Pilot interventions to improve the sleep/wake habits of elite adolescent athletes

A thesis presented in fulfilment of the requirements

for the degree of

Doctor of Philosophy

in

Public Health

at Massey University, Wellington,

New Zealand

Travis Steenekamp

2022

ABSTRACT

Both adolescent and athlete populations have been identified as at-risk groups when it comes to sleep timing, duration and quality. The aetiology of sleep issues within these populations is disparate, leading to the question of whether adolescent athletes are at particular risk considering that they span both groups. Few studies, however, have investigated the sleep patterns and behaviours of elite adolescent athletes during their everyday lives. Fewer still have attempted to intervene to improve sleep/wake patterns and behaviour where sleep concerns have been identified within adolescent athlete cohorts.

This thesis comprised two studies, the first with a group of elite adolescent swimmers and the second with rowers. Swimmers and rowers were chosen as both sporting codes have traditionally high early morning training demands. Early morning training has been identified as a predominant driver of sleep loss for athlete groups making these cohorts of particular interest. Both studies included baseline monitoring for two weeks to identify the athletes' typical sleep patterns during a normal training phase that took place during the school term. Following baseline, both athlete groups received educational training on sleep with specific sleep advice being tailored to each group using data gathered during baseline. In addition to the sleep educational material, the swimmers also had one of their early morning training sessions moved to another day of the week to try and provide them with consecutive days free of early morning training while the rowers received blue light-blocking glasses to try to limit night-time exposure to blue light.

Baseline data from both groups revealed that sleep timing as well as sleep duration varied significantly across the days of the week. Sleep duration was significantly truncated on school nights before early morning training (6.7 hours) compared to school nights before mornings without training (8.8 hours). The curtailed sleep was linked to significantly earlier wake-up times while bedtimes remained constant. Classic patterns of social jetlag were evident over the weekend.

The introduction of educational material in addition to training rescheduling did not result in a significant change to swimmers' sleep duration or sleep quality. Swimming performance also remained unchanged throughout the 6 week's intervention. A positive sleep behavioural change was noted with device use before bedtime with the swimmers reducing their screen time by 24% over the intervention period.

Similarly, the educational material coupled with blue light-blocking glasses did not significantly change actigraphic measures of sleep timing or duration. A reduction was found, however, concerning self-reported measures of fatigue and muscle soreness when comparing intervention to baseline ratings. Unlike the swimmers, the rowers did not significantly reduce their device use before bedtime.

The findings of the studies in this thesis elucidate the challenge that early morning training poses for the sleep of adolescent athletes. The adverse consequences of inadequate and disrupted sleep patterns during adolescence are well documented and confirm that significant attention should be paid to optimising the scheduling of training for adolescent athletes. The high prevalence of early morning training sessions is the result of tradition and overloaded adolescent schedules. Creative and careful solutions that involve all stakeholders need to be found to reduce the need for early morning training sessions.

ACKNOWLEDGEMENTS

My PhD journey started half a world away in Grahamstown, South Africa. My undergraduate and postgraduate studies within the Human Kinetics and Ergonomics Department of Rhodes University set me up for a lifelong love of academia. Jono, Candice, Andrew and the rest of the amazing HKE department, I cannot thank you enough for preparing me for this journey. Your mentorship put me on the path I now walk and without you in my life, I truly don't know what I would be doing right now, but it wouldn't have been this.

Leaving South Africa and moving to New Zealand was daunting for me, but perhaps even more so, for my mother Sandy. Mom, you have never stopped being my biggest supporter and fan. I cannot begin to know what it was like letting me fly off to chase my dreams, but your ongoing sacrifices for my achievements are impossible to thank enough. I love you so much and could never have made it to this point in my career without you always guiding and supporting me.

When I arrived in New Zealand, a country I had never been to, my new family became the Sleep/Wake Research Centre. To everyone at SWRC, thank you from the bottom of my heart for every bit of help and support you have offered. You were my home from home and my family abroad. Every one of you contributed to helping me cross the line with my thesis and for that, I am eternally grateful.

Jenn, you were amazing to work with. You sacrificed so much time to teach and mentor me in everything from circadian physiology to statistics to the world of rowing. Thank you for everything you have done to help and I wish you all the best with your academic future.

David, your sports science and statistical knowledge were invaluable. Your strict eye for robust and rigorous scientific work always elevated my work and will for years to come.

Philippa, you are a rockstar who I still can't believe I was privileged enough to work with. Your mentorship has meant the world to me, but your friendship is the real prize I cherish at the end of this process. You have taught me so much about bringing science into the working world. The way you push boundaries break new scientific ground while ever placing the human at the centre of your work is something I will be trying to emulate for the rest of my life.

Leigh, I don't know where to begin. You have been with me from day one of this journey, sharing in every triumph and lifting me through every fall. Your supervision went above and beyond the call of duty from day one. Thank you so much for welcoming me into your world so fully. Thank you for every ounce of effort you poured into my work and development. I don't know many supervisors who would have driven me to a swimming pool at 5 am for data collection but you did it gracefully and with a smile. I am ever in your debt.

I would like to extend a very warm thank you to all who participated in this research. It was an honour and privilege to be welcomed into your world for a brief time. To all of the coaches, athletes and parents, thank you very much for your valuable contributions to my work.

Finally, Courtney, wifey. I would never have gotten my thesis finished if not for your unwavering love and support. I came to New Zealand to get a PhD and found you along the way and now I have the honour and privilege of calling you, my wife. I love you so very much and I could never thank you enough for the sacrifices you have made to make this possible for me.

TABLE OF CONTENTS

Abstract i

Acknowledgements iii

List of Figures ix

List of Tables xii

CHAPTER 1 Introduction and background 1

1.1 Definitions of adolescence and sleep.. 1

1.1.1 Adolescence, puberty, and Tanner Stages... 1

1.1.2 Sleep 2

1.2 Sleep-wake regulation 5

1.2.1 Circadian timing system 6

1.2.2 Homeostatic sleep process 7

1.3 Interaction between the circadian biological clock and the homeostatic sleep process.. 8

1.4 Sleep need across the lifespan.. 11

1.4.1 Sleep need in adolescence 13

1.5 Sleep in athlete populations.. 15

1.5.1 Sleep loss prior to training.. 16

1.5.2 Sleep loss prior to competition 21

1.5.3 Relationship between sleep and performance.. 23

1.6 Sleep interventions for adolescent athletes.. 25

1.6.1 Sleep extension 25

1.6.2 Healthy sleep behaviours... 26

1.6.3 Assisted sleep and post-exercise recovery strategies for sleep................. 28

1.7 Measuring Sleep in Athlete Populations 29

1.7.1 Polysomnography 29

1.7.2 Actigraphy.. 30

1.7.3 Self-report tools.. 31

1.8 State of the current literature 33

1.8.1 Research aims 33

CHAPTER 2 Methodology..35
2.1 Swimmers Intervention Study 35
2.1.1 Swim clubs and co-design of potential interventions.................................35
2.1.2 Ethics and recruitment..36
2.1.3 Participants – Swimmers..37
2.1.4 Study design and methods..37
2.1.5 Intervention 38
2.1.6 Dependent measures..41
2.1.7 Statistical analyses..45
2.2 Rowers Intervention Study..47
2.2.1 Rowing teams 47
2.2.2 Ethics and recruitment..48
2.2.3 Participants – Rowers 49
2.2.4 Study design 49
2.2.5 Intervention 50
2.2.6 Dependent measures..51
2.2.7 Statistical analyses..52

CHAPTER 3 SLEEP/WAKE BEHAVIOUR OF COMPETITIVE ADOLESCENT ATHLETES IN NEW ZEALAND: INSIGHT INTO THE IMPACT OF EARLY MORNING TRAINING 54
3.1 Abstract 54
3.2 Introduction..55
3.3 Materials and Methods..57
3.3.1 Participants 57
3.3.2 Design..58
3.4 Results 61
3.4.1 Demographics..61
3.4.2 Type of night differences..64
3.4.3 Sporting code differences..66
3.4.4 Weekend training 66
3.5 Discussion 69
3.6 Conclusions..74

CHAPTER 4 EFFECTS OF SLEEP EDUCATION AND TRAINING RESCHEDULING ON THE SLEEP/WAKE BEHAVIOUR AND PERFORMANCE OF ELITE ADOLESCENT SWIMMERS. A PILOT INTERVENTION. 75

4.1 Abstract 75
4.2 Introduction 76
4.3 Method 79
4.3.1 Participants 79
4.3.2 Procedure 80
4.3.3 Classification of study periods 81
4.3.4 Measures 82
4.3.5 Statistical analysis 84
4.4 Results 85
4.5 Discussion 92
4.6 Conclusion 97

CHAPTER 5 EFFECTS OF SLEEP EDUCATION AND BLUE LIGHT BLOCKING GLASSES ON THE SLEEP/WAKE BEHAVIOUR OF ELITE ADOLESCENT ROWERS: A PILOT INTERVENTION 98

5.1 Abstract 98
5.2 Introduction 99
5.3 Method 102
5.3.1 Participants 102
5.3.2 Procedure 102
5.3.3 Measures 103
5.3.4 Statistical analysis 104
5.4 Results 105
5.5 Discussion 111
5.6 Conclusion 115

CHAPTER 6 DISCUSSION 117

6.1 Key findings 119
6.1.1 Baseline sleep 119
6.1.2 Swimmers’ intervention 123
6.1.3 Rower’s intervention 124
6.2 Limitations 125

6.3 Implications of findings 127
6.3.1 A message for sporting organisations and coaches 127
6.3.2 A message for parents 128
6.3.3 A message for health practitioners 128
6.4 Recommendations for future research 129
6.5 Conclusion 131

Reference list 132

Appendices 153

LIST OF FIGURES

Figure 1.1 The theoretical progression of sleep stages across a single night for a healthy young adult. **4**

Figure 1.2. Changes in sleep variables with age. The X-axis represents time in minutes for sleep latency, wake after sleep onset, rapid eye movement sleep, slow-wave sleep, and stages 1 and 2 of sleep for ages 5 to 85. Image taken from Ohayon et al. (2004). WASO – total time awake after initial sleep onset **5**

Figure 1.3. Representation of a typical sleep period in relation to the circadian rhythm of core body temperature, plasma melatonin, wake propensity, and responsiveness to light. Taken from Dijk & Lockley (2002). **7**

Figure 1.4. Schematic representation of the Two Process Model of Sleep Regulation (A) and the changes that occur during adolescence (B). The blue curve in both graphs illustrates Process S (homeostatic sleep process) and the red curve indicates Process C (circadian timing system). The blue arrows in A indicate the time of melatonin onset which is typically 1 to 2 hours prior to bedtime. Graph B contrasts the Sleep Regulation of a mature adult to that of an adolescent which is represented by the corresponding dotted lines. A slower build-up of sleep pressure across the day in conjunction with a phase shift in the circadian timing system results in a propensity for later sleep timing. Figure adapted from Crowley, Tarokh & Carskadon, 2012 **10**

Figure 1.5. Sleep duration recommendations across the lifespan as set by the National Sleep Foundation (Hirshkowitz *et al.,* 2015). **12**

Figure 1.6. Mean sleep duration per night is shown for ages 13 to 32. The image is taken from Maslowsky & Ozer (2013). **14**

Figure 2.1. Graphical representation of the timeline of events for the intervention study. Note that this image was produced by the author of this thesis. **38**

Figure 2.2. Training schedule before and after intervention. Session circled with the arrow indicates the training which was rescheduled. This image has been produced by the author of this thesis **40**

Figure 2.3. Photo of the watch face of the Micro MotionLogger. ... **41**

Figure 2.4. Graphical representation of the timeline of events for monitoring the rowers. ... **50**

Figure 2.5. Spectral transmittance graph of the Somnitude lenses used in the BlueBlockGlasses (https://blueblockglasses.com). ... **51**

Figure 3.1. Least Squared Means for Sleep Duration (A), Sleep Onset (B); Midsleep (C) and Sleep Offset (D) for different night conditions for all athletes. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large ... **64**

Figure 3.2. Least Squared Means for Sleep Duration (A) and Sleep Offset (B) comparisons for rowers and swimmers. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. ... **66**

Figure 3.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different night conditions for rowers. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions with weekend training only are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. ... **67**

Figure 4.1. Timeline of events during the 8-week study period. ... **81**

Figure 4.2. Depiction of training schedule changes during baseline and intervention phases of the study. Sleep timing derived from actigraphy and sleep diary data. ... **82**

Figure 4.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for study phases. Error bars denote standard deviation. Significant effects are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. ... **87**

Figure 4.4. Percentage of nights where device use was reported across the study phases (LS means). Error bars denote standard deviation. Significant effects are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. **88**

Figure 4.5. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different night conditions for swimmers under and over 15. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. **90**

Figure 4.6. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different recovery nights during baseline and intervention phases. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions with weekend training only are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. **92**

Figure 5.1. Depiction of the timeline for the 6-week study. **103**

Figure 5.2. Comparison of self-reported measure of Fatigue (A) and Muscle Soreness (B) during Baseline and the Intervention. Error bars denote standard deviation. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. **108**

Figure 5.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) comparing sleep timing on nights when glasses were worn and not worn . Error bars denote standard deviation. Dashed lines denote recommended sleep duration. **109**

Figure 6.1. Graphic representation of the sleep timing of basketball players monitored over a typical training week by Estivill-Domènech et al. (2018). **120**

Figure 6.2. Graphic representation of the sleep timing of swimmers monitored over typical training week by Steenekamp et al. (2020). **120**

LIST OF TABLES

Table 3.1. Median and range values for sleep variables for different nights of the week for all athletes and swimmers and rowers separately. **63**

Table 3.2. Post hoc results comparing actigraphy variables between night conditions for all athletes. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. **65**

Table 3.3. Post hoc results comparing actigraphy variables between night conditions and weekend training for rowers. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large. **68**

Table 4.1. Sleep variables for different nights of the week for all study phases..... **86**

Table 4.2. Post hoc results comparing actigraphy variables between night conditions... **89**

Table 5.1 Comparison of median (range) values for sleep variables for different nights of the week pre and post-intervention. **107**

Table 5.2. Post hoc results comparing actigraphy variables between night conditions.. **110**

CHAPTER 1 INTRODUCTION AND BACKGROUND

This chapter introduces the context and issues that motivated my thesis research on sleep/wake interventions for adolescent athlete populations. The fundamentals of sleep and sleep/wake regulation are outlined with emphasis on the changes that these processes undergo during adolescence. Current research on sleep needs and sleep loss for adolescents is reviewed, together with an analysis of sleep/wake behaviours among athlete populations and adolescent athletes. Methods of collecting sleep data are considered, followed by potential and previous sleep interventions which have been proposed for adolescents and athletes.

1.1 Definitions of adolescence and sleep

1.1.1 Adolescence, puberty, and Tanner Stages

Traditionally, adolescence is defined as the period between childhood and adulthood during which social cognitive and physiological behaviours undergo maturation (Sisk and Foster, 2004). Puberty, a term often used alongside and sometimes interchangeably with adolescence, is defined as the physiological activation of the hypothalamic-pituitary-gonadal axis as well as gonadal maturation (Darchia & Cervena, 2014). For simplicity's sake, this thesis uses the term adolescence to include the physiological, cognitive, and social changes which occur during the transition from childhood to adulthood. Puberty, however, will only be used when referring specifically to physiological maturation.

When discussing puberty, it is important to note that the onset and speed of physical maturation can vary significantly based on factors such as sex, ethnicity, race and environment (Emmanuel & Bokor, 2021). For this reason, chronological age is not always the best measure of pubertal development (Emmanuel & Bokor, 2021). Instead, a common method used in paediatric and adolescent practice is to refer to Tanner Stages for pubertal development (Emmanuel & Bokor, 2021). Tanner staging, however, requires invasive screening by medical professionals, which was not practicable in the present research. The thesis, therefore, uses chronological age as a proxy for pubertal development, while acknowledging Tanner staging to be a more objective measure.

1.1.2 Sleep

From a behavioural standpoint, sleep is defined as a reversible state whereby the person is unresponsive and disengaged from the environment (Carskadon & Dement, 2017). Physiologically, however, sleep is an essential series of states that aids in the recovery from the previous period of wakefulness whilst at the same time preparing the body for the upcoming time spent awake (Halson, 2014).

1.1.2.1 Not all sleep is the same – Sleep stages in healthy young adults

Sleep is not a continuous state, but a repeating cycle through a series of states which are broadly categorised as non-rapid eye movement (NREM) and rapid eye movement (REM) sleep (Carskadon & Dement, 2017). NREM is broken down further into 3 distinct stages which are commonly labelled Stages N1, N2 and N3 (Malhotra & Avidan, 2013). The progression through these stages loosely represents a depth-of-sleep continuum as Stage N1 has the lowest arousal threshold while Stage N3 has the highest (Carskadon & Dement, 2017). Sleep stages are typically measured using polysomnography (PSG) which involves multiple physiological measures including the electroencephalogram (EEG). Changes in electrical potentials indicating brain wave activity are measured via electrodes placed on the surface of the head (Malhotra & Avidan, 2013). During wakefulness, EEG measures show a predominance (>50%) of alpha brain wave activity (Malhotra & Avidan, 2013). Stage N1 is characterised by alpha waves dipping below

50% with an increase in theta activity (Malhotra & Avidan, 2013). Along with brain wave changes, drowsiness accompanies this stage, which generally only constitutes around 2% to 5% of a total night's sleep for healthy adults (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017). Stage N2 generally constitutes 45% to 55% of a night-time sleep period and is defined as light sleep in which brain waves become slower while eye movement stops (Carskadon & Dement, 2017). Brain waves are predominately theta activity during N2 with occasional bursts of faster activity, known as spindles (Malhotra & Avidan, 2013). Stage N3 sleep, which is often termed slow-wave sleep, is considered to be the deepest stage of sleep (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017). The transition between N2 and N3 is said to occur when 20% of a sleep epoch measured (typically 30 seconds) consists of delta activity (Malhotra & Avidan, 2013). Stage N3 makes up between 13% to 23% of a total sleep period and is associated with a peak in growth hormone secretion along with cessation of eye movement (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017).

REM sleep involves four to six discrete episodes when the brain becomes highly active and is characterised by a mix of alpha and theta brain waves (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017). This is also the stage in which vivid dreaming is commonly reported along with the presence of muscle atonia (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017). On an average night's sleep for a person not suffering from a sleep disorder, REM makes up 20% to 25% of sleep (Malhotra & Avidan, 2013; and Carskadon & Dement, 2017). Figure 1.1 depicts an example of the progression through the stages of sleep for a healthy young adult across a night-time sleep period.

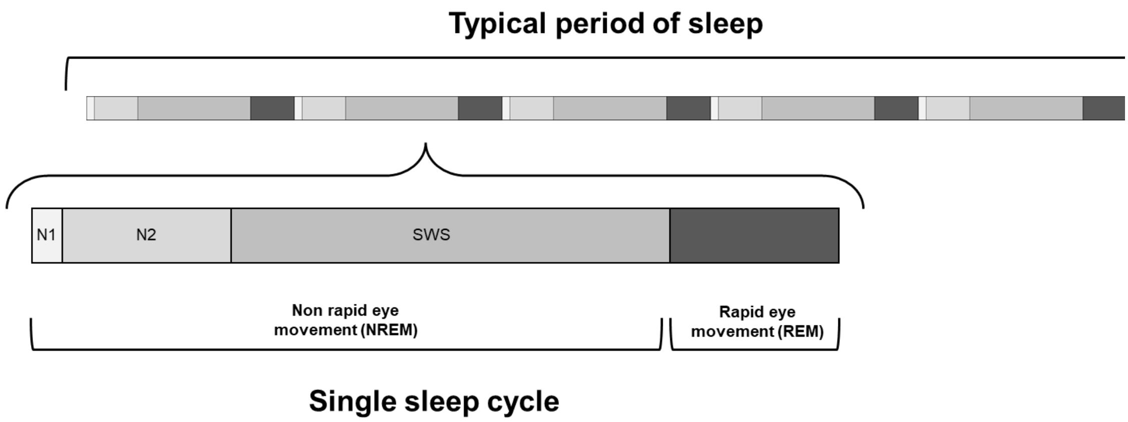


Figure 1.1 The theoretical progression of sleep stages across a single night for a healthy young adult.

The pattern of sleep stage distribution varies with age as can be seen in Figure 1.2. The major difference for adolescents is that there is a quantitative decrease in slow-wave sleep from preadolescence (Crowley, Tarokh & Carskadon, 2012; and Carskadon & Dement, 2017). Time spent in slow-wave sleep is reduced by approximately 40% during the transition from preadolescence to young adulthood even when total sleep duration is kept constant (Carskadon & Dement, 1987 and Carskadon & Dement, 2017).

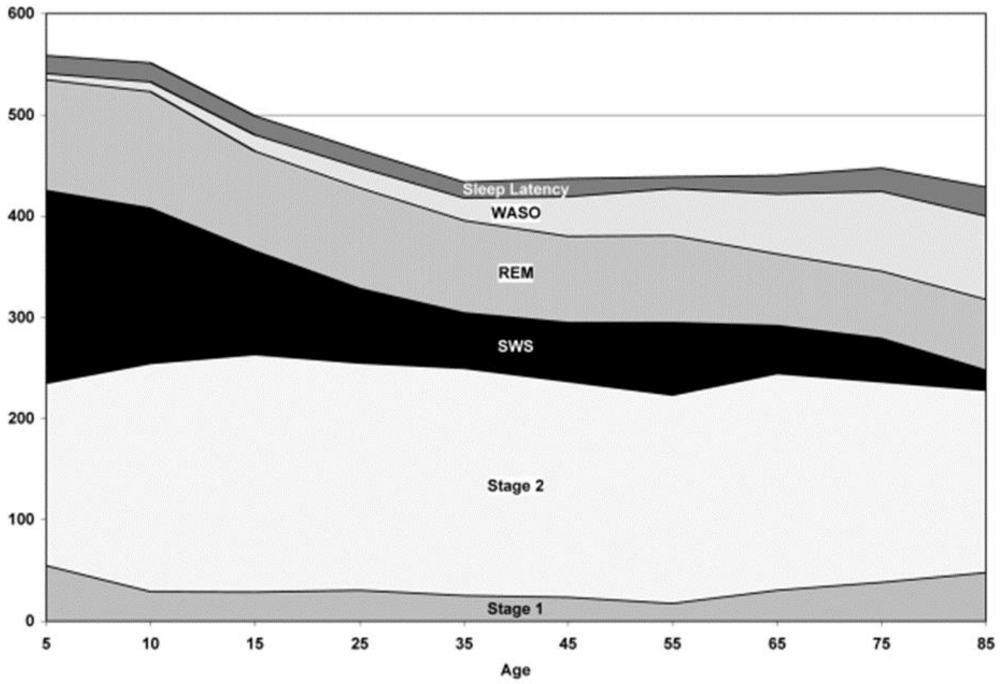


Figure 1.2. Changes in sleep variables with age. The X-axis represents time in minutes for sleep latency, wake after sleep onset, rapid eye movement sleep, slow-wave sleep, and stages 1 and 2 of sleep for ages 5 to 85. Image taken from Ohayon et al. (2004). WASO – total time awake after initial sleep onset

1.2 Sleep-wake regulation

Sleep is regulated by two main physiological mechanisms that, while working in synchrony, also have opposing effects (Borbély & Achermann, 1999; Dijk & Lockley, 2002; and Schmidt *et al.,* 2007). This Two-Process Model of Sleep Regulation was first proposed by Borbély (1982) and Daan, Beersma, & Borbély (1984). The first of these processes is the circadian timing system (Figure 1.3), which is also known as Process C (Borbély & Achermann, 1999; and Schmidt *et al.,* 2007). The second is the homeostatic sleep process, which is also referred to as Process S (Borbély & Achermann, 1999; and Schmidt *et al.,* 2007).

1.2.1 Circadian timing system

The onset of puberty is accompanied by major structural reorganisation of the brain and developmental changes in sleep and the circadian timing system (Crowley, Tarokh & Carskadon, 2014). During adolescence, the suprachiasmatic nucleus (SCN) master clock undergoes a phase delay which moves the preferred sleep time later (Carskadon et al., 1998; Carskadon et al., 2004; and Hagenauer et al., 2009). Correlations have been noted between self-reported pubertal development and circadian phase preferences (Carskadon et al., 1993). Objective measures of pubertal development have also been shown to correlate with the offset phase of melatonin secretion during a constant routine protocol (where participants are kept in constant conditions for at least 24hrs) (Carskadon et al., 1997). Females have been shown to delay sleep timing during adolescence on average about one year earlier than males, a trend which parallels pubertal onset (Roenneberg et al., 2004). The phase delay in adolescents, as measured by daily endocrine rhythms, persists even after several weeks of controlled laboratory conditions and daily schedules that allow for sufficient sleep and limited social influence (Carskadon et al., 2004 and Crowley et al., 2006). This indicates that the phase delay seen in adolescents is independent of psychosocial factors that may be coincidental to pubertal development and typical adolescent social responsibilities and activities (Hagenauer et al., 2009).

The aetiology of this phase delay is thought to be due, at least in part, to changes in the light sensitivity of the SCN pacemaker during puberty (Hagenauer et al., 2009). Evidence suggests that adolescents are less sensitive to light exposure in the early morning resulting in a lessened phase advance response (Carskadon et al., 2002 and Crowley, 2009). It is also suggested that adolescents have an exaggerated phase delay response to light exposure in the evening (Hagenauer et al., 2009). Owing to the SCN’s reliance on the light-dark cycle to synchronise to the 24-hour day/night cycle, this may be a contributing factor to the phase delay observed in adolescents globally, regardless of cultural and social factors (Carskadon, 2008).

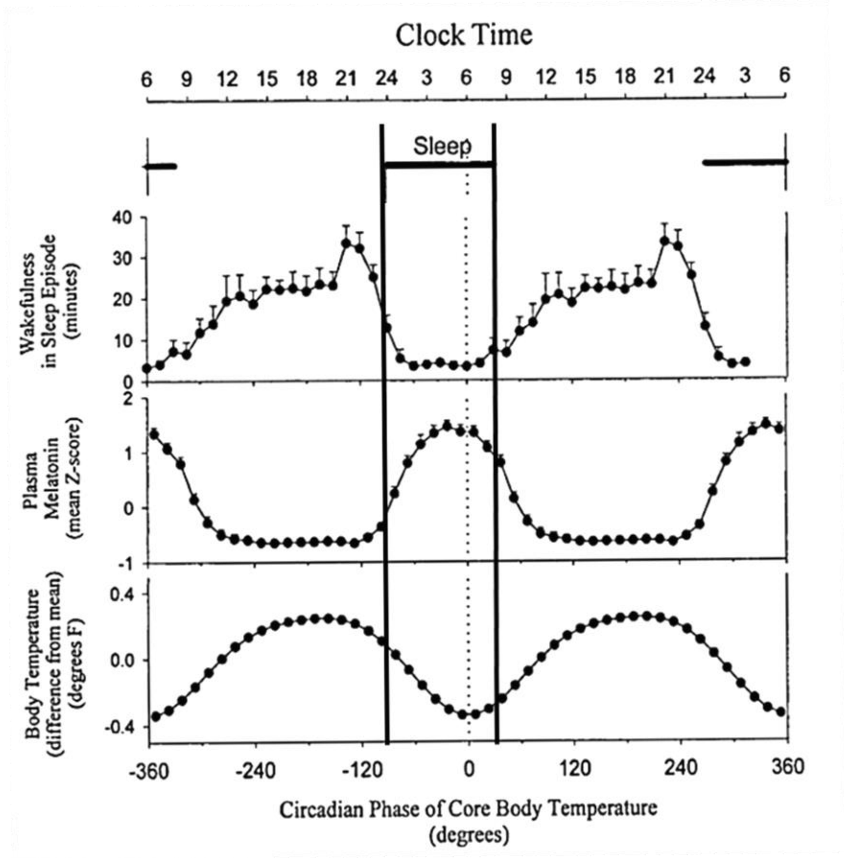


Figure 1.3. Representation of a typical sleep period in relation to the circadian rhythm of core body temperature, plasma melatonin, wake propensity, and responsiveness to light. Taken from Dijk & Lockley (2002).

1.2.2 Homeostatic sleep process

The homeostatic sleep process works as a pressure system (Borbély & Achermann, 1999; Durmer et al., 2005; Crowley et al., 2007; and Illingworth, 2020). The longer an individual is awake, the more sleep pressure accrues as a function of time, and thus, sleepiness and the likelihood of sleep increase (Schmidt et al., 2007). This increase in sleep pressure is also accompanied by decreases in alertness and cognitive performance (Schmidt et al., 2007). A physiological correlate, often measured via EEG as a marker of sleep pressure, is slow-wave activity (SWA) (Crowley, Tarokh & Carskadon, 2014). The beginning of a nocturnal sleep period is typically dominated by SWA which is when sleep pressure is highest. SWA subsequently declines exponentially across a night of sleep as sleep pressure is alleviated during slow-wave sleep (Borbély, 1982; Daan, Beersma & Borbély, 1984; Borbély et al., 1981; Borbély & Achermann, 1999; Durmer et al., 2005; and Schmidt et al., 2007).

