prior to a weekend game. You will also be asked to record your sleep patterns with a sleep diary during this period. Your sleep/wake patterns will be monitored for 1 to 6 days using the Reebok actigraphy monitors and by completing a sleep diary. After use, the data will be downloaded and analysed using sleep software in conjunction with the sleep diary to produce a individual sleep report containing the following information: bed time, wake-up time, time to fall asleep (sleep latency), sleep per night, time spent awake per night, sleep efficiency, subjective sleep quality, and naps. You will subsequently be provided with a sleep report and individual feedback on how to improve your sleep. The data will also be grouped to obtain normative sleep data for the Western Force team.

Prior to and post the game saliva samples will be collected to measure the player’s caffeine levels. The saliva samples will be collected from each participant within a 24 hrs period prior to the game to assess pre game caffeine levels. In the recovery phase or the 24 hrs post game saliva samples will also be collected to assess post game caffeine levels. The Saliva samples (2-3 ml) will be collected by asking participants to spit into a plain tube (5 ml) over a period of approximately 2-3 min. Saliva samples will be collected from participants without any form of salivary stimulation. This information will be utilised to determine the prevalence of sleep disorders in an elite rugby team and to quantify the effects of caffeine on post game sleep and recovery.

**Right of Withdrawal**

You should understand that your participation in this study is completely voluntary. You may choose to withdraw from the study at any time for any reason, without prejudice. If you choose to withdraw, there will be no compromise in the relationship between you and the investigators. By signing the informed consent you are indicating that the tests and procedures of this study have been explained to you and understood by you.

**Confidentiality**

Your involvement in this study will be confidential, only the researchers and where appropriate your coach and referring Sport Science, Sports Medicine staff will have access to your results, except as required by law. A report of the study may be submitted for publication, but individual participants will not be identifiable.

---

Please note: NS refers to the NHMRC “National Statement” for the ethical conduct of research. For further information, please go to [http://www.nhmrc.gov.au](http://www.nhmrc.gov.au) and follow the links.
Enquiries
Any inquiries regarding this study are encouraged. Please contact the investigator if you have any questions.

Ian Darican W/Prof Peter Eastwood

***************************************************************************
Please Note***************************************************************************
Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to humanethics@uwa.edu.au

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

Please note NR refers to the NHMRC ‘National Statement’ for the ethical conduct of research. For further information please go to http://www.nhmrc.gov.au and follow the links.
Appendix I  Informed consent form – adult  
(for Chapters 6, 7 and 8)

PARTICIPANT CONSENT FORM (Adult)

Project Title: Assessing an elite rugby team for sleep disorders and the effect of caffeine on game performance and subsequent day sleep and recovery.

Principal Researchers: W/Prof Peter Eastwood and Ian Duncan

This is to certify that I, ___________________________ hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the University of Western Australia under the supervision of Ian Duncan.

The investigation and my part in the investigation have been defined and fully explained to me by Ian Duncan and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.
- I understand that I am free to withdraw my data from analysis without disadvantage to myself.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participating in this investigation.
- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ___________________________ Date: ___/___/___

I the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ___________________________ Date: ___/___/___

Please note, W/Prof refers to the NH&MRC ‘N filament Statement’ for the ethical conduct of research. For further information, please go to http://www nhmrc.gov.au and follow the links.
Please Note

Approval to conduct this research has been provided by the University of Western Australia, in accordance with its ethics review and approval procedures. Any person considering participation in this research project, or agreeing to participate, may raise any questions or issues with the researchers at any time. In addition, any person not satisfied with the response of researchers may raise ethics issues or concerns, and may make any complaints about this research project by contacting the Human Ethics Office at the University of Western Australia on (08) 6488 3703 or by emailing to humanethics@uwa.edu.au.

All research participants are entitled to retain a copy of any Participant Information Form and/or Participant Consent Form relating to this research project.

Please note N.S refers to the NHMRC ‘National Statement’ for the ethical conduct of research. For further information, please go to http://www.nhmrc.gov.au and follow the links.
Appendix J  Supplementary figures (for Chapter 8)

Figure S1  (Supp Chapter 8) – Individual sleep related data
Figure S2 (Supp Chapter 8) – Proposed pharmacokinetics of caffeine

Objective known measures as collected by caffeine saliva concentrates' during this study (2 data points).
Inferred measures based upon known pharmacokinetics of caffeine (6 data points).