1.2.2.1 Homeostatic sleep pressure during adolescence

Along with the circadian phase delay, there seems to be a delay in sleep pressure build-up during adolescence (Carskadon et al., 1998; Carskadon et al., 2004; and Hagenauer et al., 2009). The build-up of sleep pressure (inferred by measuring slow wave brain activity) has been shown to be slower in post-pubescent adolescents when compared to pre-pubertal children (Jenni et al., 2005). Older adolescents have been found to take longer to fall asleep after both 14.5 hours and 16.5 hours of wakefulness compared to younger adolescents (Taylor et al., 2005). Similarly, more mature adolescents were found to have longer sleep latencies during the initial hours of a 36-hour extended wakefulness protocol than less mature adolescents (Taylor et al., 2005). These findings suggest that children become resilient to the speed at which sleep pressure builds up during adolescence (Carskadon et al., 1998; Carskadon et al., 2004; and Hagenauer et al., 2009). This delay in sleep pressure build is an additional factor in the delayed sleep timing noted in adolescent populations (Carskadon, 2008).

1.3 Interaction between the circadian biological clock and the homeostatic sleep process

Under normal circumstances, human beings fall asleep when the SCN master pacemaker promotes sleep in conjunction with an elevated sleep pressure from the homeostatic sleep process (Figure 1.4A) (Dijk & Lockley, 2002; and Schmidt et al., 2007). Humans then typically wake up when the SCN master pacemaker promotes wakefulness, in conjunction with reduced levels of sleep pressure following a restorative night's sleep (Figure 1.4A) (Dijk & Lockley, 2002; and Schmidt et al., 2007).

The two systems also interact in opposition to maintaining sustained and optimal periods of sleep and wakefulness (Schmidt et al., 2007). For instance, sleep pressure is building towards its highest during the early hours of the evening (Schmidt et al., 2007). The SCN pacemaker, however, dictates a low propensity for sleep at this time, ensuring wakefulness despite the pressure from the homeostatic sleep process (Figure 1.4A) (Schmidt et al., 2007). Similarly, sleep pressure is mostly reduced within the first 3-4 hours of sleep (Figure 1.4A) (Schmidt et al., 2007). After this period, the SCN pacemaker dictates a circadian nadir, that is, the point within the circadian oscillations when sleep is physiologically strongly promoted. This high circadian-based propensity for sleep is what reduces the likelihood of waking in the early hours of the morning (Schmidt et al., 2007). Thus, via the interaction and the opposition of these two processes the cycles of sleep and wakefulness are regulated.

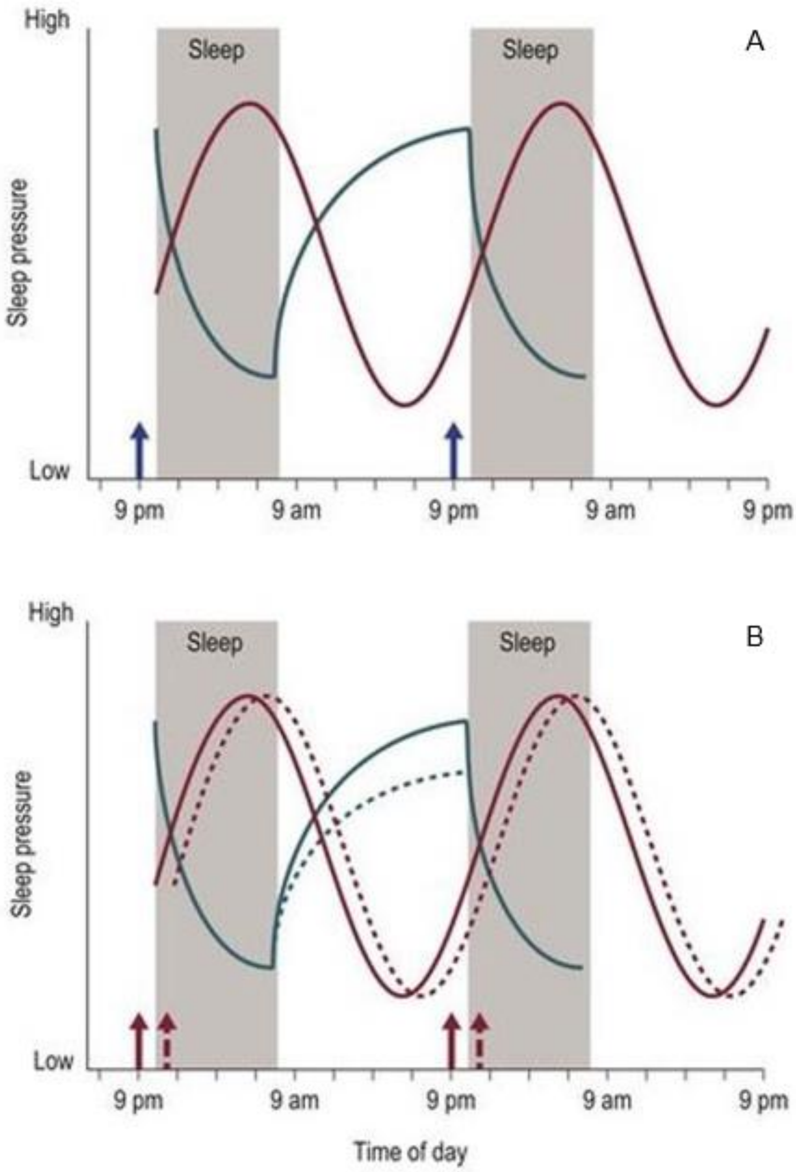


Figure 1.4. Schematic representation of the Two Process Model of Sleep Regulation (A) and the changes that occur during adolescence (B). The blue curve in both graphs illustrates Process S (homeostatic sleep process) and the red curve indicates Process C (circadian timing system). The blue arrows in A indicate the time of melatonin onset which is typically 1 to 2 hours prior to bedtime. Graph B contrasts the Sleep Regulation of a mature adult to that of an adolescent which is represented by the corresponding dotted lines. A slower build-up of sleep pressure across the day in conjunction with a phase shift in the circadian timing system results in a propensity for later sleep timing. Figure adapted from Crowley, Tarokh & Carskadon, 2012.

During adolescence, the interaction between the circadian timing system and the homeostatic sleep process results in delayed sleep timing as is shown in Figure 1.4B. The slower sleep pressure build-up during adolescence in conjunction with a phase delay in circadian timing culminates in a propensity for later bed and wake times (Crowley, Tarokh & Carskadon, 2014). These changes during adolescents are further evidenced by adolescent chronotype data (Crowley, Tarokh & Carskadon, 2014). Chronotype refers to an individual's preference to perform certain tasks at different times during the day/night cycle. Activities influenced by chronotype can include but are not limited to exercise, appetite, and sleep timing. Studies assessing chronotype across puberty have found a shift towards being an 'evening type' which is most pronounced in late adolescence (Roenneberg et al., 2004). Evidence for the shift to an 'eveningness' chronotype has been shown both when considering objective markers of puberty (Randler & Bilger, 2009) and age (Giannotti et al., 2002; Roenneberg et al., 2004; and Roenneberg et al., 2007). Findings of delayed melatonin onset in more mature adolescents (as depicted by the red arrows in Figure 1.4B) in controlled laboratory settings provide further evidence of this shift (Hagenauer et al., 2009).

1.4 Sleep need across the lifespan

The amount of sleep the human body requires for optimal health and functioning varies across the lifespan (Balkin et al., 2008; Bixler, 2009; Carskadon & Dement, 2017; Hirshkowitz et al., 2015; and Watson et al., 2015). Figure 1.5 summarises the ranges of recommended hours of sleep for different age groups.

The variability within this range reflects fluctuating sleep need from person to person and night to night (Carskadon & Dement, 2017). Average sleep need is predominantly based on the genetic make-up of the individual (Karacan & Moore, 1979; and Watson et al., 2015). Sleep need for any given night is, however, also determined by the accrued homeostatic sleep pressure since the last period of sleep, as well as the stage of the circadian process in which an individual is trying to sleep (Carskadon & Dement, 2017). On average, people who regularly obtain more or less than the recommended optimal sleep length are more likely to experience numerous health, cognitive and performance decrements (Killgore, 2010).

Figure 1.5. Sleep duration recommendations across the lifespan as set by the National Sleep Foundation (Hirshkowitz *et al.,* 2015).

Concerning overall health, there is evidence that inadequate sleep length is correlated with increased morbidity (Hall et al., 2008; Van Cauter et al., 2008; and Gangwisch, 2009;) and mortality (Kripke et al., 2002; Patel, 2006; Hublin et al., 2007; Kronholm et al., 2008; and Patel et al., 2008), including increased risk of obesity (Sekine et al., 2006; Cappuccio et al., 2007; Yu et al., 2007; and Gangwisch et al., 2009), cardiovascular disease (Meier-Ewert et al., 2004), alcohol and drug abuse (Wong et al., 2004). In adolescence, insufficient sleep has been identified as a serious health risk (Paruthi et al., 2016). Of particular note is the increased risk of depression (O'Brien & Mindell, 2005) increase in risk behaviours such as drinking and driving, smoking, and delinquency (O'Brien & Mindell, 2005; and Catrett & Gaultney, 2009) as well as suicidal ideation (Liu, 2004; and Lui & Buysse, 2006). Other health decrements associated with sleep reduction include negative metabolic functioning (Van Cauter et al., 2008) and general impairment of the immune system (Sekine et al., 2006). Despite the evidence of these risks being clearly and extensively documented, sleep loss is a common problem within most societies (Ferrara & De Gennaro, 2001; Cappuccio et al., 2007; Yu et al., 2007; and Jean-Louis et al., 2014). It is speculated that this may be a function of sleep being viewed as a perfunctory chore (Killgore, 2010; and St-Onge et al., 2016). If the benefits of sleep are not fully understood or are undervalued by the individual, sleep may be seen as a commodity to be traded, with the time rather being spent on entertainment, work or any activity deemed more lucrative (Killgore, 2010; and St-Onge et al., 2016).

1.4.1 Sleep need in adolescence

As seen in Figure 1.5, the recommended nightly sleep duration for adolescents is between 8 and 10 hours. There is, however, a global trend for teenagers to fall below this recommendation (Olds et al., 2010; Leger et al., 2012; and Short et al., 2018). Reports from countries such as Korea, Singapore and Taiwan show that adolescents regularly get between five and six hours of sleep a night (Yang et al., 2005; Chen et al., 2006; and Lo et al., 2016). A study looking at 3311 European adolescents found the average sleep duration to be eight hours per night, just reaching the lower recommendation for their age (Garaulet et al., 2011). Once data were dichotomized by

Tanner developmental stages, average sleep duration dropped below the recommendation for older adolescents (Garaulet et al., 2011). A longitudinal study from the United States of America that tracked sleep change with ageing showed a significant decrease in sleep time during adolescence (Maslowsky & Ozer, 2013). These findings are in line with studies of adolescents in New Zealand (Dorofaeff and Denny, 2006; Skidmore et al., 2013; & Galland et al., 2017). As Figure 1.6 shows, sleep duration declines over adolescent years and then subsequently recovers once individuals enter early adulthood (Maslowsky & Ozer, 2013).

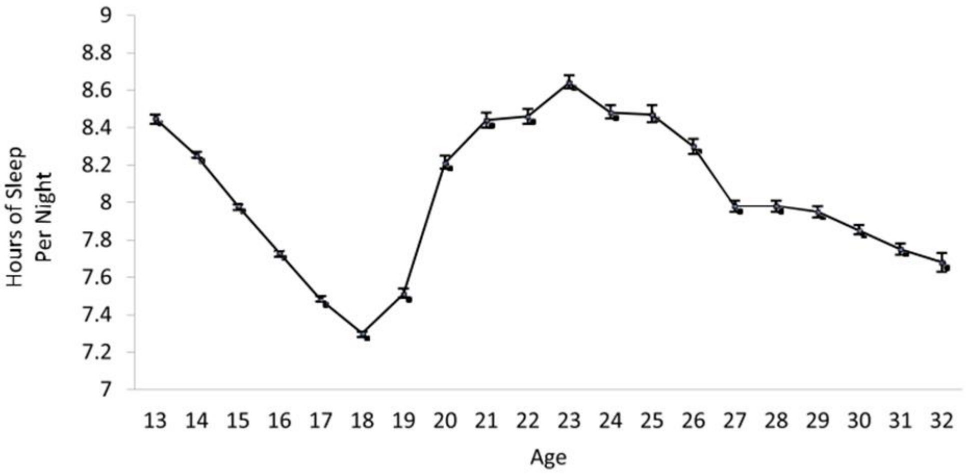


Figure 1.6. Mean sleep duration per night is shown for ages 13 to 32. The image is taken from Maslowsky & Ozer (2013).

Adolescents seem particularly predisposed to failing to meet the recommended sleep duration, particularly on school nights (Olds et al., 2010; Leger et al., 2012; and Short & Weber, 2018). This comes as little surprise when the physiological changes the human body undergoes at this time are juxtaposed with the psychosocial pressure adolescents face (Carskadon et al., 1998; Carskadon et al., 2004; Roenneberg et al., 2004; and Hagenauer et al., 2009). The phase delay seen in adolescence directly contradicts major societal commitments, namely early school start times (Carskadon et al., 1998;

Carskadon et al., 2004; Roenneberg et al., 2004; and Hagenauer et al., 2009). For teenagers to be able to get enough sleep on school nights while waking up in time for school, they would need to go to sleep at a time when the body is not physiologically promoting sleep (Carskadon et al., 1998; Carskadon et al., 2004; Roenneberg et al., 2004; and Hagenauer et al., 2009). This mismatch between physiological changes in sleep timing and timing of societal commitments has been termed the ‘perfect storm’ of adolescent sleep (Carskadon, 2011; and Crowley et al., 2018). Recent lifestyle changes, including electronic device use close to bedtime for schoolwork, communication and entertainment, are likely to further reduce the amount of nightly sleep obtained by adolescents. (Ferrara & Gennaro, 2001; Van den Bulck, 2004; Eisenstein, 2013; Chang et al., 2015; and Owens et al., 2017).

1.5 Sleep in athlete populations

The topic of athlete sleep has been an area of growing interest and concern (Vlahoyiannis et al., 2021). A recent systematic review found that of 81 identified articles quantifying athlete sleep between 1978 and 2019, 55.6% were published between the years 2016 and 2019 (Vlahoyiannis et al., 2021). The increase in research interest in this area is reflected by athletes, coaches, and organisations such as the International Olympic Committee all acknowledging the vital role sleep plays in physical and mental health as well as athletic performance (Besedovsky, Lange, & Born, 2012; Bergeron et al., 2015; Watson et al., 2015; and Krause et al., 2017). This rapidly growing body of literature indicates that athletes are at greater risk of experiencing sleep loss than the general population owing to the very nature of training and competition (Erlacher et al., 2011; Leeder et al., 2012; Sargent et al., 2012; Lastella et al., 2014; Sargent et al., 2014; Juliff et al., 2015; Lastella et al., 2015a; Lastella et al., 2015b; Gupta, Morgan, Gilchrist, 2017; Gudmundsdottir, 2019; and Vlahoyiannis et al., 2021)

1.5.1 Sleep loss prior to training

Athletes have been consistently shown to sleep less than recommended durations on nights that precede training days (Leeder et al., 2012; Hausswirth et al., 2014; Sargent et al., 2014a; Sargent et al., 2014b; Lastella et al., 2015a; Schaal et al., 2015; Suppiah et al., 2016; Blanchfield et al., 2018; Choi et al., 2018; Suppiah et al., 2018; Gudmundsdottir, 2019; Ramos-Campo et al., 2019; Walsh et al., 2019 and Vlahoyiannis et al., 2021). Australian Olympic swimmers reported sleeping on average 5.4hrs on nights prior to training days compared to 7.1hrs on nights prior to rest days (Sargent et al., 2014a). The swimmers showed a systematic pattern in terms of the amount of sleep lost relative to the time they started training in the morning (Sargent et al., 2014a). For every start time earlier than 8 am, in one-hour increments towards 5 am, there was an exponential relationship observed with respect to sleep loss (Sargent et al., 2014a). On average, 6 minutes of sleep was lost if the start time was at 7 am, 48 minutes were lost when training started at 6 am and 102 minutes were lost for a 5 am training session (Sargent et al., 2014a). These results echo those from shift work studies. Results from studies in aviation and rail operations suggest that, on average, 30 minutes of sleep tends to be lost for every hour that the start of work is earlier than 9 am (Kecklund & Akerstedt, 1995; and Akerstedt et al., 2008). It should also be noted that early morning training sessions may be a tradition born from the need for non-professional athletes to train before work or school (Sargent et al., 2014a). This may indicate that training schedules and times are possibly the greatest cause of sleep loss for athletes during their training phases.

Similar findings have been reported where 70 nationally competitive athletes slept significantly less (6.5hrs) on nights prior to training days when compared to nights prior to rest days (6.8hrs) (Sargent et al., 2014b). Poor sleep has also been found in a cohort of 124 elite athletes who were observed to obtain an average of 6.8hrs sleep per night

(Lastella et al., 2015a). It should be noted that these studies attributed the pre-training sleep loss largely to early morning training schedules and were conducted with adult athletes (Sargent et al., 2014a; Sargent et al., 2014b; and Lastella et al., 2015a).

While these sleep durations are concerning when comparing them to recommended sleep durations, the findings from adolescent athlete sleep durations are even more alarming. Vlahoyiannis et al. (2021) found that across studies quantifying sleep in athlete groups, adolescent athletes slept on average 60 minutes less than young adult athletes and 36 minutes less than middle-aged athletes. The average sleep duration of 7.2hrs among adolescent athletes across all 81 studies identified by Vlahoyiannis et al. (2021) falls far below the recommended 8-10 hours for this age group (Hirshkowitz et al., 2015; and Watson et al., 2015). Across all of the studies reviewed by Vlahoyiannis et al. (2021), the shortest mean sleep time came from a group of child athletes managing to sleep only 6.3hrs a night (Choi et al., 2018). Similar sleep durations have subsequently been reported in Icelandic adolescent swimmers, who averaged 6.6hrs ± 0.7hrs across a training week (Gudmundsdottir, 2019). Average sleep for the swimmers was even shorter on nights preceding early morning training with durations of 5.6hrs in under 16-year-olds and 5.1hrs for adolescents 16 and over (Gudmundsdottir, 2019). These findings demonstrate that athletes, in particular adolescent athletes, sleep well below recommended healthy durations, with evidence strongly pointing to early morning training as a contributing factor (Sargent et al., 2014a; Sargent et al., 2014b; Lastella et al., 2015a; Gudmundsdottir, 2019; and Vlahoyiannis et al., 2021).

Some studies have failed to show that athletes lose sleep during training (Leeder et al., 2012; Romyn et al., 2016; and Knufinke et al., 2017). In the case of Leeder et al. (2012), this can be attributed to the fact that athlete sleep was compared to a non-athlete control group. A population of 47 Olympic athletes was found to sleep an average of 6.9hrs during training (Leeder et al., 2012). This sleep duration was statistically similar to that of the matched control (7.2hrs). It must be noted that this duration would be regarded as being just under the National Sleep Foundation's minimum recommendation of 7hrs of sleep for a healthy adult (Hirshkowitz et al., 2015; and Watson et al., 2015) and well below the recommendation of sleep (8hrs) required to minimise reductions in neuro-behavioural performance (Belenky et al., 2003; and Van Dongen et al., 2003).

In addition, the athlete group experienced significantly reduced sleep quality and sleep efficiency (Leeder et al., 2012). They spent, on average, 30 minutes longer in bed despite sleeping for the same amount of time (Leeder et al., 2012). Furthermore, athletes had longer sleep latencies and higher rates of restlessness throughout the night (Leeder et al., 2012). Knufinke et al. (2017) found average self-reported sleep durations of 8.2hrs in 98 elite youth athletes aged 18.8 ±3 years during a training phase. The study does not, however, seem to have differentiated between pre-training day and pre-rest day sleep making it unclear whether this result is a true reflection of athlete sleep during a typical training phase. In addition, 41% of the athletes were classified in the study as 'poor sleepers' and 12% were diagnosed with one or more sleeping disorders (Knufinke et al., 2017). Romyn et al. (2016) did, however, find comparable training phase sleep durations (8.2hrs) for a group of netball players of a similar age (19.6 ± 1.5 years) as the population in Knufinke et al. (2017). With the sample size of 8 athletes in the Romyn et al. (2016) study and the methodological inconsistency in Knufinke et al. (2017), further research is needed to establish whether young athletes are less prone to sleep loss or whether there are other reasons for these results.

There is evidence suggesting that in addition to the time of training, the intensity of training itself affects sleep in athlete groups. Hausswirth and colleagues (2014) investigated the effect of functional overreaching from high training loads on sleep. A group of 27 athletes were assigned to a control group (n=9) where the training load was kept normal or to an overload group (n=18) where the training load was increased for 3 weeks (Hausswirth et al., 2014). Of the 18 athletes in the overload group, 9 met the criteria to be classified as functionally overreached during the training period (Hausswirth et al., 2014). Only the 9 functionally overreached athletes demonstrated a significant decrease in sleep duration from 7.2hrs ± 0.5hrs to 6.6hrs ± 0.9hrs during the training phase of the study which was subsequently reversed back to baseline levels during a tapering period (7.1hrs ± 0.8hrs, Hausswirth et al., 2014). The study also found that the functionally overreached athletes had an upper respiratory tract infection rate of 67% during the 3-week training phase of the study (Hausswirth et al., 2014). This is threefold more than the athletes in the overload group who were not functionally overreached (22%) and 6 times more than the control group (11%) (Hausswirth et al., 2014). Although the small sample size in this study suggests caution in interpreting findings.

One factor that would alter training intensity is the phase of training athletes find themselves in during a competitive season. A common breakdown of a season would be pre-season; heavy training phases; tapering phases and competition phase. The findings from Hausswirth et al. (2014) are consistent with systematic review findings that show athletes accrue less sleep on average during heavy training phases compared to pre-season/tapering and competition phases (6.7hrs vs 7.3hrs vs 7.4hrs) (Vlahoyiannis et al., 2021). There is evidence to suggest that total sleep time is not the only aspect of sleep that is altered by training intensity (Vlahoyiannis et al., 2021). Sleep architecture findings indicate that stage N3 sleep varies from a nightly average of 130 minutes during pre-season/tapering phases to 97 minutes during in-season/competition phases with the lowest average of 74.6 minutes being recorded during heavy training phases (Vlahoyiannis et al., 2021). Given the vital role stage N3 sleep plays in restorative and immunological processes, these findings suggest a possible explanation for the infection rate data from Hausswirth and colleagues (2014).

1.5.1.1 Sporting codes and sleep loss before training

Lastella et al. (2015) investigated whether sleep/wake behaviour differed for athletes from individual sports compared to athletes competing in team sports. With 124 athletes being monitored for a minimum of 7 nights, the study concluded that athletes from individual sports went to bed significantly earlier (22:49 vs 23:40), woke up earlier (06:29 vs 07:46), obtained less sleep (6.5hrs vs 7hrs) and had poorer sleep efficiency (85.9% vs 86.4%) compared to team sport athletes. Subjective sleep quality, however, was not shown to differ with sport type (Lastella et al., 2015). Breaking down sporting codes even further, race walkers reportedly slept for an average of 7.1hrs; 7hrs for mountain bikers; cyclists for 6.7hrs; swimmers for 6.4hrs and triathletes slept on average 6.1hrs during a typical training phase (Lastella et al., 2015). When considering team sport athletes, Australian Rules Football players slept on average for 6.7hrs, basketball players for 7.5hrs, rugby union players for 6.9hrs and football players for 6.9hrs (Lastella et al., 2015). These findings illustrate how different sports may place different demands on athletes and how some athletes in specific sporting codes may be more susceptible to sleep loss than others (Lastella et al., 2015). These findings are echoed in systematic review data which found average individual sport athletes to sleep 7hrs compared to 7.4hrs for team sport athletes (Vlahoyiannis et al., 2021). Team sport athletes were also found to spend, on average, more than double the amount of time in stage N3 sleep compared to individual sport athletes (139.6 minutes vs 66.9 minutes) while individual sport athletes spent more time in stage N1 (65.8 minutes vs 27.3 minutes) and stage N2 sleep (256.7 minutes vs 206.3 minutes) (Vlahoyiannis et al., 2021).

Another way of categorising sports would be based on whether the sport is mainly aerobic (endurance sports such as long-distance swimming or cycling); have a high anaerobic component (sprint or power activities such as power lifting); or is a mixture of both (sports that have endurance and high-intensity components such as tennis or football) (Vlahoyiannis et al., 2021). To date, the majority of studies investigating sleep in athlete populations have focused on endurance and mixed sporting codes with very few looking at power/strength sports (Trinder et al., 1985; and Leeder et al., 2012). With regards to sleep duration, the evidence to date suggests that power/strength athletes sleep on average for 8.7hrs whereas endurance and mixed athletes obtain 7.2hrs and 7.4hrs of sleep at night (Vlahoyiannis et al., 2021). Mixed sport athletes were seen to spend more time in stage N3 sleep compared to both aerobic and power/strength sport athletes (139.5 minutes vs 78.2 minutes vs 61.0 minutes) (Vlahoyiannis et al., 2021).

1.5.2 Sleep loss prior to competition

The focus of this thesis is sleep loss during the training phase. For completeness, the following section outlines sleep loss prior to competition, although current evidence suggests it has a different aetiology to sleep loss prior to training.

Sixty-eight percent of marathon runners surveyed on the morning of a race reported having slept worse than usual during the previous night (Lastella et al., 2014). A similar trend was found where 65.8% of elite German athletes retrospectively reported having slept worse during the night(s) preceding competitions at least once in their careers, with 62.3% reporting the same within the previous 12 months (Erlacher et al., 2011). In a comparable retrospective survey, 64% of elite Australian athletes indicated sleeping worse on at least one night preceding an important competition (Juliff et al., 2015). These results are not restricted to survey studies.

Through the use of sleep diaries, marathon runners have been shown to sleep an average of 5.9hrs the night before a race (Lastella et al., 2014). This value is much lower than even the lowest limit of the recommended range for healthy adults (Hirshkowitz et al., 2015; and Watson et al., 2015). Actigraphy data has also shown that cyclists get an average of 6.8hrs sleep on the night prior to the start of an endurance race, nearly a whole hour less than that recorded on baseline nights (7.4hrs) (Lastella et al., 2015b). Studies using more objective means of data collection (Lastella et al., 2015b) have criticised the use of retrospective techniques such as surveys (Erlacher et al., 2011; and Juliff et al., 2015). Nevertheless, the data obtained from survey studies are consistent with the findings of the more objective methods used to monitor sleep (Lastella et al., 2014; and Lastella et al., 2015b).

1.5.2.1 Aetiology of pre-competitive sleep loss

Survey studies have investigated the reasons why sleep loss occurs prior to competition (Erlacher et al., 2011; Lastella et al., 2014; and Juliff et al., 2015). Trouble falling asleep has been noted as the problem most cited by athletes (Erlacher et al., 2011; and Juliff et al., 2015). German athletes reported waking early in the morning to be the second biggest issue related to sleep loss while Australian athletes' second most common problem was waking up during the night (Juliff et al., 2015). Anxiety is also cited as a major contributor to the occurrence of these issues with sleep (Lastella et al., 2014; Romyn et al., 2016; and Erlacher & Ehrlenspiel, 2017). Athletes who reported higher anxiety levels 4 days prior to the competition were also found to be more likely to show disrupted sleep/wake behaviours the night before a competition (Ehrlenspiel et al., 2017). This suggests that anxiety in general as well as anxiety directly preceding competition may influence pre-competitive sleep loss. The possible link between anxiety and stress and pre-competitive sleep loss seems plausible, considering that cognitive stress can be a major reason for altered sleep patterns (Reilly & Edwards, 2007).

Sleeping in unfamiliar environments, trans-meridian travel, noise both inside and outside the room, familial issues, dreaming and the need for the toilet have all been cited as additional reasons why athletes lose sleep before a competition (Erlacher et al., 2011; Lastella et al., 2014; and Juliff et al., 2015). These are cited far less frequently, however, than pre-competitive anxiety (Erlacher et al., 2011; Lastella et al., 2014; and Juliff et al., 2015).

1.5.3 Relationship between sleep and performance

Integral to achieving the best possible athletic performance is how an athlete distributes work output or pattern of energy expenditure during exercise (Abbiss & Laursen, 2008). This conscious and or subconscious distribution of workload is known as ‘pacing’ or as a ‘pacing strategy’ employed to minimise the chance of premature exhaustion and to optimise athletic performance (Abbiss & Laursen, 2008 and Tucker, 2009). It is plausible that factors pertinent to theories of exercise-induced fatigue (Marcora, 2008; and Tucker, 2009) are affected by sleep loss.

1.5.3.1 Sleep and models of exercise-induced fatigue

Sleep loss has been shown to affect many aspects of waking function including visuospatial perception in terms of judging distance, lower pain thresholds for temperature, general states of hyperalgesia and increased negative emotional states (Kundermann et al., 2004; Kahn-Greene et al., 2007; Mullington et al., 2009; Killgore, 2010; and Tempesta et al, 2020). All these factors relate to perception of effort, which is intrinsic to how popular models of exercise-induced fatigue propose that physical performance is regulated (Marcora, 2008; and Tucker, 2009).

Two studies directly investigated sleep loss on self-pacing (Oliver et al., 2009; Skein et al., 2011). Oliver et al (2009) implemented a 30-minute preloaded workout at 60% of each participant’s VO2 max followed by a 30-minute self-paced treadmill run. For the self-paced run participants were informed only of the time elapsed during the run and were instructed to run as far as possible in the 30 minutes. Participants were allowed to adjust treadmill speed as much as needed, however, the speed was hidden from view

(Oliver et al, 2009). Skein et al (2011) implemented an exercise protocol which involved participants performing a 30-minute graded exercise run followed by a 50-minute intermittent sprint protocol. The 50-minute intermittent sprint protocol included a 15-meter maximal sprint every minute followed by a self-paced shuttle run at various intensities, either being hard running, jogging or walking (Skein et al, 2011). Oliver et al (2009) found that distance covered during the 30min self-paced treadmill run was significantly less after a night of total sleep deprivation when compared to after a normal night of sleep. Similarly, Skein et al (2011) found average sprint times to be significantly reduced and mean distances covered during the self-paced runs to be significantly shorter after total sleep deprivation. Both studies recorded participants' Rating of Perceived Exertions (RPE, a numeric scale commonly numbered 6-21) and both found that RPE was not significantly different even though the athletic performances, in terms of distance covered and sprint times, were significantly worse. This may, albeit tentatively, be seen as evidence that faulty perceptions of effort may affect athletic performance after sleep loss.

This was postulated by Temesi et al (2013). They implemented a 40-minute submaximal cycling task (5-minutes at 50% maximum power output and 35-minutes at 65% maximum power output) followed by a cycling stepwise failure test (5-minutes at 65% maximum power output and then 5% increase every 5-minutes until participant failure/exercise cessation). The findings were that RPE was significantly higher during the submaximal cycling task under sleep loss conditions despite workload being identical (Temesi et al., 2013). During the task to failure cycle, however, participants' RPE was found to be statistically unchanged between sleep conditions despite participants reaching fatigue significantly early (average of 99 seconds) under sleep loss conditions.

With sleep potentially being crucial to many processes of exercise regulation, it follows that the evidence from systematic reviews examining the role sleep plays in performance have identified that extending sleep or improving sleep quality appear to have positive effects on athletic performance (Thun et al., 2015; Vitale, Owens, Hopkins, & Malhotra, 2019; and Kirschen et al., 2020). Consistent with these findings, athletic performance suffers negatively when sleep is disturbed or restricted (Thun et al., 2015; and Kirschen et al., 2020).

1.6 Sleep interventions for adolescent athletes

Systematic reviews of sleep interventions in both adolescent and young adult athletes have identified three main sub-types of intervention commonly used (Bonnar et al., 2018; and Fox et al., 2020).

1.6.1 Sleep extension

Sleep extension studies aim to increase sleep duration either by increasing total night-time sleep or by introducing naps into the athletes' schedule (Bonnar et al., 2018; and Fox et al., 2020). Sleep extension trials have shown positive outcomes for both sport-specific performances (e.g., tennis serve accuracy, hitting accuracy, basketball shooting accuracy) and for general athleticism measures such as sprint time and self-rating of overall performance (Mah et al., 2009; Mah et al., 2011; and Schwartz & Simon, 2015). Sleep extension was also associated with decreased levels of daytime sleepiness and fatigue as well as improved anxiety, depression, anger, and vigour scores (Mah et al., 2009; Mah et al., 2011; and Schwartz & Simon, 2015).

In these studies, collegiate athletes were given from 1 week to 7 weeks where they were told to aim for 9-10 hours of sleep per night (Mah et al., 2009; Mah et al., 2011; and Schwartz & Simon, 2015). It should be noted that for replicating such methodology in real-world conditions with adolescent athletes, creating the opportunity for 9-10 hours of sleep per night is itself a methodological challenge. Taking the 'perfect storm model' into account, creating the opportunity for 9-10 hours of sleep per night for adolescents outside of school holidays would require major reorganisation of academic and societal commitments in the morning. Moving bedtimes forward is unrealistic given the physiological drive for sleep being later in adolescence. In the case of adolescent athletes in sporting codes where early morning training is prominent, scheduling a major sleep extension opportunity into their routine may be a logistical challenge.

One answer to the scheduling issue above would be to extend sleep not only with a focus on night-time sleep but by adding napping into an athlete's daily routine. While some studies have shown preliminary evidence that napping may be an effective recovery strategy following a bout of sleep restriction (Davies et al., 2010; Petit et al., 2014; and Romyn et al., 2018), napping has yet to be shown to be an effective method for extending 24-hour sleep duration while also improving athletic performance.

1.6.2 Healthy sleep behaviours

Systematic reviews and meta-analyses indicate that interventions aimed at improving healthy sleep behaviours are the most common sleep intervention strategy used in athlete populations (Bonnar et al., 2018; and Gwyther et al., 2022). Sleep behaviour interventions involve educating participants on behaviours that are potentially harmful and beneficial for optimal sleep patterns. Common endorsements across sleep interventions for athletes recommend that they:

- Establish a consistent bedtime routine.
- Create a quiet, cool, and dark bedroom environment.
- Avoid blue light emitted from screens at least 2 h before bed (smartphones, laptops, monitors).
- Get bright, natural light (the sun) upon awakening (the sun is ideal, but some suggest at least a 10,000-lux lamp if artificial).

- Avoid high-intensity exercise before bedtime.
- Employ effective use of napping.
- Eliminate the bedroom clock. (Halson, 2014; Bender *et al.,* 2018; Driller, Lastella, & Sharp, 2019; Harada *et al.,* 2016; O'Donnell & Driller, 2017; Tuomilehto *et al.,* 2017; Van Ryswyk *et al.,* 2017 and Vitale *et al.,* 2019).

Sleep behaviour interventions within athlete groups have shown varied success ranging from decreasing subjective sleep difficulty scores (Bender et al., 2018), to increases in subjective sleep quality scores (Driller et al., 2019; Harada et al., 2016; Tuomilehto et al., 2017; and Vitale et al., 2019), decreases in objective sleep onset variance (Driller et al., 2019), improved objective sleep efficiency (Driller et al., 2019), extended objective and subjective sleep duration (Fullagar et al., 2016; O'Donnell & Driller, 2017; Van Ryswyk et al., 2017), and improved cortisol awakening responses (Bonato et al., 2020). With regards to athletic performance, sleep behaviour interventions have shown sport-specific improvements, however, general measures of athleticism show mixed results regarding improvement (Fullagar et al., 2016; Harada et al., 2016; and Van Ryswyk et al., 2017). Sleep behaviour has been found to improve indices of mood and mental health outcomes for athletes (Harada et al., 2016; and Van Ryswyk et al., 2017). Lower scores for irritation (Harada et al., 2016); fatigue and vigour (Van Ryswyk et al., 2017) have also been reported.

With regard to sleep behaviour interventions for general adolescent populations, evidence for positive short-term outcomes has also been reported. Meta-analyses show that adolescents who are taught about sleep behaviour in school have extended sleep durations both on weekdays (Moseley & Gradisar, 2009; Cain et al., 2010; Beijiamini & Louzada, 2012; Bonnar et al., 2014; Kira et al., 2014; and Wing et al., 2015) and weekends (Beijiamini & Louzada, 2012; Kira et al., 2014; and Wing et al., 2015) and improved mood outcomes (Moseley & Gradisar, 2009; Cain et al., 2010; and Bonnar et al., 2014) compared to adolescents who received no sleep education (Chung et al., 2017). Of note, however, was that these positive outcomes did not persist at follow-up as early as 6 weeks post intervention, suggesting that the long-term effects of sleep education in general adolescent groups is limited. The long-term effect of sleep behaviour education has proven more effective for student athletes (Kaier et al., 2016). Sleep knowledge and daytime functioning were both significantly improved 2 weeks following a single 30-minute presentation on sleep, and the improvements persisted in follow-up assessments 3-4 months later. Despite these positive findings, scores on the Sleep Hygiene Index Questionnaire got worse at follow-up compared to baseline (Kaier et al., 2016).

In summary, sleep behaviour interventions show potential positive outcomes in adult athlete groups, poor results in adolescent groups and the evidence are limited for adolescent athlete populations (Kaier et al., 2016; and Fox et al., 2020).

1.6.3 Assisted sleep and post-exercise recovery strategies for sleep

Assisted sleep strategies include interventions that theoretically augment sleep while also aiding in physical recovery from exercise. These strategies have been shown to be effective in youth and collegiate athlete groups (Gwyther et al., 2022). Assisted sleep methodologies range from using whole-body red-light irradiation (Zhao et al., 2012); exposure to low-colour temperature lighting (Wada et al., 2013); brain-wave entrainment (Abeln et al.,2014) and the use of far infrared clothing (Loturco et al., 2016; Mazzardo-Martins et al., 2016; Letton et al., 2018; and Nunes et al., 2020). Cryostimulation (Schaal et al., 2015; Douzi et al., 2019; and Grainger, Comfort, & Heffernan, 2020), cold water immersion (Krueger et al., 2020), and utilization of lower body compression clothing

(Atkins et al., 2020), are all examples of strategies of post exercise recovery techniques that have also been investigated for possible effects on sleep. Of these, brain-wave entrainment, far infrared clothing, exposure to low-colour temperature lighting, and whole-body red-light irradiation have been shown to increase subjective sleep quality (Zhao et al., 2012; Wada et al., 2013; Abeln et al., 2014; Mazzardo-Martins et al., 2016; and Letton et al., 2018). Whole-body red-light irradiation and far infrared clothing were both found to improve sleep onset latency (Zhao et al., 2012; Mazzardo-Martins et al., 2016; and Letton et al., 2018).

1.7 Measuring Sleep in Athlete Populations

1.7.1 Polysomnography

The "golden standard" for measuring and assessing sleep is polysomnography (Halson, 2014; and Tuomilehto et al., 2017). Polysomnography encompasses the measurement of several bodily functions including brain activity, muscle activity, cardiac activity, and eye movements (Halson, 2014; and Tuomilehto et al., 2017). Polysomnography offers information on, but is not limited to, a participant's total time spent asleep, sleep latency, time spent in various sleep stages, number of awakenings and sleep efficiency (Halson, 2014; and Tuomilehto et al., 2017). The downfall of polysomnography is that it is time consuming, labour intensive, very costly and typically is reserved to being applied in a laboratory setting (Halson, 2014). Additionally, the operation of polysomnography equipment and the subsequent data analysis requires significant expertise. For these reasons, this method is often reserved for assessing clinical disorders related to sleep (Halson, 2014). The only study that could be found where polysomnography was used in athlete populations was Tuomilehto et al. (2017). Polysomnography was only used once athletes were identified as having a sleeping disorder, however, and not for general sleep quantification.

1.7.2 Actigraphy

An alternative method for tracking sleep is the use of actigraphy which records body movement continuously via an accelerometer (Ancoli-Israel et al., 2003; and Halson, 2014). Actigraphs can be worn comfortably on the wrist, ankle or the trunk making them non-invasive as well as allowing for full range of movement to be unobstructed 24hrs a day (Ancoli-Israel et al., 2003; and Halson, 2014). In order to use actigraphy accurately, a sleep diary must be kept by the participant for the days over which the actigraph is worn (Ancoli-Israel et al., 2003; and Halson, 2014). The participant is required to record when they actively began attempts to fall asleep and when they wake-up (Ancoli-Israel et al., 2003; and Halson, 2014). In order for the researcher to be satisfied that sleep was achieved, two criteria have to be met: firstly, the sleep diary has to indicate that the participant was lying down with the intention of going to sleep, and secondly, the data from the actigraph must indicate that movement was sufficiently low to suggest that the participant may have been in a state of sleep (Ancoli-Israel et al., 2003; and Halson, 2014). If both conditions are met then the researcher is able to tabulate total time asleep, sleep latency, number of awakenings, time spent awake after sleep onset as well as sleep efficiency (Ancoli-Israel et al., 2003; and Halson, 2014).

With correlations of 0.97, actigraphy has been shown to correlate highly with polysomnography with respect to differentiating sleep from wakefulness (Blood et al., 1997; and Jean-Louis et al., 1996). Slater et al. (2015), however, found that when compared to polysomnography, the sensitivity, specificity and accuracy of wrist actigraphy were 90%, 46% and 84%, respectively; and of hip actigraphy were 99%, 14% and 86%. It was also concluded that wrist worn actigraphy was a more valid sleep measure than hip worn actigraphy even though it has a limited ability to discern wakefulness during a given sleep period (Slater et al., 2015). It must be noted that this study was conducted using GT3X+ Actigraphs and whether these findings will prove indicative of all actigraphs is unknown.

While actigraphy is not as accurate as polysomnography, it still has some significant advantages. Actigraphs can record data continuously, for days or even weeks, which is an advantage over polysomnography as it can be used in field studies or to track a participant during their normal routines (Ancoli-Israel et al., 2003; and Halson, 2014). Actigraphy has been widely used in sleep quantification studies in athlete populations (Leeder et al., 2012; Sargent et al., 2014a; Sargent et al., 2014b; Lastella et al., 2015a; Romyn et al., 2016; and Staunton et al., 2017). Actigraphy does, however, have its limitations. In order to monitor multiple participants in a single night, multiple actigraphs are needed. The researcher also needs consistent contact with the participants to get the actigraph back for analysis. These factors create challenges for monitoring large samples during a single night or longer-term monitoring of participants who are not in the immediate vicinity

1.7.3 Self-report tools

Subjective sleep assessment tools are regarded as being the cheapest and most practical way to collect sleep/wake information on large population samples (Carney et al., 2012; and Girschik et al., 2012). The gold standard among self-reported sleep measurement tools is sleep diaries (Bootzin & Nicassio 1978; Bootzin & Engle-Friedman, 1981; Buysse et al., 2006; and Carney et al., 2012). Sleep diaries can yield information regarding sleep onset, sleep onset latency, wakefulness after sleep onset, final awakening, total sleep duration as well as total time in bed (Carney et al., 2012).

One issue that has made sleep diary research difficult to standardise is the fact that no set sleep diary is used by the majority of sleep researchers (Carney et al., 2012). For example, in Carney et al. (2012), 16 unique sleep diaries, which varied in terminology and format, were identified as being used out of a group of 22 sleep experts. The same group of experts developed a standardised sleep diary, the Consensus Sleep Diary, which aimed to address this problem (Carney et al., 2012). A core set of questions that were deemed the minimum required for a self-reported sleep diary were collated. Additions to these core items were made for specific sleep/wake concerns (Carney et al., 2012). Sleep diaries have been used in previous athlete sleep quantification research (Sargent et al., 2014a; Sargent et al., 2014b; Lastella et al., 2014; and Lastella et al., 2015a) and the Consensus Sleep Diary specifically has also been used (Knufinke et al., 2017). Some of these studies, however, used sleep diaries only to inform actigraphy analysis (Sargent et al., 2014a; Sargent et al., 2014b; and Lastella et al., 2015a).

Another form of self-reported sleep assessment is retrospective questionnaires and surveys. The Competitive Sports and Sleep Questionnaire, for example, has been used in previous research to document very large samples of athlete sleep/wake behaviour (Erlacher et al., 2011; and Juiliff et al., 2015). This questionnaire investigates pre-competitive sleep patterns over a 12-month retrospective period (Erlacher et al., 2011). While the accuracy of such a tool is not equal to any tool mentioned thus far in this section (Lastella et al., 2014; and Lastella et al., 2015b), it does offer advantages that other sleep assessments do not. The retrospective nature of the Competitive Sports and Sleep Questionnaire allows for athletes to provide pre-competition data without necessarily needing to be in competition phase at the time of the study (Erlacher et al., 2011). This allows for multiple sporting codes and athletes to be studied simultaneously regardless of whether the athletes are in-season, out of season or if they have a competition coming up soon. More objective tools would only be able to quantify pre-competitive sleep if the athlete was being monitored directly prior to competition, which limits the possible sample of athletes (Erlacher et al., 2011).

1.8 State of the current literature

The literature reviewed in this chapter highlights the following:

- Sleep is essential for growth, development, health, and well-being for adolescents.
- Sleep has also been shown to be a crucial component for optimal athletic performance.
- Adolescents are at risk of experiencing sleep loss given our understanding of the ‘perfect storm model’ of sleep changes during puberty.
- Athletes are predisposed to sleep loss because of training schedules especially when training is scheduled for the early morning.
- Early morning training for adolescent athletes theoretically would exacerbate the ‘perfect storm model’.
- Little research has focused on how early morning training alters the sleep behaviour of elite adolescent athletes.
- No available literature has documented the sleep habits of elite adolescent athletes in New Zealand
- No available literature has identified long term intervention strategies aimed at improving the sleep habits of elite adolescent athletes.

1.8.1 Research aims

Given the knowledge gaps identified above, the following aims directed the research undertaken for this thesis, which is described in subsequent chapters.

1. Investigate the sleep patterns of New Zealand adolescent athletes from different sporting codes with predominantly early morning training.

2. Assess the feasibility and efficacy of a sleep education and novel training rescheduling intervention for elite adolescent swimmers and on sleep patterns and swimming performance.
3. Assess the feasibility and efficacy of a sleep education intervention coupled with the introduction of blue light blocking glasses in a group of elite adolescent rowers.

CHAPTER 2 METHODOLOGY

Overview

This chapter provides an in-depth description of the aims, design and methodology used in the two studies conducted to address the knowledge gaps identified above. Chapters 3-5 present three scientific papers covering aspects of the research findings, and each includes a more succinct description of the relevant methods, which are restricted by journal word limits. The present chapter provides a broader overview of the rationale behind the methodological decisions for each of the studies.

2.1 Swimmers Intervention Study

2.1.1 Swim clubs and co-design of potential interventions

Swimming was identified in the literature as a sporting code where the potential for sleep loss is high. This is largely owing to swimming historically being a high-volume training sport which often requires athletes to train early in the morning. For this reason, 16 swimming clubs listed on the official Wellington Swimming website were emailed an expression of interest for conducting baseline and intervention studies with elite adolescent swimmers. Of the 16 clubs emailed, two were willing to discuss further details of the study. Meetings were arranged with the coaches from both teams to discuss the clubs' typical training schedule, the swimmers' schedules which included school, holidays and major competitions, as well as potential areas of intervention. The initial intervention proposed to the coaches was to provide their athletes with sleep education and to reschedule a morning training during the week to an afternoon session. After meeting with the coaches and learning more about their training schedules, it became clear that this first proposal was not feasible given that both teams already had training scheduled in the afternoon/early evening every day of the week.

After discussing potential alternatives with the coaches, a new proposal was presented which involved rescheduling a morning training session to another morning during the week. The intent was to try and provide the swimmers consecutive mornings in a row without an early wakeup during the week. Unfortunately, at this stage of discussion with the coaches, one of the swimming teams indicated upcoming scheduling concerns which would clash with the proposed two-month study period. The head coach was going to be out of the country, pushing the time of the study back. This in turn caused the proposed study time to clash with school holidays. These scheduling concerns resulted in the study being cancelled with this team. The other club's coach was satisfied with the new proposal and was excited to present the study design to his club.

2.1.2 Ethics and recruitment

2.1.2.1 Ethical procedures

After the final study design was agreed upon by the coach and research team, a full ethics application was submitted and approved by the Massey University Human Ethics Committee (Application SOA 18/36) prior to any contact with the swimmers.

2.1.2.2 Recruitment

Once ethical approval for the study was received, the coach arranged a meeting between the primary researcher, the swimmers and their parents at a local community centre around the corner from the training pool. The primary researcher (TS) presented the study design and handed out information letters (Appendix 1) detailing the full requirements of the study to the swimmers and their parents. The researcher fielded any questions about the study and made all in attendance aware that they could contact anyone on the research team with questions or concerns at any time. Of the 17 swimmers who were invited to the information session, 14 attended, all of whom volunteered to participate in the study.

2.1.2.3 Participant eligibility

The volunteers were given a screening questionnaire to fill out to assess their eligibility for the study (Appendix 2) The inclusion criteria and the characteristics of the study population are described in detail in Chapters 3 and 4. Volunteers had to be able to attend a minimum of 90% of the scheduled training sessions for the duration of the study and had to be free from injury at the time of the information session. To be eligible to participate as ‘elite’ adolescent swimmers, they had to have qualified or competed at a national level competition within the previous 12 months.

Volunteers meeting the study criteria who were under the age of 16 were required to give written informed assent and also needed written informed consent from a legal guardian to be allowed to participate (Appendix 3). Volunteers over the age of 16 were allowed to participate after giving informed consent but were still encouraged to discuss the study with their legal guardian (Appendix 3).

2.1.3 Participants – Swimmers

Of the 14 volunteers, 13 swimmers (mean age 14.8; SD 1.4 years; 54% female) completed the study with one having to be excluded due to sustaining an injury before the study could commence. None of the volunteers were excluded on the basis of answers given on the screening questionnaire.

2.1.4 Study design and methods

The final study design was a field-based, repeated-measures pilot study that compared the daily sleep and fortnightly swim performance of elite adolescent swimmers before and after a sleep education and training rescheduling intervention. The 8-week protocol is described in detail in Chapter 4. It included a two-week baseline training period followed by a six-week intervention period. Participants were asked to wear actigraphs and complete daily sleep diaries throughout the 8 weeks and sports-specific performance was measured twice during baseline and three times at two-week intervals during the intervention.

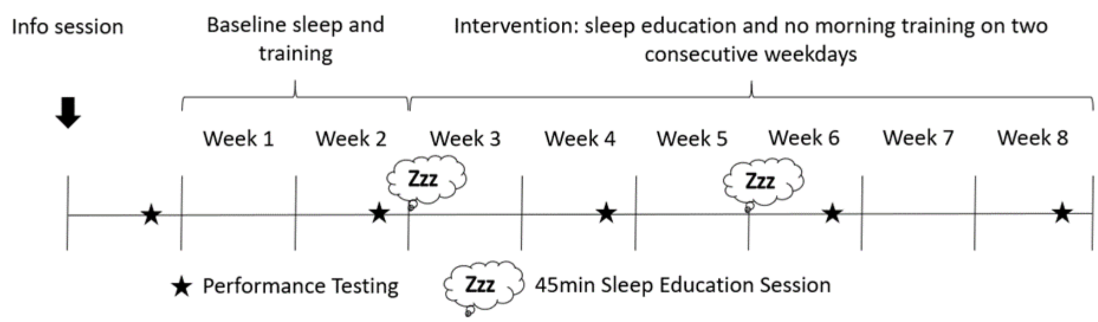


Figure 2.1. Graphical representation of the timeline of events for the intervention study. Note that this image was produced by the author of this thesis.

2.1.5 Intervention

The six-week intervention included a sleep education component and a training rescheduling component. The two components of the intervention were designed with the intention of maximising and encouraging behavioural change with regards to sleep. While the training rescheduling theoretically afforded the swimmers the opportunity to accrue consecutive extended periods sleep, the education they received was designed to help them make the most of the opportunity.

2.1.5.1 Sleep education program

The sleep education program consisted of two sleep workshops for the swimmers and a sleep education booklet (Appendix 4). All the education materials were developed and delivered by the primary researcher (TS). The first workshop took place at the beginning of the intervention period and was scheduled to last 45 minutes. The main aims of the workshop were:

- To provide athletes with a better understanding of basic circadian and sleep physiology.
- To talk about barriers to sleep and provide swimmers and their parents with strategies that may help improve their sleep/wake behaviours.
- To provide a motivational framework that would help encourage the swimmers to emphasise sleep and recovery in their everyday routines.

In an effort to make the sleep education as relevant to the swimmers as possible, the group was given general feedback based on the sleep data recorded during the first week of the baseline phase of the study. Each swimmer received an individual one-week baseline data report that aimed to address any personal sleep issues, as well as group sleep timing and duration information. They also received a sleep information booklet that reinforced the major themes covered in the workshop and served as a supplementary guide that they could work through in their own time.

Halfway through the intervention, the swimmers attended a follow-up 45-minute session where they received individual and group feedback relating to the previous month of sleep data collected. These data were used to set individual sleep targets for each swimmer to work towards in the second half of the intervention. This session also served as an opportunity to remind the swimmers of the key points addressed in the education they had received, provide a forum for the swimmers to ask questions, and to provide the researcher with feedback on their perceptions of the intervention.

2.1.5.2 Training rescheduling

The training schedule of the swimmers prior to the study and during baseline phase included eight swim training sessions a week with three early morning sessions that commenced at 5:30 on Monday, Wednesday and Friday. The swimmers also had daily afternoon training Monday to Friday with no training scheduled over weekends. For the six-week intervention period, Wednesday morning training was rescheduled to take place on Tuesday morning at 5:30. The decision as to which training session would be moved and to which day was made in consultation with the swimmers' coach. The rescheduling provided two consecutive weekday mornings free of training for the duration of the intervention while the number of training sessions per week was kept constant. While certain sessions were rescheduled, the overall number of weekly training sessions did not change, only the day on which training took place. The coach also agreed to keep training load (intensity X frequency) over the eight-week study period as consistent as possible.

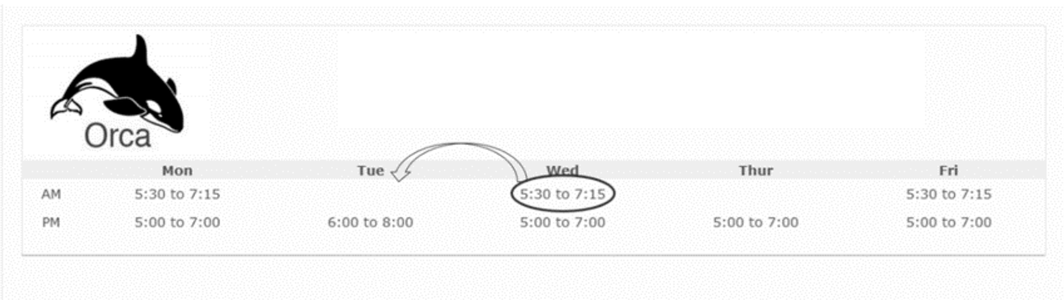


Figure 2.2. Training schedule before and after intervention. Session circled with the arrow indicates the training which was rescheduled. This image has been produced by the author of this thesis.

2.1.6 Dependent measures

2.1.6.1 Actigraphy

Objective sleep measures were obtained from Micro MotionLogger actigraphs (Ambulatory Monitoring Inc. [AMI], Ardsley, NY, USA) throughout the eight-week study period. The Micro MotionLogger is a watch that also houses an accelerometer to detect wrist movement. The watch face has a functional time display and an event marker button (Figure 2.3). The Micro MotionLogger also has a light sensor and the ability to detect when the watch is in contact with skin, via a temperature sensor.

Figure 2.3. Photo of the watch face of the Micro MotionLogger.

Prior to participants receiving their watches, each device was cleaned, a new battery was inserted, and the watch was programmed to record data in 1-minute epochs using the monitor's zero-crossing mode (Meltzer et al., 2015). Participants were asked to wear the watch on their non-dominant wrist continuously for the duration of the study (Meltzer et al., 2015). While the watches are water resistant, participants were instructed to take the watches off during long exposure to water (swimming, bathing, showering etc.) to prevent any damage or loss of data, and to record whenever they took the watch off.

Participants were also asked to press the event marker button when they actively began trying to fall asleep and upon awakening. This placed a mark within the raw data which aided the researcher in scoring actigraphy. Appendix 5 shows a copy of the instructions given to participants on how to wear and use the watch.

Data were downloaded from the Micro MotionLoggers at three time points:1) at the Friday morning training session one week into the baseline phase, to provide data for the first education session the following week; 2); two weeks into the intervention period (four weeks into the study), when the actigraph's battery was changed and the first 4 weeks of data could be scored for the second education session the following week; and 3) at the end of the intervention.

Following best practice for scoring actigraphy, participants were also asked to keep a daily sleep diary to record periods of sleep as well as when the watch may have been removed or periods of inactivity (Littner et al., 2003). The diary included a daily timeline for participants to mark the start and end time of any sleep period lasting longer than 10-minutes.

To identify sleep periods, the actigraphy data were visually checked against the sleep diary timelines, the event marker data, and the light and skin contact data., Sleep and wakefulness were inferred from activity counts per minute using the Cole-Kripke algorithm (Cole et al., 1992) in the manufacturer's software (Action-W version 2.7.3045, Ambulatory Monitoring Inc., Ardsley, New York, USA). Sleep measures extracted from the actigraphy data were:

- Sleep onset – clock time when participants first fell asleep
- Sleep offset – clock time of participants finally woke up
- Midsleep point – the halfway point between sleep onset and sleep offset
- Sleep duration – the difference between sleep onset and sleep offset

2.1.6.2 Hooper Index

Alongside the sleep timelines, the daily diary included the Hooper Index and a question regarding device use. A copy of the diary instructions and example diary filled out can be found in Appendix 5. The Hooper Index was included to measure subjective ratings of sleep quality, stress, fatigue and muscle soreness (Hooper & Mackinnon, 1995), and was selected for use in this study because of its brevity compared to other similar questionnaires. The Hooper Index has a Likert scale for each item making it quick and easy to complete on a daily basis. The Likert scales ranged from one to seven with one always representing the best-case scenario and seven the worst. To try and add colour and personality into the diary, emoji faces were added to the rating scale. The athletes were asked to complete the Index each morning upon awakening after completing their sleep timelines. An additional yes/no question was added to the daily diary regarding device use before bed. Participants were asked to indicate whether they used any electronic devices (e.g. television, mobile phone, tablet, gaming console etc) in the last hour leading up to their bedtime. At the end of each week the diary had motivational quotes or jokes that were swimming specific, to again try to encourage completion of the diary.

2.1.6.3 Performance testing

All performance-testing sessions were completed fortnightly at the same time of day (6:00) and on the same weekday (Friday mornings). Keeping the time of testing consistent limited possible confounding by circadian fluctuations in performance.

To monitor any change in swimming specific performance across the study, participants were asked to perform a simulated race in the stroke and distance of their own choosing. They were encouraged to choose, in consultation with their coach, the stroke and distance in which they were most proficient, and completed their races in the same stroke and distance for all testing sessions. The time to complete the race was then calculated as a percentage of each swimmer's personal best for the corresponding stroke and distance, to enable comparisons between swimmers.

All races were preceded by a standard warm-up routine, which was identical to that used by these swimmers and their coach prior to a competitive race. The distance and intensity of the warm-up routine was individualised for each swimmer but remained constant across all testing sessions. This is in accordance with previous methodology (Balilionis et al., 2012).

Three qualified timekeepers recorded race times. An adjusted Borg CR10 scale (Borg, 1990 and Borg, 1998) was used to measure athletes' perceptions of effort after the warm-up and again after the simulated races.

Participants were instructed not to eat anything from 22:00 the night before performance testing until after the test was completed the next morning. Water was allowed to be consumed ad libitum during this time. Participants were also asked to avoid meals that were not part of their habitual diet on the nights before performance testing. These measures were put in place to reduce the likelihood of dietary intake confounding results.

2.1.7 Statistical analyses

2.1.7.1 Classification of data

Actigraphy and sleep diary data were analysed to identify main effects for ‘Nights of the week’; ‘Intervention’ and ‘Age’. Nights of the week were classified as the following three categories:

- Morning training – night prior to a weekday morning where training took place.
- Morning off – night prior to a weekday morning where no training took place.
- Weekend off – night prior to a weekend morning (no training took place on any weekend)

Analyses for ‘Intervention’ also required data to be classified into three categories:

- Baseline – first two weeks of the study.
- First half of the intervention – first three weeks of the intervention up until the second education workshop
- Second half of the intervention – last three weeks of the intervention

For the purposes of analysis of ‘Age’, the swimmers were dichotomized into ‘Under 15’ and ‘Over 15’ groups.

The original statistical model also included main effects of ‘Sex’, however, the model lacked statistical power owing to the low sample size and was subsequently removed.

Interaction effects were calculated in conjunction with main effects and included:

- ‘Nights of the week’ by ‘Intervention’
- ‘Nights of the week’ by ‘Age’

- ‘Intervention’ by ‘Age’ – included in original model but excluded from final analyses

Nights of the week’ by ‘Intervention’ by ‘Age’ – included in original model but excluded from final analyses.

2.1.7.2 Analysis

All statistical analyses were run in SAS (version 9.3, SAS Institute Inc., Cary, NC, USA). Differences in actigraphy variables were analyzed using linear-mixed models with a Kenward-Roger adjustment (Littell *et al.,* 2007). Model assumptions of normality, linearity and constant variance were assessed visually while Kolmogorov-Smirnov test for normality was used to assess distribution of residuals (Tabachnick & Fidell, 2012). Outlying residual variables were removed where identified and the models were rerun with these missing. In all cases where this was done, the findings of the models were not altered with the outliers excluded and thus the final models included outlier data. Levene’s test was also conducted to assess inequality of variance between groups (Levene, 1960 and Tabachnick & Fidell, 2012). The alpha level for the linear-mixed models was set at 0.05 except for where significant variance between groups was identified by Levene’s test. In these instances, a more stringent alpha of 0.01 was implemented.

Cumulative logit proportional-odds models were used to analyse Hooper Index responses given that these data were multinomial and categorical (Kiernan, 2018). Device use data, which was assessed using a yes/no question, were analysed using a binomial logistic regression model (Kiernan, 2018).

Main and interaction effects for all models were further analysed using Holm-Bonferroni post hoc adjustments as well as calculating effect sizes using Cohen’s D (Field, Miles &

Field, 2012). Effect size magnitude was classified as: 0.2–0.49, small effect; 0.5–0.79, moderate effect; ≥0.8, large effect (Cumming, 2014).

2.2 Rowers Intervention Study

2.2.1 Rowing teams

Rowing was another sporting code identified in the literature to have a long tradition of early morning training. Unlike swimming, rowing is often team-based, especially during high school competition. The reported differences in sleep patterns between individual and team-based sporting codes prompted the decision to compare swimmers and rowers in the thesis research.

A convenience sample of rowing teams was approached for participation. One of the members of the research team (JZ) had a personal affiliation with a local rowing club which included several school teams. The head coach of the club was receptive to the idea of a sleep intervention study with the school teams and facilitated a meeting between members of the research team and the coaches of these teams. A different intervention was proposed to be piloted with the rowers compared to the previous study with swimmers, namely an intervention that incorporated blue light blocking glasses with sleep education. Another difference between the studies was that the rowers were to be monitored leading up to, during, and after the major regatta for the calendar year, the Maadi Cup, whereas the swimmers were monitored across an 8-week period of routine training.

2.2.2 Ethics and recruitment

2.2.2.1 Ethical procedures

Once the coaches and researchers agreed on the final study design, a full ethics application was submitted and approved by the Massey University Human Ethics Committee (Southern A, Application 18/86). Initial contact with the rowers and their parents was facilitated by the team and club coaches after ethics approval had been received.

2.2.2.2 Recruitment

An information session was arranged at the rowing club for rowers and parents to find out more about the study. However, trying to align both teams' schedules proved difficult and resulted in low turnout at the meeting. The tight timeframe to start the study to ensure that it fell in the lead up to the Maadi Cup mean that additional information sessions could not be offered. Instead, the primary researcher (TS) attended a local regatta where both teams were competing and informed rowers about the study and gave out information letters (Appendix 6) Of the 73 rowers making up both school teams, 22 volunteered to participate in the study.

2.2.2.3 Participant eligibility

Eligibility criteria for the rowers were the same as for the swimmers, based on the same screening questionnaire (Appendix 2). The only difference was that rowers had to have qualified or competed in a national level regatta within the past 12 months to be classified as an 'elite' adolescent rower for the study.

As with the swimmers, volunteers under the age of 16 needed to provide informed assent and legal guardian consent to be allowed to participate in the study (Appendix 3). Rowers over the age of 16 needed to provide informed consent and were encouraged to discuss the study with their legal guardians.

2.2.3 Participants – Rowers

Three of the 22 volunteers withdrew from data collection leaving 19 rowers (mean age 16.5; SD 1.1 years; all male) who completed this study. As both of the rowing teams were male teams, no female rowers were recruited into the study. The inclusion criteria and the characteristics of the study population are described in detail in Chapters 3 and 5.

Eleven of the rowers were from Rowing Team A and eight were from Rowing Team B. Rowing Team A had 11 scheduled training sessions a week while Rowing Team B had 10. Both teams had four early morning training sessions on weekday mornings all starting at 6:00. Unlike the swimmers, both rowing teams had weekend training sessions which were scheduled to commence at 8:00. It should be noted that while these were the booked training sessions throughout the study, not all of the sessions were used by the coaches depending on weather conditions as well as athlete needs.

2.2.4 Study design

The study design implemented with the rowers was a field-based, repeated-measures pilot study that compared the daily sleep of elite adolescent rowers before and after a sleep education intervention which included the use of BlueBlockGlasses (Somnitude Inc., Toronto, Ontario, Canada).

The baseline sleep of the rowers was initially monitored using actigraphy and a sleep diary for 10 days during typical training. Participants were then invited to attend a 45-minute sleep education workshop at Massey University, Wellington where sleep education booklets and BlueBlockGlasses were distributed to each participant. The educational material was identical to that used in the swimmers' study and was presented by the primary researcher (TS). The rowers were asked to use the BlueBlockGlasses in the two hours leading up to their bedtime (as in Bender, Werthner & Samuels, 2018).

Participants were asked to wear their actigraphs and maintain daily sleep diaries for the next six weeks. Four of these weeks were normal training weeks. The seventh week after the study began was the weeklong Maadi Cup regatta followed by a recovery week. Sleep monitoring continued throughout this time to investigate how sleep would change during a weeklong competition followed by recovery.

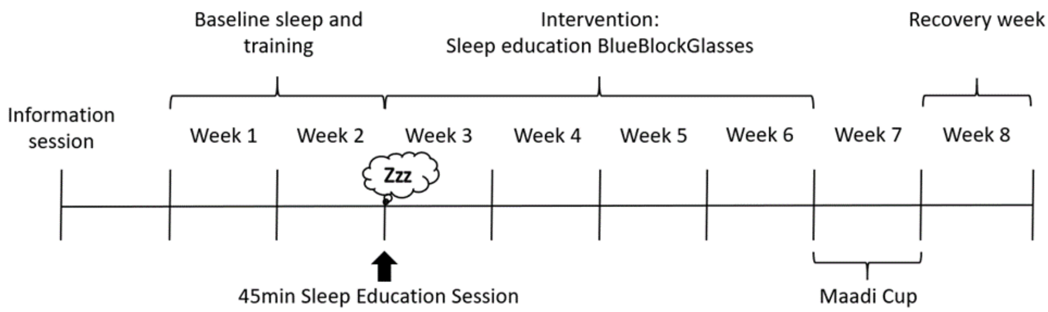


Figure 2.4. Graphical representation of the timeline of events for monitoring the rowers.

2.2.5 Intervention

The four-week intervention included the provision of sleep education material and BlueBlockGlasses to the rowers. (Figure 2.4).

2.2.5.1 BlueBlockGlasses

The blue light blocking glasses given to the rowers were BlueBlockGlasses Basic (Fitover) which were donated to the research team by Somnitude Inc., Toronto, Ontario, Canada. Figure 2.5 depicts the spectral range of light the BlueBlockGlasses allow through the lenses. The company claim that 99% of light below 520nm is blocked from passing through the lenses. The fitover design also allowed for the glasses to be worn while wearing prescription glasses (Figure 2.5). During the sleep education workshop, the rowers were informed about how blue light before bedtime can alter sleep/wake regulation and how the glasses might prevent this from happening. It was emphasized that the gold standard for eliminating or reducing blue light was to reduce or stop using electronic devices that may emit blue spectral light. The glasses were introduced as an additional strategy for reducing blue light exposure before sleep, not as an alternative to trying to reduce device use, which can have negative impacts on sleep in addition to its associated blue light exposure. The rowers were instructed to wear their glasses in the last two hours before bedtime each night.

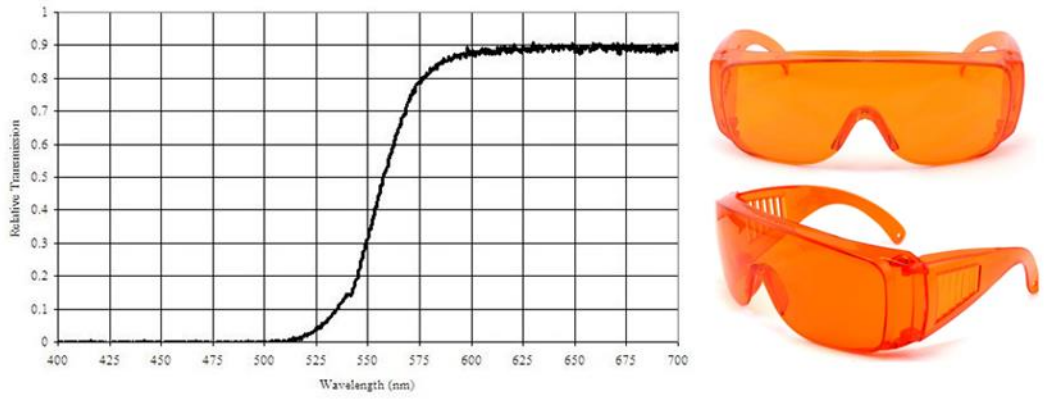


Figure 2.5. Spectral transmittance graph of the Somnitude lenses used in the BlueBlockGlasses (https://blueblockglasses.com).

2.2.6 Dependent measures

As in the swimmers' study, sleep was measured objectively using the Micro MotionLogger actigraphs (Ambulatory Monitoring Inc. [AMI], Ardsley, NY, USA) and subjectively with timelines in a daily diary, which also included the Hooper Index and a question regarding device use before bed. In addition during the intervention, the diary required the rowers to answer a yes/no question regarding whether they had used the BlueBlockGlasses in the last two hours before bed.

2.2.7 Statistical analyses

2.2.7.1 Classification of data

The rowers' actigraphy and diary data were analysed for main effects of 'Nights of the week', 'Intervention', and 'BlueBlockGlasses'. Nights of the week were classified as one of the following four:

- Morning training – night prior to a weekday morning where training took place.
- Morning off – night prior to a weekday morning where no training took place.
- Weekend off – night prior to a weekend morning without training
- Weekend training – night prior to a weekend morning training

Analysis for the main effect of Intervention compared data pre and post the introduction of the sleep education and BlueBlockGlasses. In addition to the Intervention analyses, data during the intervention period was classified as either a night where BlueBlockGlasses were used before bed and nights where they were not used. Nights with and without glasses use were compared for a main effect of BlueBlockGlasses.

The following interaction effects were calculated in addition to main effects:

- 'Nights of the week' by 'Intervention'
- 'Nights of the week' by 'BlueBlockGlasses'

2.2.7.2 Analysis

All statistical analyses were run in SAS (version 9.3, SAS Institute Inc., Cary, NC, USA). Differences in actigraphy variables were analyzed using linear-mixed models with a Kenward-Roger adjustment (Littell *et al.,* 2007). Model assumptions of normality, linearity and constant variance were assessed visually while Kolmogorov-Smirnov test for normality was used to assess distribution of residuals (Tabachnick & Fidell, 2012). Outlying residual variables were removed where identified and the models were rerun with these missing. In all cases where this was done, the findings of the models were not altered with the outliers excluded and thus the final models included outlier data. Levene's test was also conducted to assess inequality of variance between groups (Levene, 1960 and Tabachnick & Fidell, 2012). The alpha level for the linear-mixed models was set at 0.05 except for where significant variance between groups was identified by Levene's test. In these instances, a more stringent alpha of 0.01 was implemented. Holm-Bonferroni post hoc adjustments were calculated as well as Cohen's d for effect size (Field, Miles & Field, 2012). Effects were classified as small (0.2–0.49), moderate (0.5–0.79) and large (≥0.8) (Cumming, 2012).

Cumulative logit proportional-odds models were used to analyze Hooper Index items and a binomial logistic regression model was used to analyse device use.

CHAPTER 3 SLEEP/WAKE BEHAVIOUR OF COMPETITIVE ADOLESCENT ATHLETES IN NEW ZEALAND: INSIGHT INTO THE IMPACT OF EARLY MORNING TRAINING

The following chapter details data collected during the Baseline phases of both the swimmers' and rowers' studies outlined in Chapter 2. The baseline phase of the studies was crucial in determining the typical sleep behaviours of elite adolescent athletes in New Zealand. The following manuscript was prepared by the researcher and was published by the journal *Sleep Medicine* in January 2021 (Steenekamp *et al*., 2021).

3.1 Abstract

Objective: Sleep plays a crucial role in the health, wellbeing, and development of adolescent athletes' sporting and academic lives. This study aimed to monitor the sleep/wake behaviours of adolescent athletes who have frequent early morning training sessions.

Methods: 13 swimmers (mean age 14.8 ± 1.4; 46% male) and 19 rowers (mean age 16.5 ± 1.1; all male) wore actigraphs and completed sleep diaries over a 2-week training period. Diaries included the Hooper Index and a question regarding device use before bed. Participants also completed chronotype questionnaires. Nights of the week were categorised as taking place before "morning training", "mornings off", "weekend mornings off", and "weekend morning training". Actigraphy and sleep diary variables were compared for different nights of the week.

Results: All athletes were classified as "morning type". Average sleep duration across the study was 7h55 (± 1h33). Median sleep duration was significantly shorter on nights before weekday morning training (6h44) compared to weekday mornings off (8h45). This was due to an earlier wake time (04:51) while bedtime remained constant (~22:15). Athletes went to bed later, woke later and slept for longer on nights before weekend mornings off compared to weekday nights.

Conclusions:

Early morning training advanced the wake times of the athletes while bedtime remained constant. This shortened sleep below age recommended durations on the nights before early morning training during the week. These findings suggest that weekly average sleep duration does not accurately reflect athletes' nightly sleep given the large variability across a training week.

Keywords:

Sleep duration; Sleep timing; Adolescent athlete; Training schedule; Swimming; Rowing

3.2 Introduction

Emerging evidence suggests that the sleeping habits of adolescents may be preventing them from reaching their sporting potential. Insufficient sleep has been linked to negative outcomes for physical health including an increase in injury rates, poorer psychological health and well-being, as well as decrements in cognitive and physical facets of athletic performance (Fullagar *et al;* 2015; Hirshkowitz *et al.,* 2015; and von Rosen *et al.,* 2017). As outlined by the International Olympic Committee, sleep plays an essential role in the development of youth athletes (Bergeron *et al.,* 2015). Sleep requirements change across the lifespan, with the National Sleep Foundation recommending that adolescents get between 8-10 hours of sleep per night (Hirshkowitz *et al.,* 2015). Reviews and meta-analyses indicate that globally a large proportion of adolescents sleep less than these recommended durations on school nights (Carskadon, 2011; and Gradisar *et al.,* 2011). This trend is suggested to be a result of competing physiological, psychological and socio-cultural factors (Carskadon, 2011; and Bartel *et al.,* 2015).

Adolescence is accompanied by pubertal changes to both the circadian timing system and the homeostatic sleep process which, in tandem, regulate sleep and wakefulness (Carskadon, 2011; and Crowley *et al.,* 2018). These changes include a phase delay in circadian timing and a slower build-up of sleep pressure, resulting in a shift in sleep timing with a preference for later bed and wake times (Carskadon, 2011; and Crowley *et al.,* 2018). This physiological preference is often in direct conflict with adolescents' extracurricular and school commitments (Carskadon, 2011; and Crowley *et al.,* 2018). Early morning training has been suggested to be a risk factor for sleep loss in athletes for this very reason (Sargent *et al.,* 2014; Lastella *et al.,* 2015; Kölling *et al.,* 2016; and Gudmundsdottir, 2019). For adolescent athletes to obtain sufficient sleep before early morning training they would need to go to sleep during the evening 'wake maintenance zone' (Crowley & Eastman, 2018). This is a time of the night when wakefulness is being promoted by the circadian timing system and occurs later in adolescence than in adulthood (Crowley & Eastman, 2018). Sports requiring high volume training often utilise early mornings to fit enough training into the week. Participating in individual athlete sporting codes is also a risk factor for short sleep, with adult athletes who participate in team sports obtaining more sleep (7h00) than their individual sport counterparts (6h30) (Lastella *et al.,* 2015). Lastella and colleagues (2015) attribute this difference in part to the timing of training, with individual sport athletes having more early morning training sessions.

In addition to the physiological changes occurring in adolescence, technology use for academic, social and recreational purposes prior to bed is increasingly prevalent (Bartel *et al.,* 2015). Device use and evening light exposure have been identified as significant risk factors for delayed bedtimes in adolescents as bright light, in addition to the alerting effect of stimulating content, can further delay melatonin secretion (Bartel *et al.,* 2015). Over the weekend adolescents often go to bed later, wake later and extend the duration of sleep (Carskadon, 2011; and Crowley *et al.,* 2018). This disrupts the circadian timing system making it difficult to fall asleep on subsequent school nights (Carskadon, 2011; and Crowley *et al.,* 2018). For adolescent athletes, weekends are not always a respite with weekend training and competition possibly further disrupting sleep patterns.

This study aimed to investigate the sleep patterns of New Zealand adolescent athletes from different sporting codes with predominantly early morning training. It was hypothesised that adolescent athletes would obtain sufficient sleep on nights not impacted by early morning training the next day. It was expected that on nights preceding an early morning training session sleep would be shortened owing to the early rise time and the inability of athletes to advance their bedtimes.

3.3 Materials and Methods

3.3.1 Participants

The athletes recruited were from a coeducational swimming club and two male rowing teams. Swimming and rowing were chosen as both sports are historically high-volume activities with frequent morning training sessions (Secher and Volianitis, 2007; & Allen and Hopkins, 2015). While swimming is an individual sport, rowing can be both individual and team orientated with athletes from both selected rowing teams competing almost exclusively in multi-person crews. In total, 17 swimmers and 72 rowers were approached to take part in the study. 14 swimmers and 22 rowers volunteered to participate. Study inclusion criteria required athletes to be between the ages of 13 and 18 years; nonsmokers; with no diagnosis of sleep or mood disorders; not currently taking any medication known to affect sleep and no international travel in the previous month. Volunteers completed the Athlete Sleep Screening Questionnaire (ASSQ) (Samuels *et al,* 2016; & Bender *et al.,* 2018) to identify any potential undiagnosed sleep issues. Athletes who were injured at the time of recruitment or unable to attend at least 90% of training sessions during the study period were excluded. All the athletes in the study had competed, or had qualified to compete, in a national level competition within the previous 12 months. One swimmer could not complete the study due to an injury and three rowers' data sets were unusable due to a large percentage of missing data. No athletes were excluded based on the ASSQ. In total, 13 swimmers (mean age 14.8; SD 1.4 years; 46% male) and 19 rowers (mean age 16.5; SD 1.1 years; all male) completed this study. The study was approved by the Massey University Human Ethics Committee (Application SOA 18/36). Informed consent was received from all participants over the age of 16 and participant assent with parental consent was received for athletes younger than 16.

3.3.2 Design

Data reported here were collected for 14 days during a typical training phase. This duration of data collection provides a stable estimate of habitual sleep duration and night to night variability (Mah *et al.,* 2011) and was also the baseline phase of a larger 8-week research program: Athletes were monitored immediately prior to a 6-week educational and training rescheduling intervention. Swimmers were monitored in August 2018 as it was a consolidated period of training without the interruption of major competitions or school holidays. Rowers were monitored in February 2019 during the competitive rowing season but two months prior to the most significant school regatta.

The number and organization of training sessions differed between the swimmers and rowers as well as between the two rowing teams. Swimmers were scheduled for 8 training sessions per week, 3 of which were early morning sessions commencing at 5:30

on Monday, Wednesday and Friday. No training sessions were scheduled on weekends for the swimmers. The rowing teams had either 9 or 10 scheduled training sessions per week depending on the team. Both rowing teams had 4 weekday early morning sessions starting at 6:00 with Thursday morning off for one rowing team and Friday morning off for the other. The rowing teams had weekend training sessions which were scheduled to start at 8:00 on both Saturday and Sunday. While session intensity was not measured, coaches were instructed to keep training intensity as consistent as possible during the study period.

3.3.2.1 Classification of nights

Types of night were coded based on whether sleep took place prior to a weekend or weekday morning as well as whether it was prior to a training morning or a morning off. Sleep was therefore categorized as taking place prior to “morning training” (training on weekday mornings), “morning off” (weekday mornings free from training), “weekend off” and “weekend training”.

3.3.2.2 Measures

Athletes wore Micro MotionLogger devices (Ambulatory Monitoring Inc. [AMI], Ardsley, NY, USA) on their non-dominant wrist continuously for the total duration of the study (Meltzer *et al.,* 2012). Data were collected using the device’s zero-crossing mode and recorded in 1-minute epochs (Meltzer *et al.,* 2012). Using the manufacturer’s software (Action-W version 2.7.3045, Ambulatory Monitoring Inc., Ardsley, New York, USA), sleep and wakefulness were inferred based on activity count using the Cole-Kripke algorithm (Cole *et al.,* 1992). In conjunction with actigraphy, sleep was recorded on timelines in a sleep diary. Data from the sleep timelines and the MotionLogger’s event marker were used to confirm the timing of sleep periods detected by actigraphy. Measures taken from the Motionlogger included sleep onset (when participants fell asleep), midsleep point (the halfway point between sleep onset and offset); sleep offset (when participants woke up), and sleep duration (calculated from sleep onset and offset).

The Hooper Index was included in the sleep diary to measure subjective ratings of sleep quality, stress, fatigue and muscle soreness (Hooper *et al.,* 1995). The 4 items of the Hooper Index were rated on a 1-7 Likert scale with 1 representing best-case scenario and 7 the worst. Athletes were asked to complete the Hooper Index each morning upon awakening, after completing their sleep timelines. The diary also included a yes/no question regarding whether participants used an electronic device in the hour before bedtime.

The Morningness-Eveningness Scale for Children (MESC) (Carskadon *et al.,* 2018) was incorporated into participants' sleep diaries and used as a one-off measure of chronotype. MESC scores range from 14 to 42 with lower scores indicating greater eveningness and higher scores indicating greater morningness. In addition to the screening purposes of the ASSQ, this questionnaire was also used for measures of habitual caffeine use, evening device use and chronotype. ASSQ chronotype scores range from 0 to 14 with scores ≥ 4 indicating eveningness.

3.3.2.3 Statistical analysis

All statistical analyses were run in SAS (version 9.3, SAS Institute Inc., Cary, NC, USA). Actigraphy variables were analyzed using linear-mixed models. The models included main effects of night of the week, sport and age and an interaction effect of night of the week with sport. A Kenward-Roger adjustment was used for the degrees of freedom calculation (Littell *et al.,* 2006). The assumptions of the model were checked visually, and the distribution of residuals was assessed using the Kolmogorov-Smirnov test for normality. Levene's test was used to determine whether the variance was constant between groups. The alpha level for the study was set at 0.05, however, where Levene's test showed variances were not constant, a more conservative alpha level was used when interpreting the results of fixed-effects ($p<0.01$) (Tabachnick and Fidell, 2006). Post hoc tests with Holm-Bonferroni adjustments were run to further understand fixed effect results and Cohen's d was used to calculate effect sizes (Field *et al.,* 2012). The magnitude of effects was classified as follows: 0.2–0.49, small effect; 0.5–0.79, moderate effect; ≥0.8, large effect (Cumming, 2014). Models that included all athletes excluded the rowers' weekend training data as rowers had weekend training while the swimmers did not. A separate linear-mixed model, using only the rowers' data, was run to analyse the effect of weekend training on sleep and included main effects of night of the week. Items on the Hooper Index were analysed using a cumulative logit proportional-odds model and device use was analysed using a binomial logistic regression model. Chronotype responses for the MESC and ASSQ were analysed for age, sex and sport differences using Student T-Tests.

3.4 Results

3.4.1 Demographics

The average score on the MESC was 35.4 (SD 3.0; range 30-41) indicating that on average athletes were more "morning type". The average score for chronotype on the ASSQ was 8.2 (SD 2.0; range 5-13) which also suggests the athletes tended towards being "morning type". No significant differences in age, sex or sport were found for either measure of chronotype. Results from the ASSQ indicated that 37% of the adolescents napped infrequently (63% reporting no naps) and 16% reported low habitual caffeine intake (84% reporting zero caffeine intake). Electronic devices were reportedly used before bedtime between 3-6 nights of the week by 75% of the athletes while the other 25% reported infrequent use.

Average sleep duration over the two weeks of the study for all athletes was 7h55 (± 1h33) with average sleep onset and sleep offset of 22:44 (± 1:03) and 6:38 (± 1:28) respectively. The median and range of sleep variables for different night categories can be found in Table 3.1.

Table 3.1. Median and range values for sleep variables for different nights of the week for all athletes and swimmers and rowers separately.

	Morning off	Morning training	Weekend off	Weeker trainin
	Median (Min-Max)	Median (Min-Max)	Median (Min-Max)	Mediar (Min-Ma
Sleep Duration				
All Athletes	8h45 (5h45 - 11h33)	6h44 (4h01 - 8h30)	9h08 (6h09 - 13h58)	NA
Rowers	8h34 (6h22 - 10h00)	6h55 (4h29 - 8h30)	9h17 (6h35 - 13h58)	7h54 (5h11 - 9h
Swimmers	9h04 (5h45 - 11h33)	6h36 (4h01 - 8h03)	9h00 (6h09 - 12h04)	NA
Sleep Onset				
All Athletes	22:24 (21:01 - 00:49)	22:13 (20:32 - 00:45)	23:31 (21:08 - 3:07)	NA
Rowers	22:32 (21:25 - 00:49)	22:22 (21:15 - 00:45)	23:43 (21:37 - 3:07)	22:47 (21:19 - 1
Swimmers	22:19 (21:01 - 00:46)	22:05 (20:32 - 00:44)	23:24 (21:08 - 2:17)	NA
Midsleep				
All Athletes	2:53 (1:20 - 4:38)	1:32 (00:28 - 3:02)	4:10 (1:48 - 6:56)	NA
Rowers	2:53 (2:12 - 4:19)	1:45 (1:17 - 3:02)	4:11 (3:40 - 6:56)	2:56 (2:01 - 4
Swimmers	2:41 (1:20 - 4:38)	1:25 (00:28 - 2:44)	4:09 (1:48 - 6:28)	NA
Sleep Offset				
All Athletes	7:11 (4:42 - 9:00)	4:51 (4:14 - 5:44)	8:52 (5:39 - 11:34)	NA
Rowers	7:11 (6:07 - 8:16)	5:13 (4:55 - 5:44)	9:04 (8:12 - 11:34)	7:02 (5:31 - 7:
Swimmers	7:16 (4:42 - 9:00)	4:42 (4:14 - 4:58)	8:38 (5:39 - 11:21)	NA

Note: Median and range provided as data were not normally distributed. Range is for all values ac
all possible nights.

3.4.2 Type of night differences

Linear mixed model analyses revealed main effects for type of night with respect to sleep duration (p<0.001, df=2, 268, F=233.28), sleep onset (p<0.001, df=2, 268, F=60.32), midsleep time (p<0.001, df=2, 266, F=439.49), sleep offset (p<0.001, df=2, 275, F=658.66) and sleep quality (p=0.02, df=2, 227, F=3.95) (Figure 3.1). No statistically significant main effect for type of night was found for stress, fatigue, muscles soreness and device use before bed. No significant differences in age were seen for any actigraphy or sleep diary variables. Table 3.2 presents post-hoc tests for models with significant main effects.

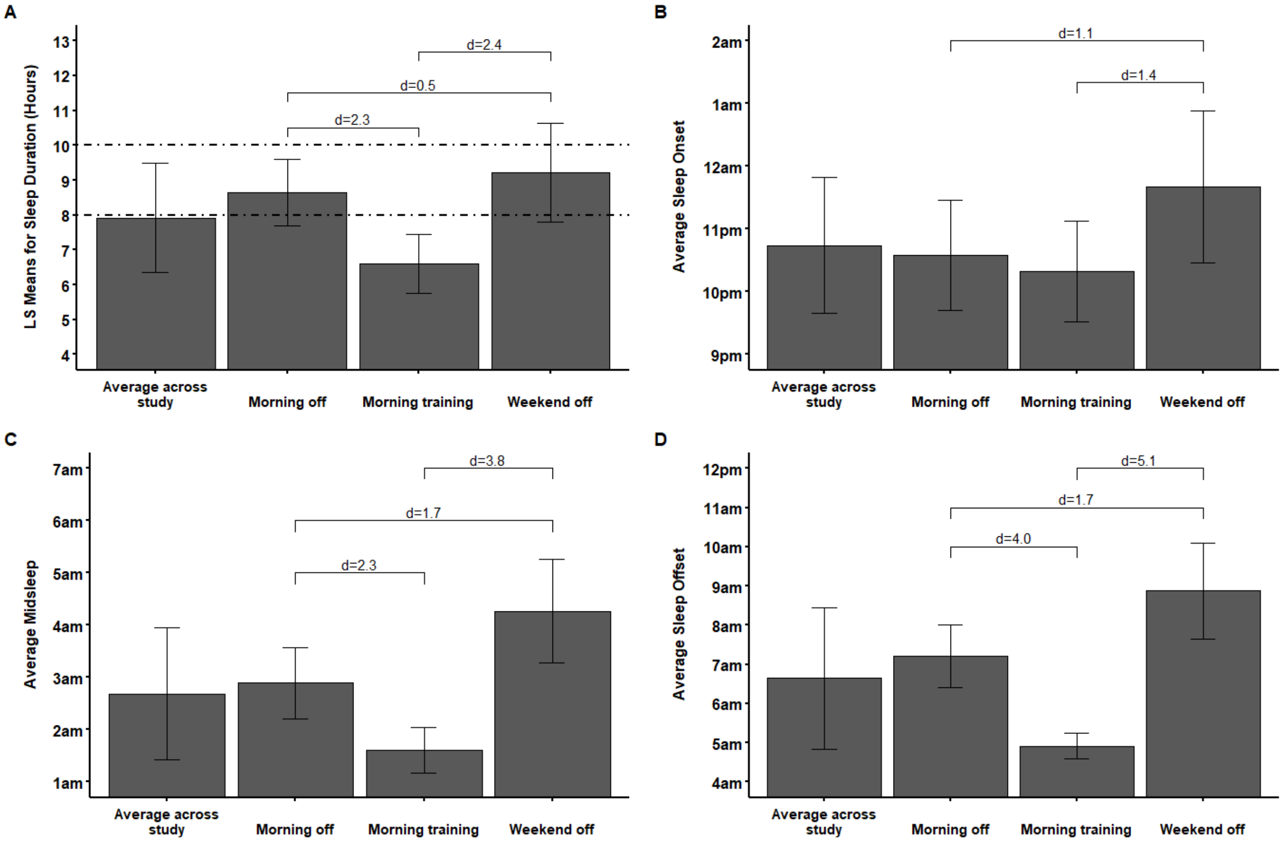


Figure 3.1. Least Squared Means for Sleep Duration (A), Sleep Onset (B); Midsleep (C) and Sleep Offset (D) for different night conditions for all athletes. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = larg

Table 3.2. Post hoc results comparing actigraphy variables between night conditions for all athletes. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

	Comparison of nights before:		LS Means Estimate (Mins)	Confidence Interval Lower (Mins)	Upper (Mins)	DF	t Value	Adj p-Value	Cohen's d
Sleep Duration									
	Morning off	Morning training	123.2	105.3	141.0	264	16.6	**<.0001**	2.3
	Morning off	Weekend off	-44.8	-66.8	-22.8	270	-4.9	**<.0001**	0.5
	Morning training	Weekend off	-168.0	-189.2	-146.8	271	-19.1	**<.0001**	2.4
Sleep Onset									
	Morning off	Morning training	9.8	-4.2	23.7	261	1.7	1	0.3
	Morning off	Weekend off	-63.5	-80.6	-46.4	264	-8.9	**<.0001**	1.1
	Morning training	Weekend off	-73.3	-89.8	-56.8	265	-10.7	**<.0001**	1.4
Midsleep									
	Morning off	Morning training	72.9	61.9	83.9	264	15.9	**<.0001**	2.3
	Morning off	Weekend off	-85.4	-99.0	-71.9	268	-15.2	**<.0001**	1.7
	Morning training	Weekend off	-158.3	-171.4	-145.2	269	-29.2	**<.0001**	3.8
Sleep Offset									
	Morning off	Morning training	135.0	120.7	149.3	270	22.7	**<.0001**	4.0
	Morning off	Weekend off	-108.3	-125.8	-90.9	278	-14.9	**<.0001**	1.7
	Morning training	Weekend off	-243.3	-260.1	-226.5	278	-34.8	**<.0001**	5.1

Note: Bold values represent statistically significant results.

3.4.3 Sporting code differences

Sleep duration (*p*=0.03, *df*=1, 24.2 *F*=5.23) and sleep offset (*p*=0.01, *df*=1, 27.8, *F*=7.97) differed significantly between swimmers and rowers (Figure 3.2). Aross the two week baseline study, the swimmers slept less on average (*t*=-2.29, *p*=0.031, *d*=0.02) and woke earlier (*t*=-2.82, *p*=0.01, *d*=0.1).

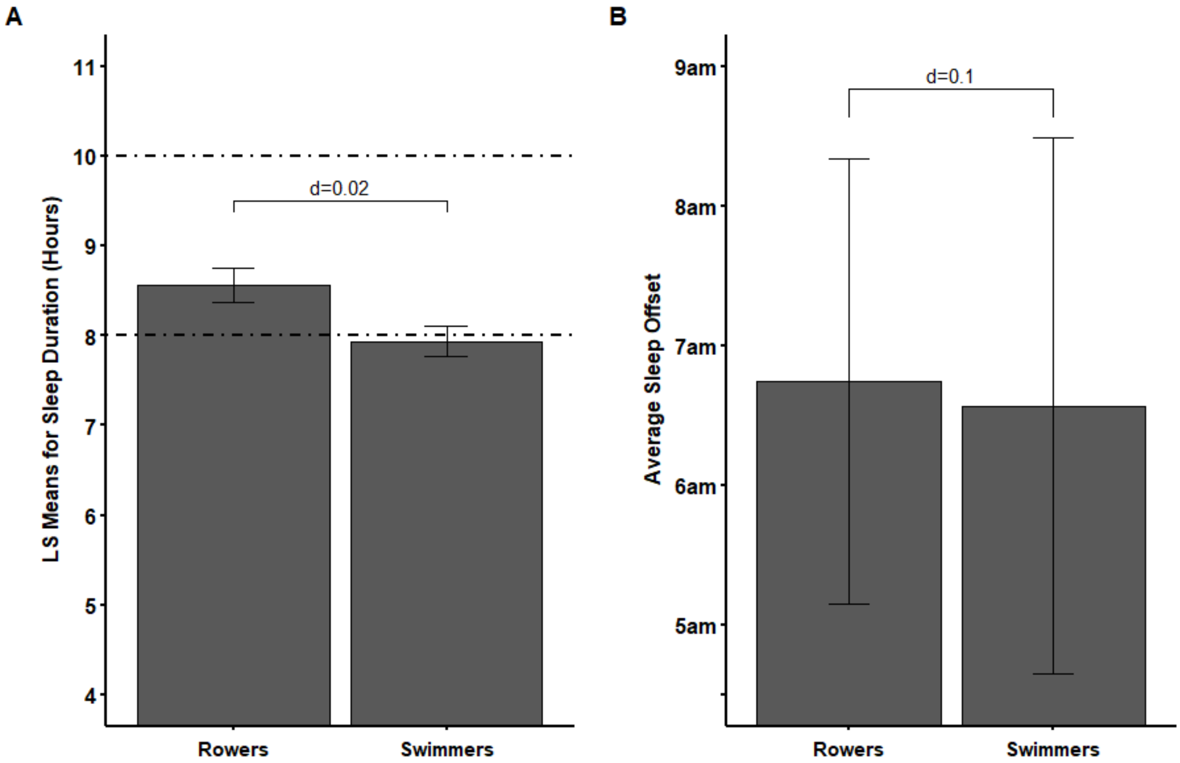


Figure 3.2. Least Squared Means for Sleep Duration (A) and Sleep Offset (B) comparisons for rowers and swimmers. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

3.4.4 Weekend training

Linear mixed model analysis of rowers' data that included weekend training mornings found significant main effects for type of night with respect to sleep duration (*p*<0.001, *df*=3, 125, *F*=74.61), sleep onset (*p*<0.001, *df*=3, 123, *F*=16.75), midsleep time (*p*<0.001, *df*=3, 124, *F*=180.43) and sleep offset (*p*<0.001, *df*=3, 133, *F*=295.22) (Figure 3.3). No statistically-significant main effect for type of night was found for stress, fatigue, muscles soreness and device use before bed. Post-hoc analyses for significant main effects are presented in Table 3.3.

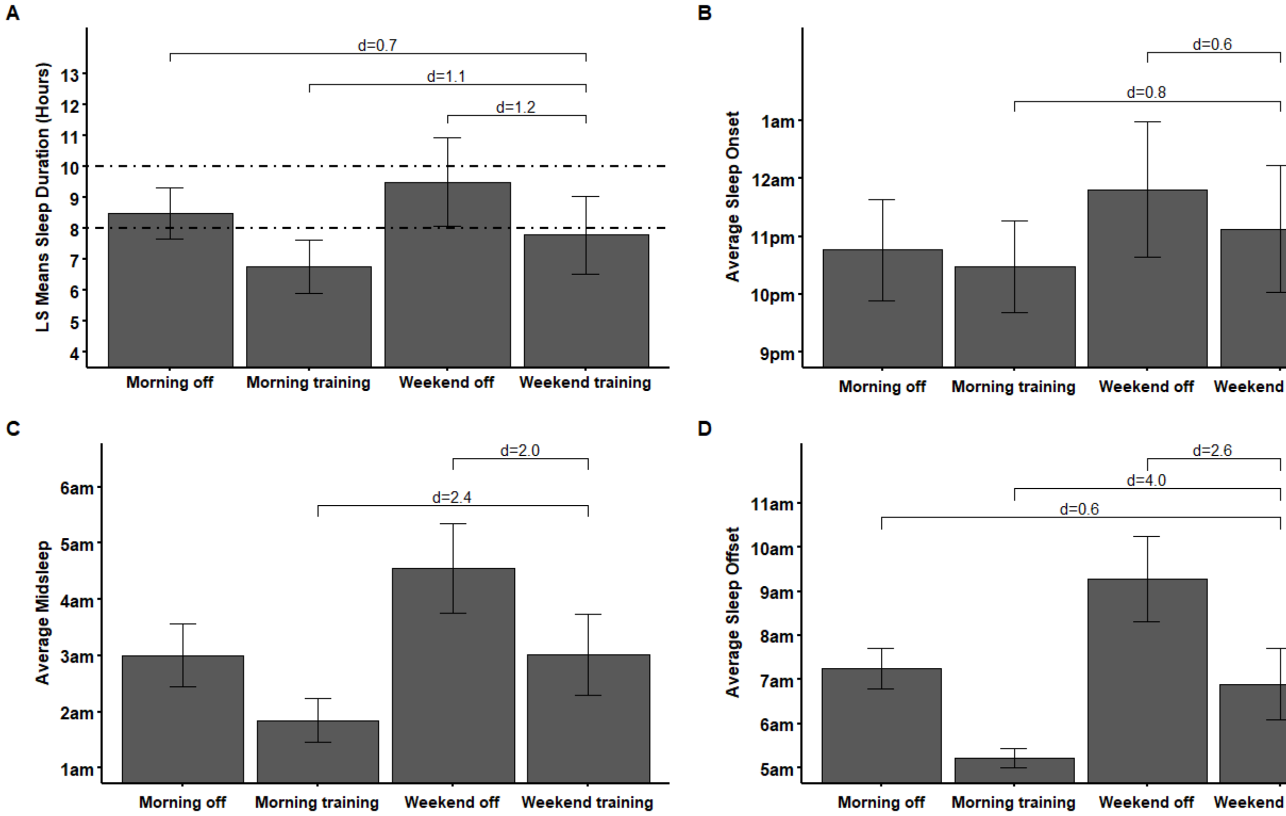


Figure 3.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different night conditions for rowers. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions with weekend training only are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

Table 3.3. Post hoc results comparing actigraphy variables between night conditions and weekend training for rowers. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

	Comparison of nights before:		LS Means Estimate (Mins)	Confidence Interval Lower (Mins)	Confidence Interval Upper (Mins)	DF	t Value	Adj p-Value	Cohen's d
Sleep Duration									
	Morning off	Weekend training	41.9	4.2	79.6	125	3.0	**0.0034**	0.7
	Morning training	Weekend training	-67.6	-105.0	-30.2	125	-4.8	**<.0001**	1.1
	Weekend off	Weekend training	106.5	63.0	150.1	127	6.6	**<.0001**	1.2
Sleep Onset									
	Morning off	Weekend training	-23.2	-52.2	5.8	123	-2.2	0.0675	0.4
	Morning training	Weekend training	-33.0	-61.8	-4.2	123	-3.1	**0.0106**	0.8
	Weekend off	Weekend training	32.4	-1.2	65.9	124	2.6	**0.0326**	0.6
Midsleep									
	Morning off	Weekend training	-2.4	-22.3	17.5	124	-0.3	0.7464	0.0
	Morning training	Weekend training	-67.6	-87.4	-47.8	124	-9.2	**<.0001**	2.4
	Weekend off	Weekend training	86.1	63.1	109.2	125	10.0	**<.0001**	2.0
Sleep Offset									
	Morning off	Weekend training	20.9	-4.3	46.1	132	2.2	**0.0280**	0.6
	Morning training	Weekend training	-100.4	-125.4	-75.4	133	-10.8	**<.0001**	4.0
	Weekend off	Weekend training	143.2	114.5	171.8	138	13.4	**<.0001**	2.6

Note: Bold values represent statistically significant results.

3.5 Discussion

The primary aim of this research was to observe how early morning training impacted the sleeping patterns of New Zealand adolescent athletes. Regardless of sporting code, the sleep of adolescent athletes in this study varied depending on whether sleep took place prior to a weekday or weekend morning and whether training was scheduled for the next morning or not. Median sleep duration on nights prior to weekday mornings free from training (8h45) and nights before weekend mornings without training (9h08) fell within age recommended durations (Hirshkowitz *et al.,* 2015). These durations are also in line with findings of other studies of adolescents in New Zealand (Dorofaeff and Denny, 2006; Skidmore *et al.,* 2013; & Galland *et al.,* 2017). Conversely, median sleep duration for nights before weekday morning training (6h44) and nights before a weekend morning with training (7h54; rowers only) fell below age recommended durations. As hypothesised, early morning training was found to significantly reduce the sleep duration of adolescent athletes (reduction of 2 hours per night on average).

These findings depict a similar pattern to that seen with adolescent Icelandic swimmers (Gudmundsdottir, 2019) for whom average total sleep time across a week of training was 6h32 (range 5h02 - 8h30). While the Icelandic swimmers slept less for all night categories across a normal week compared to the New Zealand athletes in the current study, the pattern of fluctuating sleep duration and timing driven by early morning training is similar. In both cases, the average sleep values for the week do not reflect the variability in sleep and thus it is recommended that reporting only weekly averages for sleep variables in these populations be avoided.

As with general population findings, the athletes in this study went to bed and woke up significantly later on weekends compared to during the week (Dorofaeff and Denny, 2006; Skidmore *et al.,* 2013; & Galland *et al.,* 2017). Later bed and wake up times were accompanied by extended sleep durations which are also consistent with findings from other studies of New Zealand adolescents (Dorofaeff and Denny, 2006; Skidmore *et al.,* 2013; & Galland *et al.,* 2017). Adolescent athletes exhibiting patterns of social jetlag is also consistent with other studies when weekend morning training is absent from athletes' schedules (Suppiah *et al.,* 2015; & Suppiah *et al.,* 2016).

In the rowing group, athletes also had morning training on weekends although the timing of this session was more comparable to school start times than weekday morning training. While there was no statistically significant difference in bedtime on nights before weekend mornings with training and nights prior to weekday mornings off, wake time was significantly earlier and sleep duration was significantly shorter on nights before weekend mornings with training. The hallmarks of social jetlag were less pronounced on nights preceding weekend morning training, which is in line with the findings of Brand *et al*, (2010) who found less weekday to weekend variability for sleep measures in an adolescent athlete group who had weekend sporting commitments compared to a sedentary control group.

Accruing a sleep debt throughout the week and 'catching up' on sleep over the weekend is associated with disruption to the circadian timekeeping system. This circadian disruption has been associated with negative metabolic and psychological health outcomes for adolescents (Díaz-Morales and Escribano, 2015; & Malone *et al.,* 2016) and has potentially negative effects on academic outcomes (Dorofaeff and Denny, 2006; & Díaz-Morales and Escribano, 2015). It is currently unclear whether the additional disruption to sleeping patterns during the week imposed by intermittent early morning training further exacerbates these issues for adolescent athletes. It also remains unclear whether routine exercise may mask some of these negative effects given that regular exercise has been found to have positive effects on sleep architecture and sleep patterns as well as subjective ratings of sleep (Chennaoui *et al.,* 2015). Further research aiming to address these issues is needed to fully understand the complex and bi-directional relationship between sleep and physical activity.

The reduction in sleep duration found on weeknights prior to training was due to advanced wake times while bedtimes did not change and remained similar to those observed for other New Zealand adolescents (Dorofaeff and Denny, 2006; Skidmore *et al.,* 2013; & Galland *et al.,* 2017). Despite knowing that they would need to attend early morning training sessions, the rowers and swimmers in this study did not shift their bedtimes earlier the night before to compensate for the earlier wake times. To maintain optimal sleep durations, bedtime prior to morning training sessions would have had to shift to a time in the circadian body clock cycle when the brain is likely to be promoting wakefulness (the evening wake maintenance zone) (Wyatt, 2007). It is possible that even if the adolescent athletes had tried to go to bed earlier in advance of early morning training, the homeostatic and circadian mechanisms that drive sleep timing may not have allowed for earlier sleep onset. This has broader implications for future interventions in these populations. Given that swimming and rowing both involve high volumes of training and that this training must be organised around school times, a reduction or rescheduling of training (while beneficial for sleep) may not always be feasible. Successful interventions will need extensive co-design and commitment from these young athletes and their supporters (eg, parents, coaches, and teachers).

Findings from both the ASSQ, sleep diaries and actigraphy data indicate that the athletes in this study napped very rarely. Only two instances of napping occurred during the two weeks of monitoring. In contrast, Kölling *et al*. (2016) found a large percentage of adolescent rowers took the opportunity to nap regularly during a baseline week at a training camp. Most naps took place between 12:00 and 15:00 which was a scheduled daily rest break (Kölling *et al.,* 2016). This suggests that adolescent athletes may be inclined to add a nap to their daily routine when their schedules allow. While this may represent an opportunity for intervention it must be noted that in the current study, athletes' schedules did not allow many opportunities for daytime napping to take place. This highlights the unique schedules and circumstances each adolescent athlete population presents and that any sleep intervention would need to be specifically tailored to individual athlete groups and possibly also the individual athletes.

Weekly device use in the hour before bed, as reported by the athletes on the ASSQ, was between 3 and 6 nights a week. Sleep diary data revealed, however, that the athletes used electronic devices an hour before bed on over 90% of nights during the study. This is of concern, as short-wavelength light, or blue light is emitted in high proportion by electronic devices (Bartel *et al.,* 2015). Blue frequency light has an alerting effect while also suppressing melatonin and delaying the circadian biological clock (Van Der Lely *et al.,* 2015). Limiting blue light before bedtime should have a positive effect on sleep/wake regulation. The findings of this study suggest either a lack of sleep health knowledge or a failure to implement good sleep health practices by the adolescent athletes. This is not a unique finding, as it is commonly reported that adolescents in general use electronic devices before bed, be it for entertainment, social or school purposes (Gradisar *et al.,* 2013). No significant difference was found with regards to device use and different types of nights in the current study indicating that the athletes maintained comparable levels of device use regardless of whether or not they had training the following morning. This is a potential area for intervention in adolescent athlete populations with regards to improving sleep health.

The athletes in the current study tended to be “morning types” according to the results of the MESC and ASSQ. These findings are counter to the evidence of phase delay and evening preference throughout adolescence (Carskadon, 2011; & Carskadon, 2018) and could be due to inaccuracies in the measures, given that neither has been validated for this specific population. The MESC has been validated for adolescents but not athlete groups while the reverse is true for the ASSQ. The findings of the current study provide evidence for the scales producing similar findings, however, further validation in this population needs to be conducted for both scales. It is also possible that individuals who choose and continue to participate in sporting codes with early morning training commitments are more naturally inclined to be morning types. It may be that evening types drop out of sports with high morning training demands during adolescence given the mismatch with their circadian preferences. While there is supporting evidence of this from adult athlete studies (Lastella *et al.,* 2016; & Vitale *et al.,* 2017), more evidence in adolescent athlete groups is needed to confirm this hypothesis. This theory should be further investigated as it may play a role in both talent identification and retention for school sporting programs.

The current study did not have a comparison group of either adolescent athletes who partake in training later in the day or a sedentary group. Furthermore, the athletes in the study were recruited from 2 sporting codes and 3 separate teams. This meant that participants often had different training schedules as well as different scholastic commitments. It would have been ideal to keep this consistent for analyses, however, finding a large enough sample that fit the inclusion criteria and had the same schedule was not possible. Despite the small sample size, approximately 300 nights of actigraphy data were collected in total. This allowed for a comprehensive picture of sleep patterns to be gained for the athletes in this study. That being said, the small sample of female participants did mean that the statistical models did not have sufficient power to include sex differences in the final models. Another challenge was finding a 2-week period that represented a baseline training phase where training intensity was kept constant without upcoming competition or scholastic events such as holidays, tests or exams. With careful consultation with coaches and athletes, this was achieved in the current study, however, this issue should be taken into consideration when undertaking similar research endeavours.

3.6 Conclusions

The current study monitored the sleep/wake patterns of 13 adolescent swimmers and 19 rowers during a 2-week training phase. All had reduced sleep duration on nights before weekday early morning training as a result of unchanged bedtimes. Weekday to weekend variability in sleep patterns was evident especially when weekend mornings were free of training. Importantly, although weekly sleep duration averages suggested athletes' sleep duration was similar to that of the general adolescent population, it did not accurately reflect the night-to-night variability and disruptive effects of early morning training. Using weekly average sleep durations to assess sleep in athlete populations should, therefore, be cautioned. Stakeholders in the development of adolescent athletes including coaches, parents and school administrators should be aware of the impact early morning training may have on adolescent athletes' sleep. Further research is needed to investigate potential interventions which could mitigate the effect of early morning training.

Acknowledgements

We would like to acknowledge and thank the coaches and athletes for their participation in the current study.

Funding

Travis Steenekamp was awarded a Massey University Doctoral Scholarship to undertake this research.

CHAPTER 4 EFFECTS OF SLEEP EDUCATION AND TRAINING RESCHEDULING ON THE SLEEP/WAKE BEHAVIOUR AND PERFORMANCE OF ELITE ADOLESCENT SWIMMERS. A PILOT INTERVENTION.

4.1 Abstract

Objective: Few studies have implemented field interventions aimed at improving the sleep of elite adolescent athletes. This study tested the feasibility and efficacy of sleep education coupled with training rescheduling for improving sleep and performance in elite adolescent swimmers.

Methods: The sleep of 13 swimmers (mean age ± SD 14.8 ± 1.4; 54% female) was monitored for 2 baseline and 6 intervention weeks using diaries and actigraphy. Participants completed the Hooper Index and recorded bedtime device use daily. Fortnightly swimming performance was measured via race simulations. The intervention was comprised of education sessions and repositioning a training session to provide consecutive weekday mornings free of training.

Results: Compliance using the actigraphs and sleep diary was 78%. While midsleep point and sleep offset were significantly earlier during the second half of the intervention, sleep duration and quality were unchanged. No significant difference was found in swimming performance. Device use before bedtime reduced by 24% over the intervention.

Conclusions: These findings suggest that adolescent athletes are motivated to make changes to improve sleep but due to their physiology and schedule are unable to alter

the timing and duration of sleep. Coaches, parents, swimmers and authorities need to work together to consider the implications of early morning training and possible solutions.

Keywords:

Sleep Intervention; Sleep timing; Adolescent athlete; Training schedule; Swimming

4.2 Introduction

Early sport specialisation and young peak competition age make adolescence a crucial developmental time in determining the success of a competitive swimmer (Vaeyens *et al.,* 2009; and Allen & Hopkins, 2015). Swimming has historically been a sport centred on the principle of volume training with the need for early morning as well as evening training to reach weekly distance goals (Chatard & Stewart, 2011). While training philosophies have been refined over the years, early morning training is still commonplace for swimmers today making competitive adolescent swimmers an at-risk group for significant sleep restriction (Sargent *et al.,* 2014 and Gudmundsdottir, 2019). Furthermore, the time required for training and competition must fit into an adolescent's already busy social and academic schedule which often results in sleep being compromised (Godber, 2012).

Athletes, coaches and organisations such as the International Olympic Committee all acknowledge that sleep is essential to health and athletic performance (Bergeron *et al.,* 2015). With an increased awareness of the importance of sleep, intervention studies that aim to increase the amount or quality of sleep for athletes have become a topic of interest. Systematic reviews of sleep interventions in both adolescent and young adult athletes have identified three main sub-types of intervention commonly used (Bonnar *et al.,* 2018; and Fox *et al.,* 2020).

The first category includes sleep extension interventions which aim to increase sleep duration either by increasing total nighttime sleep or by introducing naps into athletes' schedules (Bonnar *et al.,* 2018; and Fox *et al.,* 2020). The second category involves interventions that focus on sleep health and sleep-related behaviour to increase sleep duration and improve sleep quality (Bonnar *et al.,* 2018; and Fox *et al.,* 2020). The third category includes interventions that utilise post-exercise recovery strategies, such as ice baths, stretching etc, which have been postulated to improve sleep (Bonnar *et al.,* 2018). Any intervention designed for adolescent swimmers may incorporate elements of these intervention categories but also needs to consider the sleep and circadian physiology of adolescents and the lifestyle of young swimmers.

Puberty is accompanied by changes to the biological mechanisms responsible for sleep/wake regulation: the circadian timekeeping system and the homeostatic sleep process (Carskadon, 2011; Greene, Bjorness & Suzuki, 2017; Crowley *et al.,* 2018; and Astiz, Heyde & Oster, 2019). During adolescence there is typically a phase delay in circadian timing and a slower rise in sleep pressure build-up, resulting in later bed and wake times (Carskadon, 2011; and Crowley *et al.,* 2018). The circadian timekeeping system produces a period of increased alertness, known as a wake maintenance zone, 2- to 3-hours prior to the onset of evening melatonin secretion (Lavie, 1986; and Strogatz *et al.,* 1987). Adolescents have been shown to have a later wake maintenance zone and find falling asleep during this period more difficult than adults (Crowley and Eastman, 2017). Any intervention that aims to extend sleep by shifting bedtimes earlier needs to take this physiological drive for wake into account. Device use and late-night light exposure have also been theorised to be significant drivers of delayed bedtime in adolescent groups (Wood *et al.,* 2013; and Van Der Lely *et al.,* 2015). Bright light, particularly light in the blue frequency range, suppresses and delays melatonin secretion in young adults which can phase delay the circadian timekeeping system and disrupt sleep (Chang *et al.,* 2015). With device use before bedtime prolific amongst adolescent groups (Arora *et al.,* 2018), this is an area where behavioural intervention may be beneficial. Despite both Bonnar *et al*. (2018) and Fox *et al.* (2020) noting the potential benefits of sleep behaviour education in older athletes, neither review identified a study that investigated the efficacy of sleep education in adolescent athletes.

Encouraging later wake times is another potential mechanism for increasing sleep duration in adolescents but is socially impractical due to school start times often dictating wake times (Carskadon, 2011; and Crowley *et al.,* 2018). With a phase delay in adolescent circadian timekeeping systems, the average adolescent will fall asleep after 11:00 pm (Crowley *et al.,* 2018). To obtain the recommended 8-10 hours sleep for their age, wake time would ideally be approximately 8:00 am. This physiological preference for sleep timing is in direct conflict with school start times.

The mismatch between physiology and socio-cultural factors has been termed the 'perfect storm' model of poor sleep in adolescence (Carskadon, 2011; and Crowley *et al.,* 2018). This model serves as an explanatory tool for why adolescent populations around the world routinely sleep less than recommended durations throughout the school week (Crowley *et al.,* 2007; Carskadon, 2011; Gradisar *et al.,* 2013; Hirshkowitz *et al.,* 2015; and Watson *et al.,* 2015). Sleep loss during the school week is often juxtaposed with later bed and wake times and extended sleep periods over the weekend (Carskadon, 2011; and Crowley *et al.,* 2018). The change in sleep timing and duration between the school week and weekend is known as 'social jetlag' (Wittman *et al.,* 2006).

Early morning training in adolescent swimmers provides an extreme example of the perfect storm model by pushing wake times even earlier. Recovery sleep following one night of sleep restriction in adolescents has been demonstrated to be insufficient to return sleep macrostructure to baseline values (Carskadon, Harvey & Dement, 1981;

and Kopasz *et al.,* 2010). Early morning training is highly likely to result in acute sleep restriction for adolescents. If morning training sessions are separated by days off (e.g. train one morning, have a morning off training, train the next morning), then adolescent athletes may experience social jetlag throughout the week and weekend. Re-arranging training to increase the number of recovery days represents a novel intervention that is yet to be tested in adolescents.

The primary aim of this study was to pilot a sleep education and novel training rescheduling intervention for adolescent swimmers. The sleep education intervention follows the recommended principles outlined by Bonnar *et al.,* (2018) and training rescheduling was added with the aim of increasing consecutive recovery days during training weeks.

4.3 Method

4.3.1 Participants

A coeducational swimming club was approached to take part in this intervention. Seventeen swimmers from the club received information about the study and 14 volunteered to take part. Participants were required to be between the ages of 13 and 18; non-smokers; have no prior diagnosis of a sleep or mood disorder and not currently be taking medication with known side effects on sleep. The Athlete Sleep Screening Questionnaire (ASSQ) (Samuels *et al.,* 2015; and Bender *et al.,* 2018) was completed by volunteers to identify undiagnosed sleep problems and/or recent international travel. Volunteers were required to be free from injury and able to attend a minimum of 90% of training sessions throughout the study. All volunteers had to meet the study criteria of being an elite swimmer, defined for this study as having competed or qualified to compete at a national level competition within the previous 12 months. Participant assent and parental consent were received for swimmers younger than 16 years of age and participant consent were received for swimmers over 16 years old. The study was approved by the Massey University Human Ethics Committee (Application SOA 18/36).

4.3.2 Procedure

This pilot intervention was a field-based, repeated-measures study that compared the daily sleep and fortnightly performance of adolescent swimmers before and after a sleep education and training rescheduling intervention. Data were collected across 8 consecutive weeks, which included a 2-week baseline phase and a 6-week intervention period (Figure 4.1). The intervention comprised sleep education sessions and training rescheduling. Sleep education involved a 45-minute workshop at the beginning of the intervention (end of week 2) and another 45-minute follow up session at week 5 (halfway through the intervention period) (Figure 4.1). Parents and coaches were welcome and encouraged to join these sessions. The initial workshop included individualised feedback on sleep recorded during the first baseline week. To supplement the workshop, swimmers also received a sleep information booklet to work through in their own time as well as summaries of group sleep data from the first baseline week. The follow-up session involved giving swimmers similar feedback relating to the previous month of sleep data. This data was used to set individual sleep targets for each swimmer to work towards in the second half of the intervention. For example, each participant was given a bedtime goal 15 minutes earlier than their previous month’s average bedtime which advanced another 15 minutes each week. A timeline of events of the study can be found in Figure 4.1.

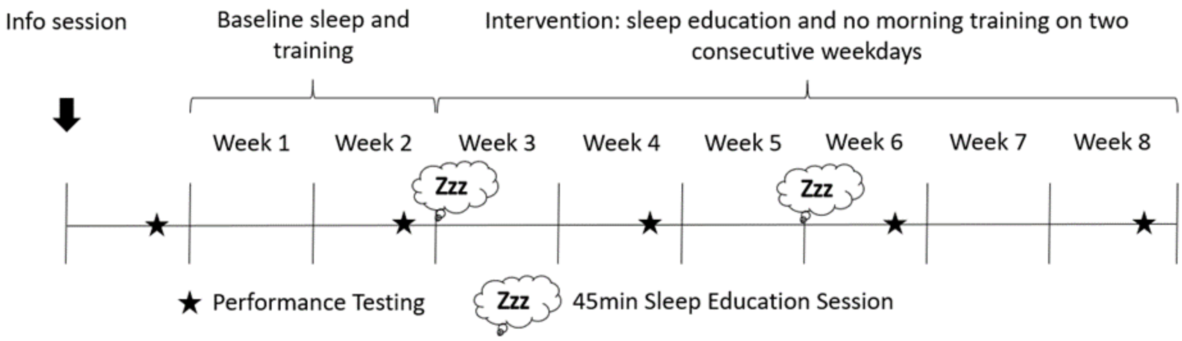


Figure 4.1. Timeline of events during the 8-week study period.

During the baseline phase, the swimmers followed their usual training schedule of 8 training sessions a week with early morning training (starting at 5:30 am) on Monday, Wednesday and Friday, and daily afternoon training. No training sessions took place on weekends. For the intervention, Wednesday morning training was rescheduled to take place on Tuesday at 5:30 am. This adjustment provided two consecutive weekday mornings free of training for the duration of the intervention while the number of training sessions per week was kept constant (Figure 4.2). The coach was asked to keep the training load as consistent as possible throughout the study.

4.3.3 Classification of study periods

For statistical purposes “Nights of the week” were coded based on whether the following morning was a “morning training”, “morning off” or a “weekend off”. “Intervention” periods were defined as “Baseline”, “First half of intervention” and “Second half of intervention”.

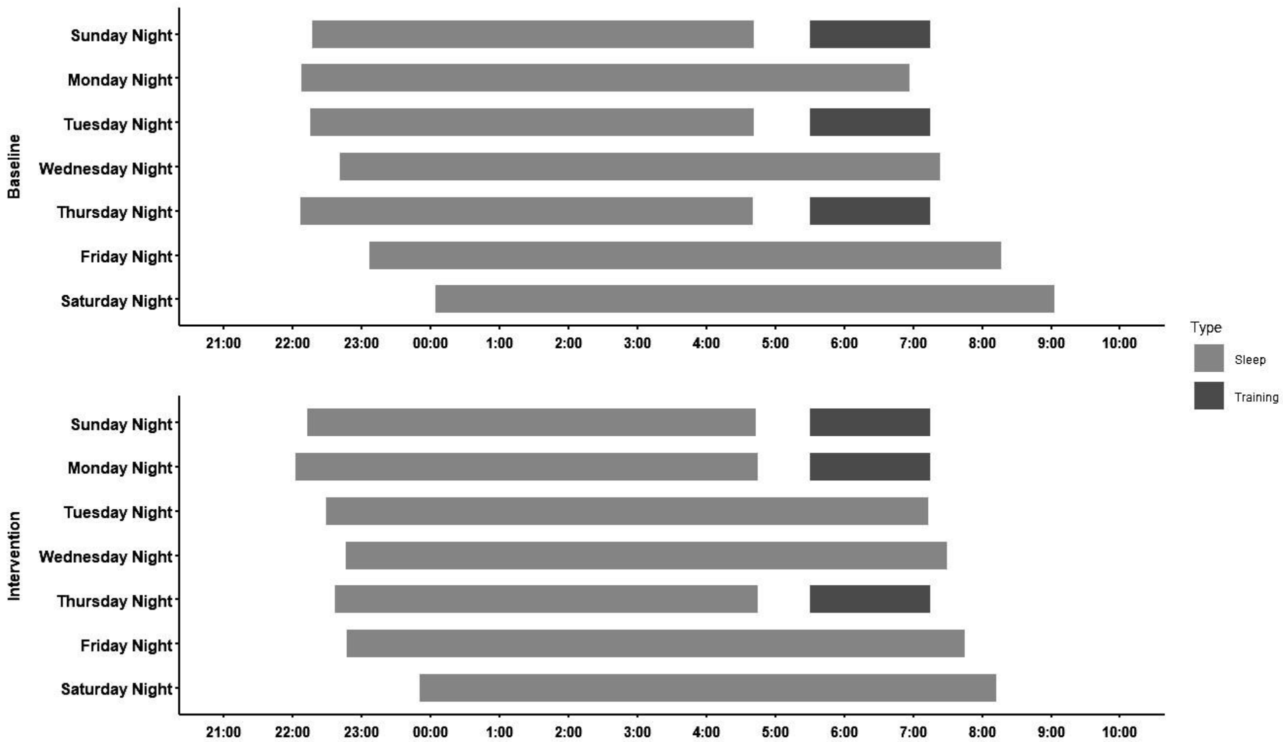


Figure 4.2. Depiction of training schedule changes during baseline and intervention phases of the study. Sleep timing derived from actigraphy and sleep diary data.

4.3.4 Measures

The swimmers wore Micro MotionLogger devices (Ambulatory Monitoring Inc. [AMI], Ardsley, NY, USA) on their non-dominant wrist continuously for the 8-week study (Meltzer *et al.,* 2013). Data were recorded in 1-minute epochs using the monitor's zero-crossing mode (Meltzer *et al.,* 2013). Sleep and wakefulness were inferred from activity using the Cole-Kripke algorithm (Cole *et al.,* 1992) in the manufacturer's software (Action-W version 2.7.3045, Ambulatory Monitoring Inc., Ardsley, New York, USA). Measures taken from actigraphy were:

Sleep Onset – the time participants first fell asleep

Sleep Offset – the time participants finally woke up

Midsleep point – the midway point between Sleep Onset and Sleep Offset

Sleep Duration – the difference between Sleep Onset and Sleep Offset

Swimmers were asked to press the event button on the MotionLogger when going to bed and upon awakening. They also recorded their bed and wake times on a timeline in a sleep diary. Researchers confirmed periods of sleep in the actigraphic recording by consulting the event marker data and timelines.

The sleep diaries incorporated the Hooper Index for daily subjective ratings of sleep quality, stress, fatigue and muscle soreness (Hooper & Mackinnon, 1995). Items on the Hooper Index were rated on a Likert scale (1-7) upon awakening each morning with 1 always being best and 7 always the worst response possible. The daily sleep diary also featured a yes/no question regarding electronic device use in the hour before bedtime.

The chronotype of the swimmers was measured using the Morningness-Eveningness Scale for Children (MESC) (Carskadon *et al.,* 1993). A measure of chronotype was also included in the ASSQ, which was used in the screening process for volunteers, and provided indications of habitual napping, and caffeine and evening device use.

Swimming performance was measured every second week at 6:00 am during the Friday morning training session. In total, swimmers' performance was measured twice during baseline and three times during the intervention period (Figure 4.1). Swimming performance was measured as time to complete a simulated race in the stroke and distance of the swimmers' choosing. Individuals completed their race in the same stroke and distance for all testing sessions. All races were preceded by a standard warm-up routine, which was identical to that used by the swimmers prior to a competitive race. The distance and intensity of the warm-up routine were individualised for each swimmer but remained constant across all testing sessions. Three qualified timekeepers recorded race times. An adjusted Borg CR10 scale (Borg, 1990 and Borg, 1998) was used to measure athletes' perceptions of effort (Ratings of Perceived Exertion RPE) after the warm-up and again after the simulated races. Participants were instructed not to eat anything from 22:00 the night before performance testing until after the test was completed the next morning, however, water could be consumed *ad libitum* during this time. Participants were also asked to avoid meals that were not part of their habitual diet on the nights before performance testing. These measures were put in place to reduce the likelihood of dietary intake confounding results.

4.3.5 Statistical analysis

All statistical analyses were completed in SAS (version 9.4, SAS Institute Inc., Cary, NC, USA). Linear-mixed models with a Kenward-Roger adjustment were used to analyze actigraphically derived sleep variables. All models included the main effects of "Intervention" (3 levels = "baseline"; "first half of intervention"; "second half of intervention"); "Nights of the week" (3 levels = "morning training"; "morning off"; "weekend off") and "Age". For "Age" analyses the swimmers were split into two groups: those "15 and under" and those "Over the age of 15". Sex differences were originally included in analyses but were subsequently removed as the model lacked statistical power due to the small sample size. Interaction effects for "Intervention" by "Nights of the week" and "Age" by "Nights of the week" were also included in all models. Model assumptions were assessed visually and the Kolmogorov-Smirnov test for normality was used to assess the distribution of residuals. An alpha of 0.05 was set for all statistical tests except for instances when Levene's test indicated inequality in variances between groups. In such cases, a more stringent alpha level of 0.01 was used when interpreting fixed effects. Holm-Bonferroni post hoc adjustments and Cohen's d were also calculated. Effect size magnitude was classified as small (0.2–0.49), moderate (0.5–0.79) and large (≥0.8).

Hooper Index items were analyzed with a cumulative logit proportional-odds model and a binomial logistic regression model was used to analyse device use. The main effects of "Intervention"; "Nights of the week" and "Age" as well as the interaction effect of "Age" by “Treatment” were calculated for the Hooper Index items. General linear models were used to analyze performance and perceptions of effort data.

Additional analyses were run to determine if the two consecutive mornings off training during the week influenced actigraphic sleep variables or items from the Hooper Index. A general linear mixed model compared the two nights before mornings off during the baseline period (“Monday Night Baseline” and “Wednesday Night Baseline”), and the two nights before mornings off during the intervention period (“Tuesday Night Intervention” and “Wednesday Night Intervention”). This analysis included the main effects of “Night of the Week” (4 levels) and “Age” (2 levels) as well as the interaction of “Night of the Week” by “Age”.

4.4 Results

In total, 13 swimmers (mean age 14.8; SD 1.4 years; 54% female) out of the 14 initial volunteers completed the study. One swimmer was excluded due to an injury sustained prior to the study beginning. None of the volunteers were excluded due to ASSQ responses. All swimmers were classified as ‘morning type’ with an average score of 35.2 (SD = 3.1) on the MESC and 8.5 (SD = 2.3) on the ASSQ. No effect of sex or age was found for either measure of chronotype. The ASSQ results found 3 swimmers to report infrequent napping and one reported low caffeine intake at the time of recruitment. The rest of the participants reported no napping or caffeine consumption. All but one swimmer reported using electronic devices prior to bed for most nights of the week on the ASSQ. Across a total of 728 nights, swimmers wore their actigraphs on 575 nights, achieving a compliance rate of 79%. Compliance with wearing the actigraphs was 96% during baseline and 92% during the first half of the intervention. The second half of the intervention saw compliance fall to 55%. Similarly, overall compliance with filling in the sleep diary was 78% over the entire study with 96% during baseline, 94% during the first half of the intervention and 51% during the second half of the intervention.

The median and range for sleep variables on different nights of the week for each phase of the study are provided in Table 4.1 (data not normally distributed).

Table 4.1. Sleep variables for different nights of the week for all study phases.

	Mornings off Median (Min-Max)	**Morning training** Median (Min-Max)	**Weekend off** Median (Min-Max)
Sleep Duration (hours minutes)			
Baseline	8h47 (5h45 - 11h33)	6h36 (4h01 - 8h03)	9h00 (6h09 - 12h04)
First half of intervention	8h40 (5h33 - 11h27)	6h32 (3h06 - 8h28)	9h07 (5h58 - 12h00)
Second half of intervention	8h44 (5h18 - 15h16)	6h36 (4h36 - 8h10)	8h02 (5h41 - 10h38)
Sleep Onset (24 h clock time)			
Baseline	22:19 (21:01 - 00:46)	22:05 (20:32 - 00:44)	23:24 (21:08 - 2:17)
First half of intervention	22:39 (20:42 - 1:38)	22:05 (20:33 - 1:43)	23:31 (21:35 - 2:44)
Second half of intervention	22:33 (20:57 - 1:14)	22:09 (20:05 - 00:00)	23:07 (21:36 - 00:30)
Midsleep (24 h clock time)			
Baseline	2:41 (1:20 - 4:38)	1:25 (00:28 - 2:44)	4:09 (1:48 - 6:28)
First half of intervention	2:52 (1:30 - 4:58)	1:24 (00:41 - 3:15)	4:10 (00:05 - 6:59)
Second half of intervention	2:59 (1:31 - 5:14)	1:29 (00:35 - 2:21)	3:06 (1:28 - 4:57)
Sleep Offset (24 h clock time)			
Baseline	7:16 (4:42 - 9:00)	4:42 (4:14 - 4:58)	8:38 (5:39 - 11:21)
First half of intervention	7:23 (4:44 - 9:14)	4:44 (4:14 - 5:00)	8:28 (5:03 - 11:15)
Second half of intervention	7:22 (4:41 - 12:18)	4:49 (3:32 - 5:26)	6:59 (5:17 - 9:45)

Data are median and range in specified units.

For actigraphic sleep variables, main effects of intervention were found for sleep duration (p=0.03, df=2, 547, F=3.6); midsleep point (p<0.001, df=2, 546, F=8.7); and sleep offset (p<0.001, df=2, 547, F=12.8). No significant main effect of intervention was found for sleep onset (p=0.29, df=2, 546, F=1.26). Despite the intervention having a main effect on sleep duration, post hoc results showed no significant difference between intervention periods as is seen in Figure 4.3A. Post hoc results did, however, indicate that midsleep point and sleep offset were significantly earlier during the second half of the intervention compared to baseline and the first half of the intervention, although the effect size was small.

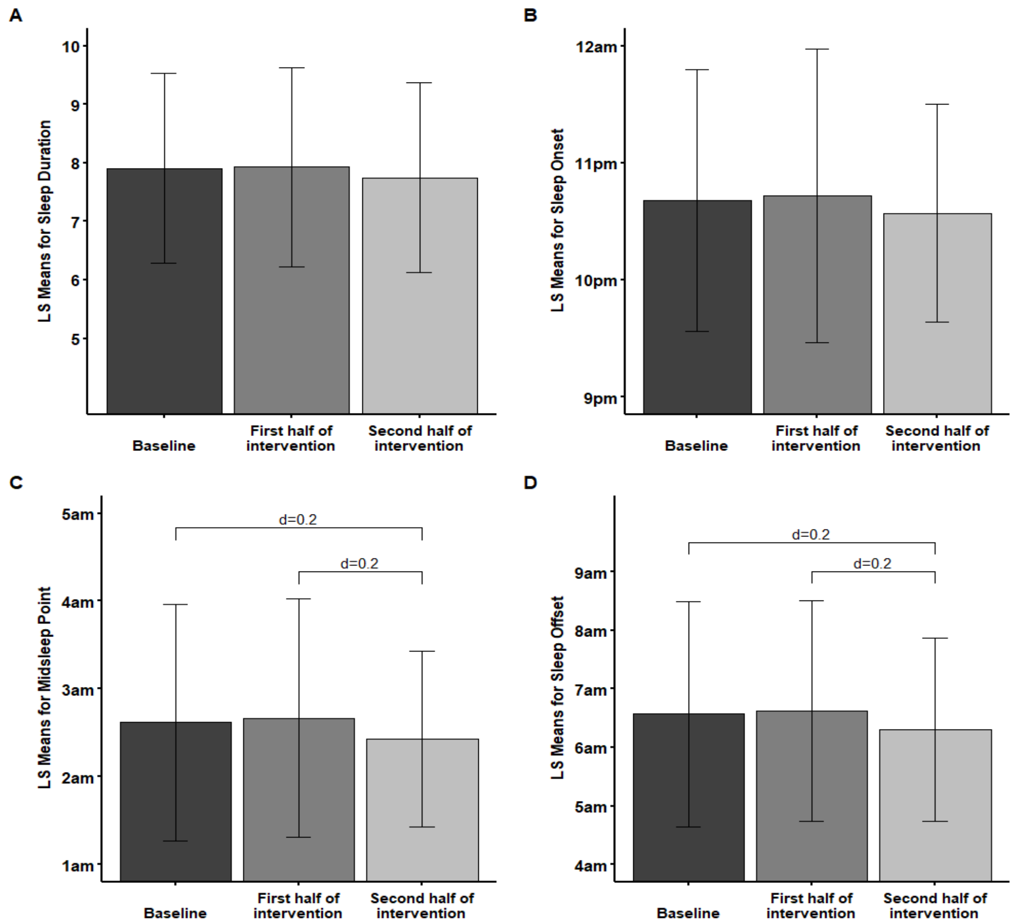


Figure 4.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for study phases. Error bars denote standard deviation. Significant effects are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

A main effect of intervention was found for the fatigue item of the Hooper Index (*p*=0.05, *df*=2, 542, *F*=3.03), however, no significant differences were identified following post hoc analysis. Similarly, no significant main effect of intervention was found for sleep quality (*p*=0.31, *df*=2, 544, *F*=1.18); stress (*p*=0.63, *df*=2, 544, *F*=0.46); or muscle soreness (*p*=0.07, *df*=2, 545, *F*=2.68).

Device use was found to change significantly across intervention periods (*p*<0.001, *df*=2, 544, *F*=11.93). There was a significant reduction in device use before bedtime between the baseline and the first half of the intervention and between baseline and the second half of the intervention (Figure 4.4). A significant reduction from the first half of the intervention to the second half of the intervention was also seen (Figure 4.4).

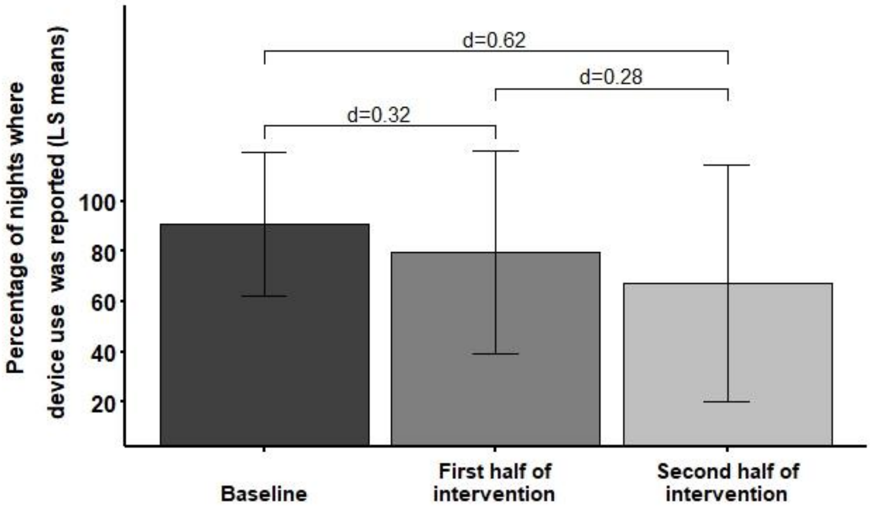


Figure 4.4. Percentage of nights where device use was reported across the study phases (LS means). Error bars denote standard deviation. Significant effects are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

No significant main effect of intervention was found for swimming performance (*p*=0.98, *df*=4, *F*=0.11), or in ratings of perceived exertion (RPE) following the warm up (*p*=0.34, *df*=4, *F*=1.17) and post-race RPE (*p*=0.82, *df*=4, *F*=0.38).

Main effects for night of the week were found for sleep duration (p<0.001, df=2, 547, F=327.0), sleep onset (p<0.001, df=2, 546, F=58.7), midsleep point (p<0.001, df=2, 546, F=507.1), and sleep offset (p<0.001, df=2, 547, F=862.7). Post hoc results identifying differences for these effects can be seen in Table 4.2.

Table 4.2. Post hoc results comparing actigraphy variables between night conditions.

	LS Means		LS Means	t(df)	Adj p Value	C
Sleep Duration						
Morning training	06h29	Morning off	08h49	-22.8 (547)	**<.0001**	
Morning training	06h29	Weekend	08h50	-19.4 (547)	**<.0001**	
Morning off	08h49	Weekend	08h50	-0.2 (547)	1	
Sleep Onset						
Morning training	22:16	Morning off	22:31	-3 (546)	0.09	
Morning training	22:16	Weekend	23:20	-10.8 (546)	**<.0001**	
Morning off	22:31	Weekend	23:20	-7.9 (546)	**<.0001**	
Midsleep						
Morning training	01:29	Morning off	02:55	22.1 (546)	**<.0001**	
Morning training	01:29	Weekend	03:44	-29.6 (546)	**<.0001**	
Morning off	02:55	Weekend	03:44	-10.6 (546)	**<.0001**	
Sleep Offset						
Morning training	04:43	Morning off	07:19	-32.4 (547)	**<.0001**	
Morning training	04:43	Weekend	08:10	-36.4 (547)	**<.0001**	
Morning off	07:19	Weekend	08:10	-8.7 (547)	**<.0001**	

Bold values represent statistically significant results.

No significant main effects of age were found for any of the actigraphy or sleep diary variables. Age and night of the week interaction effects were, however, found for sleep duration (p=0.001, df=2, 547, F=6.83), sleep onset (p=0.01, df=2, 546, F=4.61), midsleep time (p<0.001, df=2, 546, F=8.73) and sleep offset (p<0.001, df=2, 5547, F=11.07). Post hoc analysis revealed no significant differences between the age groups for the same night of the week, for example when comparing age group differences on nights before morning training (Figure 4.5).

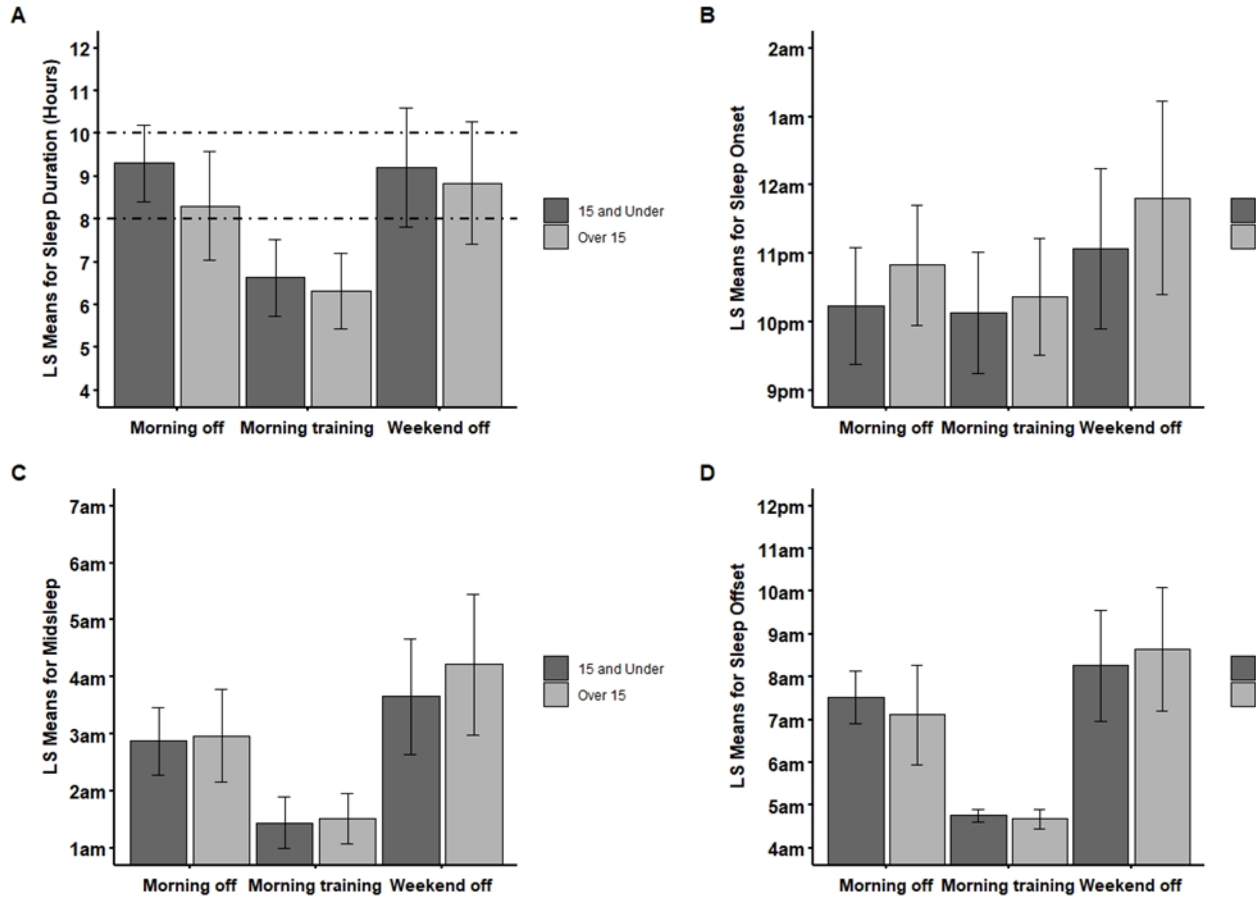


Figure 4.5. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different night conditions for swimmers under and over 15. Error bars denote standard deviation. Dashed lines denote recommended sleep duration.

Significant main effects for differences between the four recovery nights (Monday and Wednesday nights during baseline and Tuesday and Wednesday nights during the intervention) were found for sleep onset (*p*=0.002, *df*=3, 171, *F*=5.13); midsleep point (*p*<0.001, *df*=3, 171, *F*=8.65); and sleep offset (*p*=0.003, *df*=3, 171, *F*=4.96). No significant main effects were found for sleep duration (*p*=0.89, *df*=3, 172, *F*=0.21). The results of post hoc analyses, which can be seen in Figure 4.6, indicate a significantly later sleep onset on Wednesday nights during the intervention compared to the Monday nights during baseline. Wednesday nights during the intervention also had significantly later midsleep points compared to both Monday nights during baseline and Tuesday nights during the intervention.

No significant effects of nights of the week were found for sleep quality (p=0.76, df=3, 162, F=0.39), stress (p=0.97, df=3, 161, F=0.08), fatigue (p=0.44, df=3, 161, F=0.89), and muscle soreness (p=0.40, df=3, 161, F=1.00).

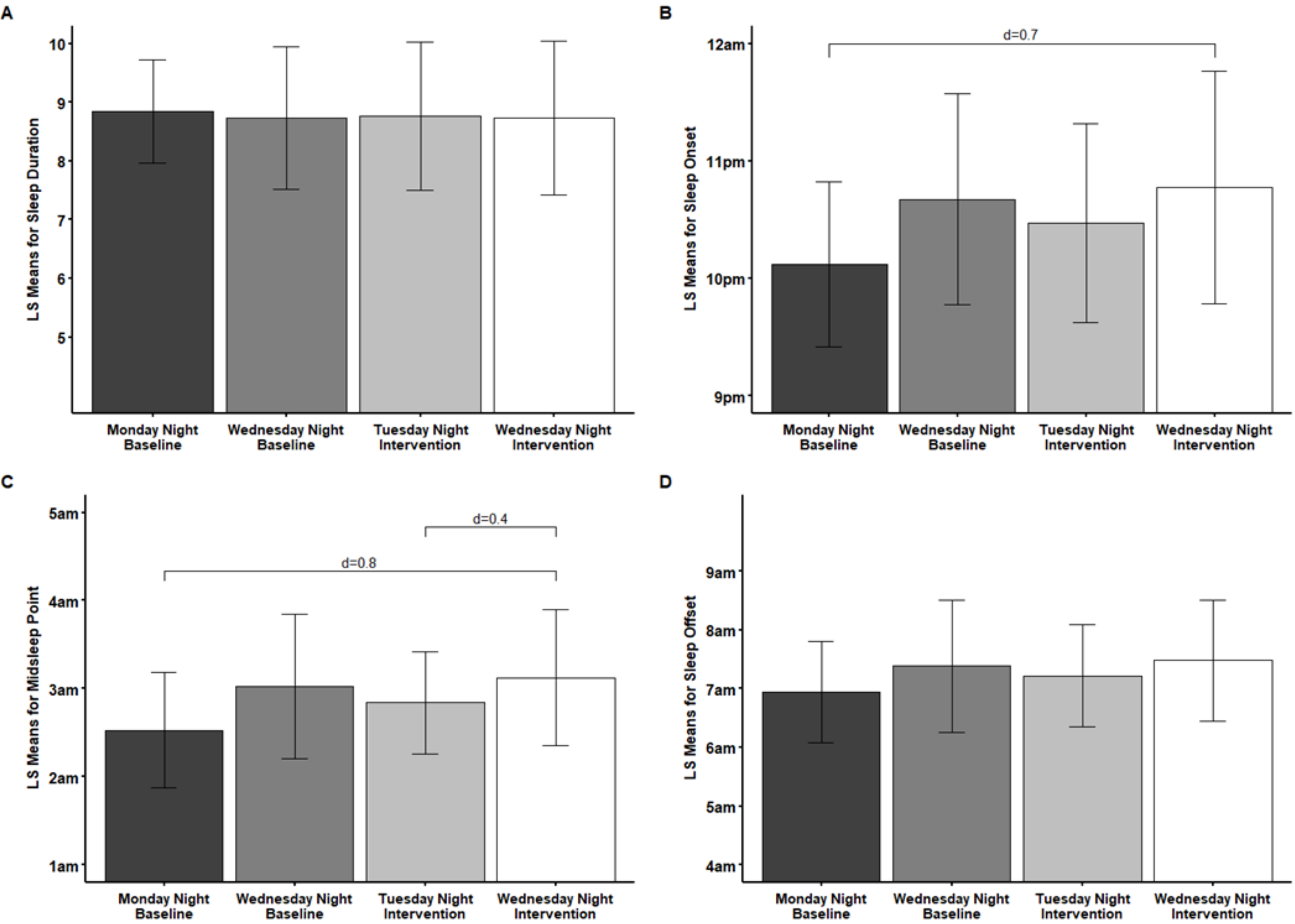


Figure 4.6. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) for different recovery nights during baseline and intervention phases. Error bars denote standard deviation. Dashed lines denote recommended sleep duration. Significant interactions with weekend training only are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

4.5 Discussion

The study aim was to determine whether a pilot intervention that included both sleep education and training rescheduling was feasible and whether it could positively impact the sleep/wake behaviour of elite adolescent swimmers. While significant changes were not seen for objective measures of sleep duration, subjective measures of mood, or swimming performance, some changes in sleep timing were found and there was a reduction in device use before bedtime.

With regards to the feasibility of the study, the swimmers reported during their feedback session that the schedule change was manageable, and some preferred the midweek break from morning training. The coach, however, found the change more difficult as his schedule had not been changed in many years. The swimmers reported that the daily sleep diaries were manageable and the actigraphs easy to wear and use. The significant drop-off in compliance with the actigraphs and diaries during the second half of the intervention suggests this may not have been the case after five weeks. Compliance decreased disproportionately amongst the older swimmers. When asked whether the athletes would have preferred an online diary or mobile app, the consensus was that the paper version was preferable. They did, however, suggest setting alarms or reminders on their phones to help them remember to fill in the sleep diaries in the morning.

To the authors' knowledge, this is one of the first efforts to implement a sleep education intervention in an elite adolescent athlete population. Sleep education interventions have, however, been implemented in general adolescent groups as well as in young adult athletes. The current findings are contrary to school-based sleep education interventions within adolescent populations (reviewed in Chung et al., 2017) and young adult athletes (Kaier et al., 2016; and Van Rywyk et al., 2017) which found that education programs typically result in short-term weekday and weekend sleep extensions which revert to control levels at follow-up. School-based education improved sleep knowledge in most of the studies reported in Chung et al's review, (2017), however, none of the studies found positive long-term changes in sleep-related behaviours. In young adult athletes, sleep workshops significantly improved daytime sleepiness and functioning and increased athletes' sleep knowledge but resulted in an increase in self-reported unhelpful sleep-related behaviours during the intervention period (scoring lower on the Sleep

Hygiene Index) (Kaier et al., 2016). Encouragingly, the current findings suggest that some positive behavioural changes relating to device use are possible in a group of highly motivated young swimmers.

The current intervention did not result in significant changes to sleep duration. One possible explanation for this is that the swimmers' schedules did not allow for substantial change. Baseline findings show that the swimmers were already going to sleep early for their age with median bedtimes of ~ 22:00 on weeknights (Crowley and Eastman, 2017). Similarly, waketimes before training sessions in the baseline phase were as late as they could be while still allowing participants enough time to get to training. Given that morning training start times could not be moved later due to fixed school times and pool availability, the intervention was designed to provide two consecutive mornings free of training during the week. This was in addition to the weekend which was also free of training. The schedule change did not, however, result in significant changes to weekly average sleep.

In the second half of the intervention, midsleep point and sleep offset were significantly earlier compared to both baseline and the first half of the intervention (Figure 4.3). When considering the median data presented in Table 1, it can be seen that these differences were largely driven by changes taking place on weekend nights. A potential explanation for this finding is that some of the swimmers were training and competing in other sports that involved an increase in weekend competition during the second half of the intervention. This represents a limitation of the study which should be taken into consideration in future research.

The intervention may also have been less effective than intended due to the relatively limited available contact time with adolescents, which was less than half that of most sleep education interventions (Chung et al., 2017). This does not, however, explain the behavioural change seen concerning device use habits before bed. These results suggest that the studied swimmers, unlike the athletes in Kaier et al. (2016), were motivated enough by the intervention to make sleep-related behavioural changes. During an informal follow-up with the swimmers' coach a year after the study, he reported that many of the swimmers had also started programming their smartphones to automatically switch to “do not disturb” mode when connected to their home WIFI networks. The coach indicated that these athletes had done this to try and reduce contact time with their phones, particularly in the evenings. While follow-up changes were not measured as part of this study, this does suggest that at least for some of the swimmers there was a change in sleep-related behaviours that lasted beyond the study. This method of intervention is a novel approach that could be tested in the future.

Sleep on recovery nights (nights before mornings free of training) was compared before and after the intervention to identify whether consecutive nights off would improve sleep duration and or change sleep timing on recovery nights. Results suggested that sleep onset and midsleep point for the second night of rest during the week for in the intervention (Wednesday nights) was significantly later than on the first recovery night of the week (Monday nights) during baseline. Midsleep point was also significantly later on the second night of rest of the week during the intervention (Wednesday nights) compared to the first night of rest of the week for the intervention (Tuesday nights). There seemed to be an overall trend for sleep on the second recovery night of the week to be later in timing regardless of whether the intervention was in place or not. Despite significant changes to sleep timing being found, sleep duration remained unchanged on recovery nights regardless of the intervention being introduced. This may suggests that recovery sleep duration on nights before mornings free from training remains consistent for this population regardless of when it takes place during the week or if take place over consecutive nights or not. It may also be the case that a change in recovery sleep patterns, as was trialled by this intervention, may need to persist occur for longer for notable changes to sleep duration to be seen. Further investigations into the patterns of recovery nights of sleep and their interaction with early morning training are needed.

Regardless of the study phase, significant differences were seen for different nights of the week. Sleep was reduced well below recommended durations on nights prior to morning training. Sleep prior to weekend mornings also shifted later compared to weeknights. The implications of these findings have been previously discussed (Steenekamp *et al*, 2021).

No main effects of age were seen for any actigraphy or sleep diary variables. Figure 4.5, however, shows that younger swimmers tended to sleep longer and go to bed earlier than the older swimmers. The small number of participants in each age group likely resulted in insufficient statistical power to identify differences.

Swimming performance was not found to change over the intervention although several participants broke personal best records during the trial both during and outside of the performance testing. The null result could be due to several factors. It is not possible to confirm whether training intensity was kept constant throughout, although the coach was asked to do so. Swimming performance has also been demonstrated to be significantly worse during the early morning with performance showing its own circadian rhythm which peaks in the afternoon and early evening (Kline et al., 2006). Testing the swimmers at 6:00 am, a time they were unaccustomed to performing maximal races, could have confounded performance results. While the swimmers are very familiar with the performance test used, they were not habituated to performing at that time of day.

4.6 Conclusion

The current study demonstrates that certain adolescent swimming groups and their support networks are open to changing their training schedules and behaviour to improve sleep. Future research should aim to test different patterns of training and recovery in lab-controlled conditions, ideally with polysomnography, to identify optimum training and recovery schedules for elite adolescent athletes. More evidence is also needed to further understanding of sex and age differences with regards to the reciprocal relationship between training and sleep in young athletes. Early morning training sessions as evidenced here disrupt the sleeping patterns of adolescent athletes and should be limited or, ideally eliminated wherever scheduling allows. Unfortunately, the busy schedules of adolescents do not, in most settings, allow for this. To eliminate morning training and keep training load consistent, a massive rescheduling commitment would need to be undertaken by all stakeholders in the adolescents' lives. This would include the schooling system, the coaches and sporting regulatory bodies, parents and guardians, friends and family, and most of all the athletes themselves.

Acknowledgements

We would like to acknowledge and thank the coaches and athletes for their participation in the current study.

Funding

Travis Steenekamp was awarded a Massey University Doctoral Scholarship to undertake this research

CHAPTER 5 EFFECTS OF SLEEP EDUCATION AND BLUE LIGHT BLOCKING GLASSES ON THE SLEEP/WAKE BEHAVIOUR OF ELITE ADOLESCENT ROWERS: A PILOT INTERVENTION

5.1 Abstract

Objective: Rowing has a long tradition of early morning training. Early morning training is a major cause of sleep loss in adolescent athlete populations. The purpose of this study was to determine the feasibility and efficacy of sleep education and blue light blocking glasses for improving sleep in elite adolescent rowers.

Methods: The sleep of 13 rowers (mean ± SD age 16.2 ± 1.1 y) was recorded for 2 baseline and 4 intervention weeks using actigraphy and sleep diaries. The diaries included the Hooper Index and a question on device use. The intervention included a sleep education program and the introduction of blue light blocking glasses 2 hours before bedtime.

Results: Baseline measures indicated a strong pattern of insufficient sleep prior to early morning training. Use of the blue light blocking glasses during the intervention was sporadic with an average compliance of 61% (SD ± 27%). No measures of actigraphically-recorded sleep changed after introduction of the intervention. Self-reported measures of fatigue ($p=0.05$, $d=0.1$) and muscles soreness ($p=0.02$, $d=0.2$) did drop significantly with small effect sizes assocaited with the reduction. Electronic device use before bedime remained consistent throughout baseline and intervention.

Conclusions: The intervention trialled in this study did not improve sleep patterns dictated by early morning training. Training schedules need to be considered carefully in order to maximise sleep opportunities for adolescencts as their circadian physiological preference does not match with early wake times.

Keywords:

Sleep Intervention; Sleep timing; Adolescent athlete; Blue light; Rowing

5.2 Introduction

With the importance of sleep being championed by major sporting bodies such as the International Olympic Committee, methods for optimising sleep have become a focus for researchers, athletes, coaches, and athlete support networks (Bergeron *et al.,* 2015). Athlete populations that train early in the morning are particularly at risk of insufficient sleep (Sargent *et al.,* 2014; Lastella *et al.,* 2015; and Gudmundsdottir, 2019). Adolescent rowers are one such population.

While rowing is classified as an endurance sport, it is unique in that it also requires the activation of approximately 80% of a person’s skeletal muscle mass (Hosea and Hannafin, 2012). The high aerobic and anaerobic demands of competition require a predominance of high-volume training at higher power outputs compared to most endurance sports (Secher and Volianitis, 2013). For New Zealand adolescent rowers, this results in 10 - 15 hours of training over 5 to 8 sessions during a typical week (Walters *et al.,* 2017). Given the busy academic and social schedules of adolescents, many of these training sessions are consequently scheduled before school (Walters *et al.,* 2017). Rowing has an added constraint of needing to occur outdoors and on the water and is, therefore, subject to the weather, which again pushes training to the early morning when water conditions are often more amenable to training.

The perfect storm model of adolescent sleep has been proposed to explain the worldwide phenomena of adolescent sleep loss (Carskadon, 2011; and Crowley *et al.,* 2018). The model suggests that adolescents have a physiological preference for later bed and wake times (Carskadon, 2011; and Crowley *et al.,* 2018). This is a direct consequence of pubertal changes in both the circadian timing system and the homeostatic sleep process which together regulate sleep and wakefulness (Carskadon, 2011; and Crowley *et al.,* 2018). For many adolescents, however, school start times dictate wake times. In the case of rowers, early morning training exacerbates the mismatch between circadian physiological preference and the need to wake early. The juxtaposition between physiology and training makes it difficult for adolescent rowers to obtain the 8-10 hours of sleep recommended for their age (Crowley *et al.,* 2007; Carskadon, 2011; Gradisar *et al.,* 2015; Hirshkowitz *et al.,* 2015; and Watson *et al.,* 2015).

Sleep interventions have been trialled in athletes as well as in general adolescent populations (as reviewed in Chung *et al.,* 2017; Bonnar *et al.,* 2018; and Fox *et al.,* 2020). A common form of intervention is to introduce sleep education to motivate behavioural change that aims to improve sleep habits (Bonnar *et al.,* 2014; Kaier *et al.,* 2016; and Van Ryswyk *et al.,* 2016). Such interventions have been trialled in adult athlete groups and have shown positive effects but have not been widely trialled with younger athletes (Bonnar *et al.,* 2018).

Another intervention category that has gained popularity in recent years is the use of blue-light blocking devices (van der Lely *et al.,* 2014; Schechter *et al* 2018; Knufinke *et al.,* 2019; and Knufinke *et al.,* 2020). The identification of melanopsin receptors in the mammalian eye has advanced current understanding of how light entrains the circadian timing system (Hankins *et al.,* 2007). Melanopsin receptors are sensitive to light in the blue frequency range which suppresses melatonin secretion (Brainard *et al.,* 2001;

Thapan *et al.,* 2001; Hankins *et al.,* 2002; and Hankins *et al.,* 2007). Exposure to light levels as low as 15 lux (normal room lighting being 100 lux) for an hour in the late evening has been shown to significantly suppress melatonin in pre- to mid pubertal adolescents (Crowley *et al.,* 2015). Decreased or delayed melatonin release is associated with a delay in sleep onset and sleep disruption (Chang *et al.,* 2015). Electronic devices such as smartphones, tablets, computers and television screens all emit a predominance of blue frequency light. Unsurprisingly, the regular usage of such devices at night has been linked to delayed bedtimes and disrupted sleep in adolescent groups (Wood *et al.,* 2013; and Van Der Lely *et al.,* 2015). To offset night-time blue light exposure, interventions have been designed to either limit or discourage the use of electronic devices. Education strategies aim at an overall reduction or elimination of the usage of such devices in the period leading up to bedtime. Alternatively, methods can be introduced to limit blue light exposure while still allowing device use. Blue light blocking glasses fall into this category.

Blue light blocking glasses include lenses designed to block light in the blue spectral range. It is theorised that an individual wearing these glasses can maintain electronic device use while minimising the disruption that blue light has on sleep/wake regulation. While largely unstudied in adolescent athletes, positive results have been found in adolescent males and recreational adult athletes (van der Lely *et al.,* 2014; Bender, Werthner & Samuels, 2017; Knufinke *et al.,* 2019; and Knufinke *et al.,* 2020). The feasibility of getting adolescent rowers to wear blue light blocking glasses prior to bedtime is unknown.

Accordingly, the purpose of the current study was to determine the feasibility and efficacy of a sleep education intervention coupled with the introduction of blue light blocking glasses in a group of elite adolescent rowers. It was hypothesised that the intervention would improve subjective ratings of sleep and mood as well as extend sleep duration. A secondary aim was to identify whether sleep timing was different on nights before early morning training and whether the intervention altered these patterns.

5.3 Method

5.3.1 Participants

Two high school male rowing teams were invited to participate in a pilot intervention. Both teams combined had a total of 73 rowers who were informed of the study, and 22 individuals volunteered to take part. Rowers were required to be between the ages of 13 and 18; free of injury for the prior 6 months; be able to attend at least 90% of scheduled training sessions; non-smokers; not currently taking medication with known side effects on sleep and could not have a diagnosed sleep or mood disorder. Rowers were required to complete the Athlete Sleep Screening Questionnaire (ASSQ) (Samuels *et al.,* 2015; and Bender *et al.,* 2018) to identify undiagnosed sleep problems as well as previous travel across time zones. Volunteers had to be an elite rower, which was defined as having competed or qualified to compete at a national level regatta in the previous 12 months. Parental consent and participant assent were obtained for rowers younger than 16 while participant consent was obtained for rowers 16 years and older. The study received ethical approval from the Massey University Human Ethics Committee (Southern A, Application 18/86).

5.3.2 Procedure

A repeated-measures, field-based intervention study was piloted to compare daily measures of sleep before and after sleep education and the introduction of blue light blocking glasses (BlueBlockGlasses, Somnitude Inc., Toronto, Ontario, Canada). The 6-week study comprised a 2-week baseline period and a 4-week intervention. At the start of the intervention, participants attended a 45-minute sleep education workshop and received a sleep education booklet to reinforce the content covered during the workshop. Coaches and parents were invited to the education session as well. All participants received blue light blocking glasses at the workshop and were instructed to wear them in the two hours leading up to their bedtime (as in Bender, Werthner & Samuels, 2017).

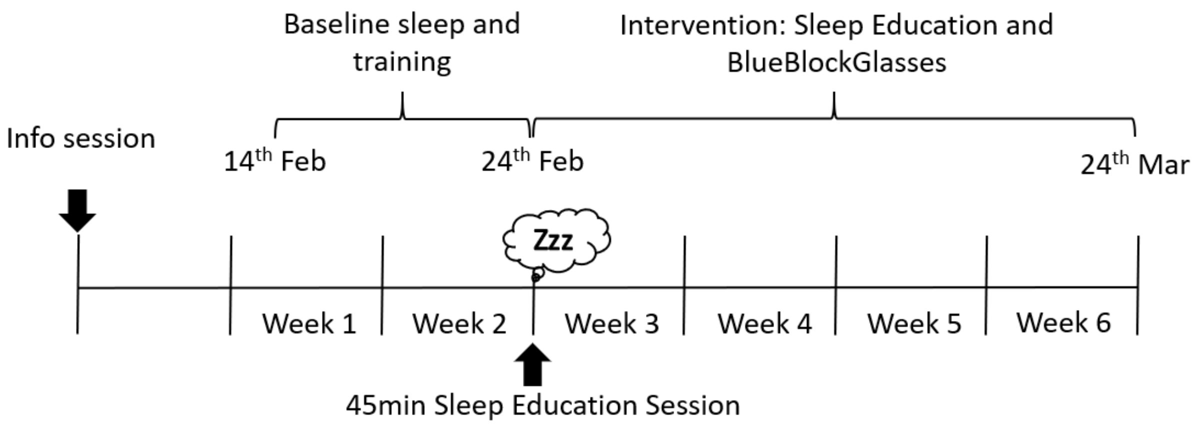


Figure 5.1. Depiction of the timeline for the 6-week study.

Coaches were asked to keep the training load as constant as possible throughout the 6-week study. One of the rowing teams had 9 scheduled training sessions a week while the other team had 10. Both teams had 4-weekday early morning training sessions which commenced at 6:00am. Both teams also had weekend training scheduled to start at 8:00am on both Saturday and Sunday.

5.3.3 Measures

MotionLogger devices (Ambulatory Monitoring Inc. [AMI], Ardsley, NY, USA) were worn by the rowers on their non-dominant wrist continuously for the 6-week study (Meltzer *et al.,* 2015). Data were recorded in 1-minute epochs using the monitor's zero-crossing mode (Meltzer *et al.,* 2015). Sleep and wakefulness were inferred from the activity count using the Cole-Kripke algorithm (Cole *et al.,* 1992) in the manufacturer's software (Action-W version 2.7.3045, Ambulatory Monitoring Inc., Ardsley, New York, USA). The rowers were asked to press the event button on the watch when going to bed and upon awakening. Sleep timing was also recorded daily on a timeline in a sleep diary. The event marker data and sleep timelines were then used to confirm periods of sleep as recorded by actigraphy. Actigraphic measures that were extracted from the watches were:

Sleep Onset Latency –time to fall asleep from when participants indicated trying to fall asleep

Sleep Onset –time participants first fell asleep

Midsleep point –midway point of a sleep period

Sleep Offset –time participants finally woke up

Sleep Duration –difference between Sleep Onset and Sleep Offset

The daily sleep diary incorporated the Hooper Index which was filled in alongside the sleep timelines each morning upon awakening. The Hooper Index is a subjective measure of sleep quality, stress, fatigue and muscle soreness rated on a 1-7 Likert scale (Hooper & Mackinnon, 1995). The sleep diary also incorporated a yes/no question regarding device use in the last hour before the rowers' bedtime and a yes/no question regarding the wearing of the blue light blocking glasses in the last 2 hours before bedtime.

Rower chronotype was measured using the Morningness-Eveningness Scale for Children (MESC) (Carskadon *et al.,* 1993). While the primary use of the ASSQ was to screen volunteers, the questionnaire also captured habitual caffeine use, evening device use and chronotype for those who participated in the study.

5.3.4 Statistical analysis

Data was analysed to compare sleep before and after the intervention was introduced. Additional analyses were conducted on data from the intervention period only to compare sleep on nights the blue light blocking glasses were used to those where they were not used. Data from all 6 weeks of the study were analysed to identify effects on nights of the week. Nights of the week were defined as taking place before "morning training", "morning off", "weekend off", and "weekend training". Interaction effects of "intervention by night of the week" and "blue light blocking glasses by night of the week" were also included in statistical models.

All statistical analyses were run in SAS (version 9.4, SAS Institute Inc., Cary, NC, USA). Actigraphic sleep variables were analysed using linear mixed models and incorporated the Kenward-Roger adjustment (Littell *et al.,* 2006). Assumptions of the model were assessed visually and through Kolmogorov-Smirnov tests of normality. A threshold of p=0.05 was set for significance for all statistical tests. Levene's test was run to assess variance in the data and where significant a more conservative alpha of p=0.01 was set (Tabachnick & Fidell, 2013). Cumulative logit proportional-odds models were used to analyze Hooper Index items and a binomial logistic regression model was used to analyse device use. Holm-Bonferroni post hoc adjustments were calculated as well as Cohen's d for effect size (Field, Miles & Field, 2012). Effects were classified as small (0.2–0.49), moderate (0.5–0.79) and large (≥0.8) (Cumming, 2012).

5.4 Results

In total, 13 (mean ± SD 16.2 ± 1.1 y) of the 22 volunteer rowers' data are presented here. Three volunteers withdrew from the study after consenting to participate. A further 6 participants had to be excluded from final analyses owing to large amounts (≥40%) of missing data. No volunteers were excluded from the study based on screening and ASSQ results. The rowers were all classified as 'morning type' according to both MESC scores (35.7 ± 2.9) and ASSQ chronotype questions (7.8 ± 1.4). Of the 13 rowers who were included in the analyses, compliance with wearing the actiwatches was higher at baseline compared to intervention (81% during baseline; 70% during intervention).

Compliance with filling in the diary was consistent over the entire study period (82% during baseline; 83% during intervention).

Results indicate that actigraphic measures of sleep duration (*p*=0.37, *df*=1, 278, *F*=0.81), sleep onset latency (*p*=0.39, *df*=1, 277, *F*=0.74), sleep onset (*p*=0.65, *df*=1, 274, *F*=0.21), midsleep point (*p*=0.17, *df*=1, 275, *F*=1.89), and sleep offset (*p*=0.16, *df*=1, 282, *F*=1.96) did not differ signficantly before versus after the intervention. There was a significant interaction of intervention and nights of the week for sleep duration (*p*=0.04, *df*=3, 272, *F*=2.73). Despite this, post hoc analyses found no significant change for sleep duration for the same type of weeknight pre- and post-intervention (Table 5.1). Median and range values for different nights of the week pre- and post-intervention are shown in Table 5.1.

Ratings of fatigue (*p*=0.05, *df*=1, 293, *F*=3.98, d=0.1) and muscle soreness (*p*=0.02, *df*=1, 293, *F*=5.29, d=0.2) on the Hooper Index were significantly lower during the intervention compared to baseline (Figure 5.2). Sleep quality (*p*=0.42, *df*=1, 294, *F*=0.64, d=0.1) and stress (*p*=0.97, *df*=1, 294, *F*=0.00, d<0.1), were not found to be significantly different pre- and post-intervention. Device use also remained unchanged by the intervention (*p*=0.64, *df*=1, 286, *F*=0.22, d<0.1).

Table 5.1 Comparison of median (range) values for sleep variables for different nights of the week pre and post-intervention.

	Baseline Median (Min-Max)	Intervention Median (Min-Max)	Comparison	
			Adj p Value	Cohen's d
Sleep Duration				
Mornings off	8h41 (7h12 - 9h29)	8h37 (6h34 - 11h47)	1	<0.1
Morning training	6h57 (5h10 - 8h30)	7h15 (5h11 - 8h45)	1	0.3
Weekend off	9h30 (8h42 - 13h58)	8h47 (7h48 - 11h58)	0.11	0.6
Weekend training	8h00 (6h45 - 9h55)	7h52 (6h14 - 10h13)	1	0.1
Sleep Onset Latency				
Mornings off	8min (1-56min)	11min (1-74min)	1	0.2
Morning training	11min (4-59min)	10min (1-87min)	1	<0.1
Weekend off	10min (4-86min)	7min (1-13min)	1	0.7
Weekend training	7min (4-35min)	11min (3-43min)	1	0.2
Sleep Onset				
Mornings off	22:25 (21:37 - 23:45)	22:22 (21:04 - 00:45)	1	<0.1
Morning training	22:12 (21:15 - 23:54)	21:59 (20:29 - 23:48)	1	0.3
Weekend off	23:42 (21:37 - 1:26)	00:01 (21:26 - 1:37)	1	0.4
Weekend training	22:50 (21:19 - 00:28)	22:44 (21:07 - 00:57)	1	0.1
Midsleep				
Mornings off	2:47 (2:12 - 3:54)	2:47 (1:19 - 4:48)	1	0.1
Morning training	1:43 (1:17 - 2:34)	1:41 (00:51 - 3:02)	1	0.1
Weekend off	4:11 (3:51 - 5:53)	4:20 (2:40 - 5:37)	1	<0.1
Weekend training	2:55 (2:01 - 4:05)	2:52 (1:06 - 4:10)	1	0.2
Sleep Offset				
Mornings off	7:01 (6:29 - 8:04)	7:08 (4:58 - 9:27)	1	0.1
Morning training	5:13 (4:55 - 5:44)	5:16 (4:28 - 7:11)	1	0.2
Weekend off	9:09 (8:24 - 11:34)	8:47 (7:55 - 10:09)	0.32	0.5
Weekend training	7:02 (5:34 - 7:45)	6:57 (5:04 - 7:58)	1	0.2

Note: Median and range values have been provided as the data was not normally distributed.

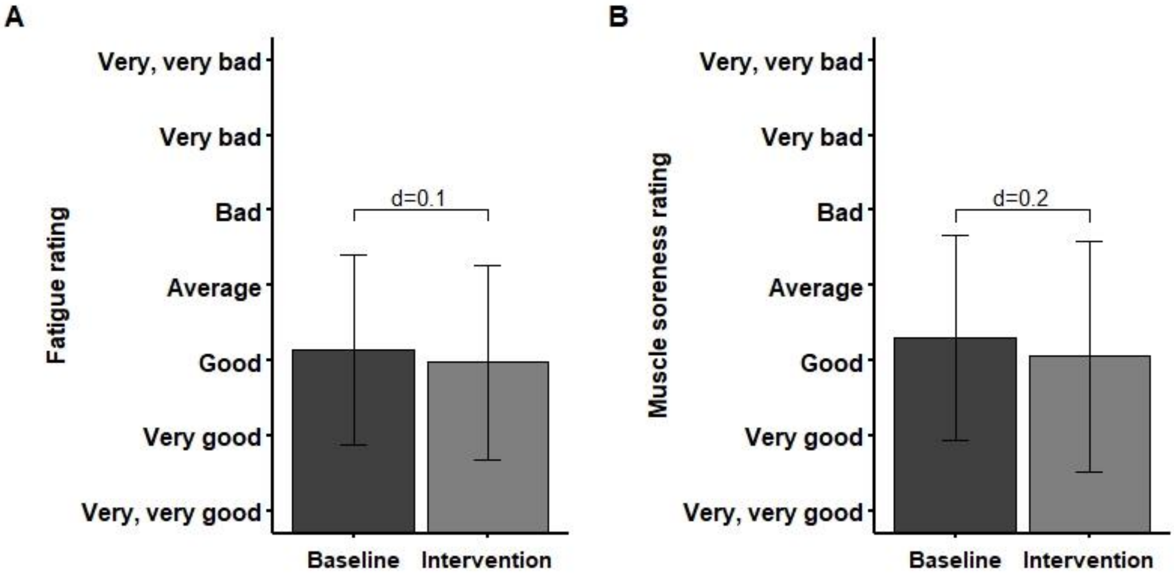


Figure 5.2. Comparison of self-reported measure of Fatigue (A) and Muscle Soreness (B) during Baseline and the Intervention. Error bars denote standard deviation. Significant interactions are marked with brackets with effect sizes above. Magnitude of effects: 0.2–0.4 = small; 0.5–0.79 = moderate; ≥0.8 = large.

Across the 263 nights of sleep diary data collected during the intervention period, the blue light blocking glasses were reportedly used on 164 nights. Individual compliance for wearing the glasses was 61% on average (SD ± 27%, range 10%-100%). Analyses comparing sleep between participants with high and low compliance rates could not be conducted due to the small sample size. The blue light blocking glasses were almost always used when devices were used as well. Only 4% of individuals reported using the glasses in the absence of using electronic devices.

Figure 5.3 shows the comparison between nights during the intervention when glasses were worn and when they were not. No significant differences were found when comparing nights where glasses were worn and when they were not for sleep duration (p=0.17, df=1, 142, F=1.87), sleep onset latency (p=0.30, df=1, 142, F=1.09), sleep onset (p=0.10, df=1, 138, F=2.69), midsleep point (p=0.32, df=1, 138, F=1) wake time (p=0.40, df=1, 140, F=0.7), sleep quality (p=0.46, df=1, 176, F=0.54), stress (p=0.72, *df*=1, 175, *F*=0.13), fatigue, (p=0.29, *df*=1, 174, F=1.15) and muscle soreness (p=0.11, *df*=1, 174, F=2.47).

Figure 5.3 also depicts variability in sleep timing across the week. Main effects for night of the week were found for sleep duration (p<0.001, *df*=3, 268, F=94.54), sleep onset (p<0.001, *df*=3, 264, F=30.33), midsleep point (p<0.001, *df*=3, 266, F=247.23) and sleep offset (p<0.001, *df*=3, 275, F=376.64). No main effect of night was found for sleep onset latency (p=0.68, *df*=3, 268, F=0.5). Post hoc analyses which further explore the main effects for night of the week are presented in Table 5.2.

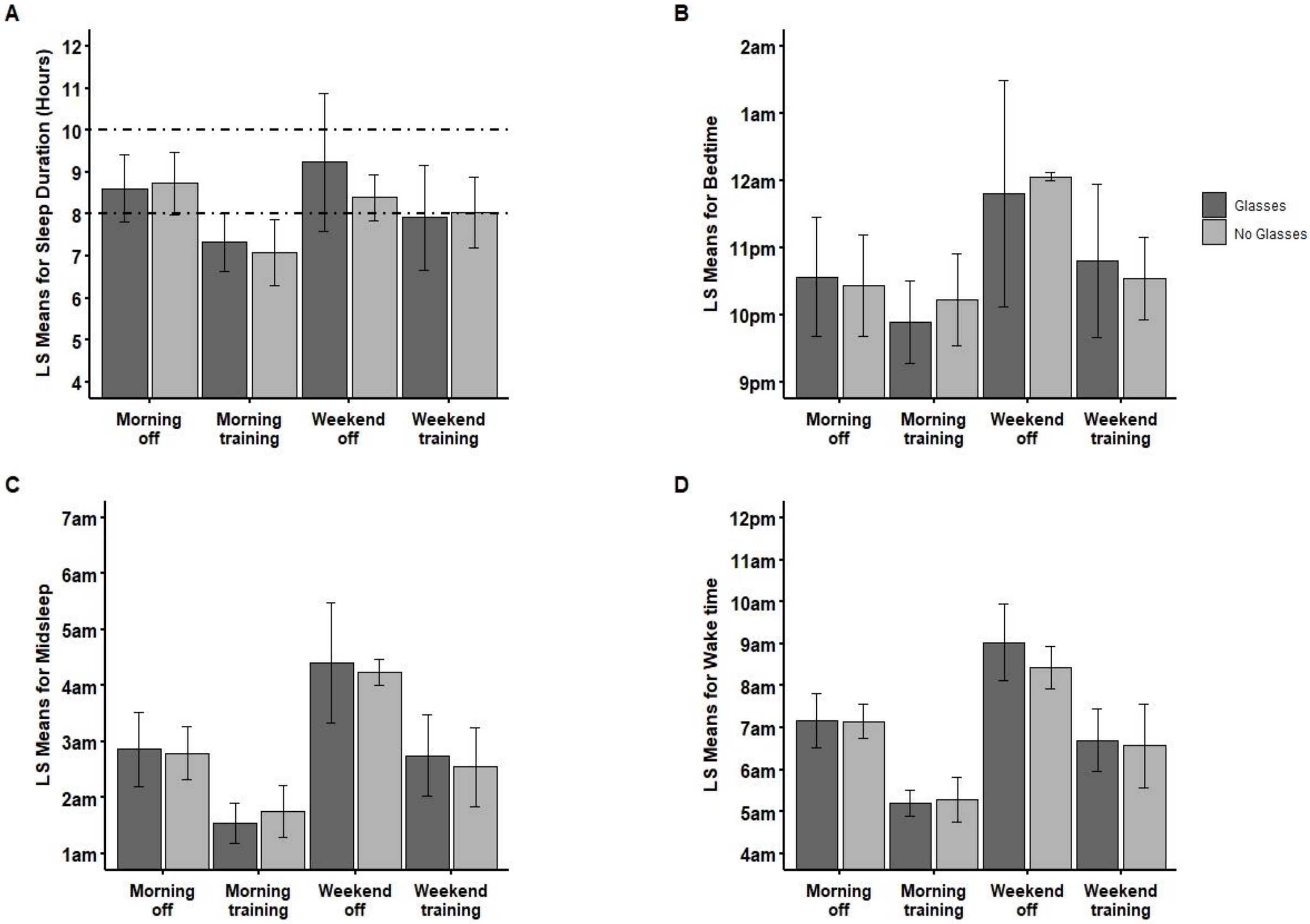


Figure 5.3. Least Squared Means for Sleep Duration (A), Sleep Onset (B), Midsleep (C) and Sleep Offset (D) comparing sleep timing on nights when glasses were worn and not worn . Error bars denote standard deviation. Dashed lines denote recommended sleep duration.

Table 5.2. Post hoc results comparing actigraphy variables between night conditions.

	LS Means Estimate		LS Means Estimate	t(df)	Adj p Value	Cohen's d
Sleep Duration						
Morning Training	7h02	Morning off	8h35	-12.78 (272)	**<.0001**	1.9
Morning Training	7h02	Weekend off	9h37	-14.37 (276)	**<.0001**	2.7
Morning Training	7h02	Weekend training	7h53	-5.33 (273)	**<.0001**	1.0
Morning off	8h35	Weekend off	9h37	-5.72 (274)	**<.0001**	1.0
Morning off	8h35	Weekend training	7h53	4.23 (273)	**<.0001**	0.7
Weekend off	9h37	Weekend training	7h53	8.1 (277)	**<.0001**	1.4
Sleep Onset						
Morning Training	22:17	Morning off	22:34	-2.84 (271)	0.077	0.5
Morning Training	22:17	Weekend off	23:34	-8.78 (273)	**<.0001**	2.0
Morning Training	22:17	Weekend training	22:59	-5.35 (272)	**<.0001**	0.8
Morning off	22:34	Weekend off	23:34	-6.84 (272)	**<.0001**	1.4
Morning off	22:34	Weekend training	22:59	-3.18 (272)	**0.031**	0.3
Weekend off	23:34	Weekend training	22:59	3.36 (274)	**0.018**	0.9
Midsleep						
Morning Training	1:47	Morning off	2:50	-15.29 (271)	**<.0001**	2.3
Morning Training	1:47	Weekend off	4:22	-25.2 (273)	**<.0001**	5.9
Morning Training	1:47	Weekend training	2:55	-12.22 (272)	**<.0001**	2.1
Morning off	2:50	Weekend off	4:22	-14.83 (272)	**<.0001**	2.9
Morning off	2:50	Weekend training	2:55	-0.72 (272)	1	0.1
Weekend off	4:22	Weekend training	2:55	12.01 (274)	**<.0001**	2.4
Sleep Offset						
Morning Training	5:16	Morning off	7:07	-21.39 (275)	**<.0001**	3.9
Morning Training	5:16	Weekend off	9:11	-30.94 (282)	**<.0001**	7.8
Morning Training	5:16	Weekend training	6:49	-13.47 (276)	**<.0001**	2.9
Morning off	7:07	Weekend off	9:11	-16.3 (280)	**<.0001**	3.3
Morning off	7:07	Weekend training	6:49	2.58 (276)	0.086	0.6
Weekend off	9:11	Weekend training	6:49	15.89 (283)	**<.0001**	3.0

Bold values represent statistically significant results.

5.5 Discussion

The main aim of this study was to test the feasibility and efficacy of an intervention that incorporated both sleep education and blue light blocking glasses in a group of adolescent rowers. It was hypothesized that the intervention would extend sleep duration and improve subjective ratings of mood and sleep quality. Although sleep duration did not change significantly as a result of the intervention, self-reported measures of fatigue and muscle soreness did reduce. Sleep quality and stress did not change. Baseline findings indicated significant variation in the rowers' sleep patterns across a typical training week. These differences were largely driven by the presence of early morning training which shortened sleep by shifting sleep offset earlier. This pattern was not improved by the intervention.

Blue light blocking glasses have been trialled in male adolescents and adult athlete groups previously, with varying degrees of success (van der Lely *et al.,* 2014; Bender, Werthner & Samuels, 2017; Knufinke *et al.,* 2019; and Knufinke *et al.,* 2020). The most notable effects of blue light blocking interventions in athletes is a reduction in sleep onset latency as well as improvements in subjective sleep quality and mood (Bender *et al.,* 2017; Knufinke *et al.,* 2019; and Knufinke *et al.,* 2020). In the current study, no differences were found for measures of sleep quality, stress or sleep onset latency. Fatigue and muscle soreness were seen to reduce significantly with the intervention. There were, however, no significant differences seen for either fatigue or muscle soreness when comparing nights when the glasses were used to nights when they were not used. Results showed sporadic and inconsistent use of the glasses by the rowers. It is possible that to detect changes in sleep or subjective mood, more consistent use of the glasses would be required by participants. Given the small study sample, it was not possible to compare compliant and sporadic users to further investigate this hypothesis.

It should also be noted that while significant changes in fatigue and muscle soreness were found post introduction of the intervention, effect sizes for these changes remained small. It is also possible that fatigue and muscle soreness changed pre – to- post-intervention due to changes in training load across the 6-week study. Ideally session ratings of perceived exertion would have been measured across the study to ensure that training load did not fluctuate. Given the time commitment required from the coaches to enable their teams to participate in the study session, ratings of perceived exertion were omitted to limit the burden on the part-time coaches.

There are several recognised mechanisms for how evening electronic device use may affect the sleep of adolescents (Cain & Gradisar, 2010). The first is the direct displacement of sleep as a function of time spent using devices (Cain & Gradisar, 2010). The second mechanism is the physiological arousal that results from viewing stimulating content (Cain & Gradisar, 2010). Bright light, particularly in the blue spectrum, may suppress melatonin and delay the circadian timing system and is the third mechanism through which device use may influence sleep. Lastly, there has been a small body of evidence suggesting that electromagnetic radiation from smartphones could impact sleep architecture and delay melatonin production (Hamblin & Wood, 2002; Loughran *et al.,* 2005; and Wood *et al.,* 2006). A major limitation of relying on blue light blocking glasses to improve sleep is that the glasses only reduce the effects of light on sleep (Cain & Gradisar, 2010) and do not address these other mechanisms. The education provided to the rowers emphasised the need to reduce or avoid device use before bed and to only use the blue light blocking glasses if device use could not be avoided, for example for homework. The same educational material was presented to a group of swimmers in a similar intervention which did not include the use of blue light blocking glasses. The swimmers in that study significantly reduced device use after the educational intervention with some indication of long-term behavioural change

(Steenekamp *et al*., under review). These results suggest that in highly motivated groups of young athletes, the preferred approach may be to start with sleep education and only introduce blue light blocking glasses if sleep education does not result in behavioural change. Giving adolescent athletes blue light blocking glasses from the outset may give them a false sense of protection from the effects of device use before bed and potentially even promote ongoing device use.

Another aspect of the current study was to identify how sleep fluctuates and is influenced by the presence of early morning training. In New Zealand, rowing has more than double the attrition rate during high school years than other sports (Sport New Zealand, 2012; and Walters *et al.,* 2017), which suggests that there are aspects of this sport that are unattractive to or unmanageable for adolescents. Training times and their impact on sleep could be a key factor that discourages adolescents from staying in this sport. A better understanding of this issue and how to retain adolescent rowers is important in the campaign to get and keep adolescents physically active (Walters *et al.,* 2017).

A strong pattern of sleep timing was seen throughout the study and was unchanged by the introduction of the intervention. Sleep timing and duration were dependent on whether the following day was a weekday or weekend and whether there was training scheduled for the following morning. Sleep before morning training during the week was over half an hour shorter than on weekday nights preceding training weekday nights before mornings off, largely due to wake time being advanced by almost two hours. The rowers appear to compensate for this by going to sleep slightly earlier on nights before training, however, least mean squared estimates indicated this was only by 18 minutes. One of the reasons why the rowers could not simply go to bed significantly earlier to compensate for early morning training is due to the wake maintenance zone (Dijk and Czeisler 1995; Shekleton et al. 2013). The wake maintenance zone is a period in the early evening where the circadian drive for alertness makes it very difficult to fall asleep

(Kelly *et al.,* 2015). During adolescence, the circadian timing system shifts later while the homeostatic drive for sleep rises more slowly (Kelly *et al.,* 2015). The combination of these alterations to the two sleep wake regulation processes during adolescence results in a later wake maintenance zone (Crowley and Eastman, 2018). This could mean that even if the rowers chose to try to go to bed earlier to compensate for the early wake times for training, their circadian physiology may have inhibited sleep if their desired bedtimes coincided with their wake maintenance zone.

Rowing as a sport has some unique considerations. Training on the open water is largely dependent on weather and water conditions. Both the teams in this study are from schools in Wellington, New Zealand and training sessions take place in Wellington Harbour. The water is normally more amenable to rowing in the early morning prior to the wind increasing. This also results in both teams sometimes travelling out of the city on weekends to train on still bodies of water that provides better conditions. While weekend training is scheduled to start mid-morning, this only offers the rowers the opportunity to sleep in if the training takes place in the city. If the training requires travel, the rowers need to get up early in order to get to the training lake which can be several hours away. This further demonstrates how training schedules can dictate the sleeping patterns of young rowers.

A limitation of this study was that only male teams were recruited to participate. Another is that despite the large sample population the study had to draw from, less than 30% of the rowers volunteered for the study. Furthermore, participant withdrawal and low compliance saw another 9 rowers’ data excluded, leaving a final sample of 13 rowers. Future studies aiming to implement similar interventions could try and address this issue with longer recruitment periods and more direct contact with participants. Researchers only made contact with the rowers at the beginning of the study, during the sleep education session and when the Actiwatch batteries needed replacing after one month.

In hindsight, scheduling regular check-ins, attending training sessions and increasing overall rapport with the participants could have mitigated these issues. A similar study with adolescence swimmers had high compliance and retention (Chapter 4). A major difference between these populations was the status of the coaches. The swimmers had a full-time paid coach whereas the rowing coaches were volunteers with careers apart from their coaching commitments. The ability of coaches to commit time to such a study should also be considered when designing similar interventions.

5.6 Conclusion

The intervention piloted in this small study did not find a significant change in sleep timing and duration after introducing sleep education and blue light blocking glasses to adolescent rowers. It should be noted that with a relatively small sample, large effects would have been needed to see effects of the intervention on sleep, given the inter- and intra-individual variability of the participants. A positive outcome of the intervention was the indication of reduced levels of fatigue and muscle soreness. The clear pattern of reduced sleep duration with early morning training suggests this is the primary factor influencing rower's sleep behaviour. Interventions, such as the one trialled here, have yet to show evidence of sufficiently influencing sleep given the strong physiological drivers of sleep onset in adolescents coupled with the extreme truncation of sleep by early morning training. With a large body of evidence showing the crucial role sleep plays in health and development during adolescence, careful consideration needs to be given to the need for early morning training for adolescent rowers.

Acknowledgements

We would like to acknowledge and thank the coaches and athletes for their participation in the current study.

Funding

Travis Steenekamp was awarded a Massey University Doctoral Scholarship to undertake this research.

CHAPTER 6 DISCUSSION

Sleep plays a vital role in maintaining and optimising physical health, cognitive functioning, immunity, metabolic regulation, and recovery from physical activity (Besedovsky, Lange, & Born, 2012; and Krause *et al.,* 2017). A large body of scientific literature shows, however, that adolescents around the world commonly do not meet their recommended sleep requirements (Yang *et al.,* 2005; Chen *et al.,* 2006; Olds *et al.,* 2010; Garaulet *et al.,* 2011; Leger *et al.,* 2012; Maslowsky & Ozer, 2013; Lo *et al.,* 2016; and Short & Weber, 2018). It has also been documented that athlete populations are at increased risk of insufficient or poor sleep owing to the nature of athletic endeavours, over and above the risk factors that would typically affect sleep in the general population (Vlahoyiannis *et al.,* 2021). Previous literature identifies early morning training as a praticular barrier to sleep in all athlete groups (Leeder *et al.,* 2012; Hausswirth *et al.,* 2014; Sargent *et al.,* 2014a; Sargent *et al.,* 2014b; Lastella *et al.,* 2015a; Schaal *et al.,* 2015; Suppiah *et al.,* 2015; Blanchfield *et al.,* 2018; Choi *et al.,* 2018; Suppiah *et al.,* 2018; Gudmundsdottir, 2019; Ramos-Campo *et al.,* 2019; Walsh *et al.,* 2019 and Vlahoyiannis *et al.,* 2021).

Chapter 1 highlighted, however, that few studies have investigated the sleep of elite adolescent athletes. Where these studies have been conducted, average sleep is often presented rather than a nuanced picture of how sleep fluctuates across days in the presence and absence of early morning training. Several sleep intervention studies have been conducted with athlete and adolescent populations, however very few have focused on adolescent athlete populations. Where these studies have been conducted, they are usually confined to controlled environments such as training camps or competitions rather than *in situ* interventions following adolescent athletes during their everyday routines.

Thus, the research in this thesis aimed to investigate the sleep/wake behaviours of elite adolescent athletes with a predominance of early morning training and to pilot the effects of sleep interventions within such populations. The following research questions were posed to address these aims:

1. Does early morning training alter the sleep/wake behaviour of elite adolescent athletes?

2. Can sleep education coupled with training rescheduling improve elite adolescent athletes sleep/wake behaviour?

3. Can sleep education coupled with blue light blocking technology improve elite adolescent athletes sleep/wake behaviour.

Two studies were undertaken to answer these research questions. The first study monitored the sleep/wake behaviour of elite adolescent swimmers during a typical training phase. Following baseline monitoring the swimmers underwent sleep education training and had one of their training sessions rescheduled. The second study monitored the sleep/wake behaviour of elite adolescent rowers during a typical training phase. Following baseline, the rowers were presented with the same sleep education material as the swimmers, but instead of training rescheduling were given blue light blocking glasses for pre-bedtime use. The baseline monitoring phases of both studies were designed to address the first research question while the interventions addressed questions 2 and 3.

6.1 Key findings

6.1.1 Baseline sleep

The main finding of Chapter 3 was that median sleep duration was significantly truncated on nights prior to weekday early morning training (6.7hrs) compared to nights before weekday mornings off (8.8hrs) (p<.0001; d=2.3). The large magnitude of the effect size suggests that this difference was relatively consistent throughout the sample rather than due to a small subgroup. While the pattern of early morning training leading to sleep loss is well established in adult athlete literature (Leeder *et al.,* 2012; Hausswirth *et al.,* 2014; Sargent *et al.,* 2014a; Sargent *et al.,* 2014b; Lastella *et al.,* 2015a; Schaal *et al.,* 2015; Suppiah *et al.,* 2016; Blanchfield *et al.,* 2018; Ramos-Campo *et al.,* 2019; Walsh *et al.,* 2019 and Vlahoyiannis *et al.,* 2021), the present findings add to the limited work confirming this trend in adolescent athletes (Suppiah *et al.,* 2016; Estivill-Domènech *et al.,* 2018; and Gudmundsdottir, 2019). Other studies that have quantified sleep amongst adolescent athlete populations (Sargent *et al.,* 2013; Roach *et al.,* 2013; Suppiah *et al.,* 2015; Gerber *et al.,* 2018; and Choi *et al.,* 2018), have neglected to document sleep differences on nights prior to training and nights prior to days of rest during the week. For example, Gerber *et al*, (2018) control for possible confounding variables in their comparison study looking at adolescent athletes with and without burnout, including type of sport and time spent training, but do not mention the timing of training. The findings of the current thesis suggest that any future research endeavour into the sleep quantification of adolescent athletes has to take the timing of training into account.

In the current study, shortened sleep prior to early morning training was due to advanced wake times while bedtimes remained largely unchanged and in line with those observed for general New Zealand adolescents (Dorofaeff & Denny, 2006; Skidmore *et al.,* 2013; and Galland *et al.,* 2017). These findings are consistent with those of Estivill-Domènech *et al.,* (2018) (Figure 6.1), however, Gudmundsdottir, (2019) does not report sleep onset or offset times, which limits any comparison with their data set.

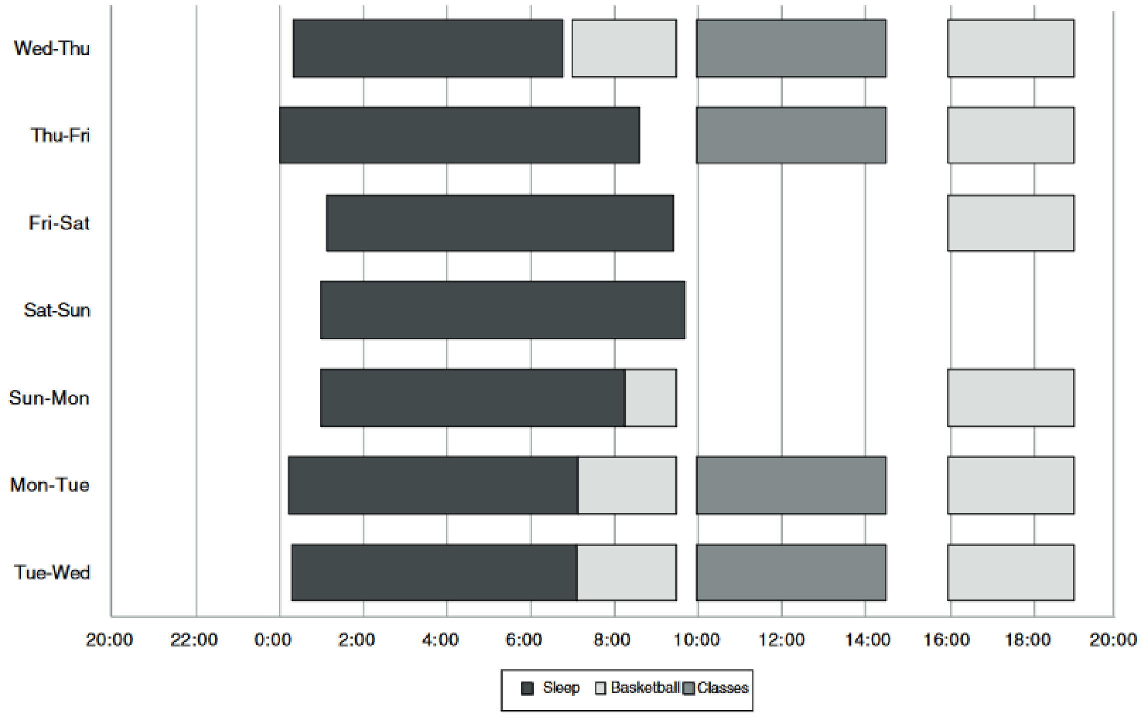


Figure 6.1. Graphic representation of the sleep timing of basketball players monitored over a typical training week by Estivill-Domènech et al. (2018).

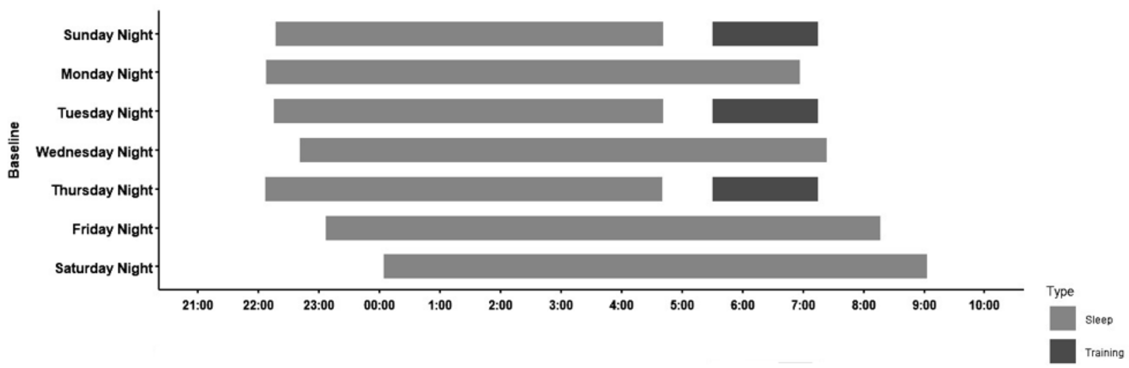


Figure 6.2. Graphic representation of the sleep timing of swimmers monitored over typical training week by Steenekamp et al. (2020).

The findings from Chapter 3 as well as the Estivill-Domènech *et al.,* (2018) study demonstrate a clear curtailment of sleep by waking early for morning trainings with no change in bedtimes (Figure 6.1 & 6.2). To maintain recommended sleep durations on nights prior to early morning training, the basketball players in Estivill-Domènech *et al.,* (2018) and the swimmers and rowers in Chapter 3 would have needed to advance their bedtimes significantly. The slower sleep pressure build-up during adolescence in conjunction with a phase delay in circadian timing, however, dictates a propensity for later bed and wake times (Crowley, Tarokh & Carskadon, 2012). The adolescent athletes in these studies would need to advance their bedtimes to a time in the circadian timing system's cycle when the adolescent brain is likely to be promoting wakefulness (the wake maintenance zone) (Dijk and Czeisler 1995; Wyatt, 2007; and Shekleton et al. 2013). Even if the athletes attempted to bring forward their bedtimes significantly, falling asleep early could well prove a frustrating endeavor because of the physiological factors controlling sleep timing (Kelly *et al.,* 2015; and Crowley and Eastman, 2018). Another way athletes could compensate for the reduced night-time sleep would be the adoption of daytime naps. The findings Chapter 3, however, indicate that the adolescent swimmers and rowers reported very few instances of napping and napping was not mentioned in Estivill-Domènech *et al.,* (2018) or Gudmundsdottir, (2019). If early morning trainings cannot be avoided, then supplementing shortened night-time sleep periods with daytime naps for adolescents is an area that could be explored. It should be noted, however, that many of the athletes in Chapter 3 either had classes, swimming or rowing training, or other extracurricular activities that removed opportunities for afternoon napping.

Chapter 3 also demonstrated that the swimmers and rowers showed signs of social jetlag over weekends whenever training was not present. The athletes went to bed and woke up significantly later on weekends compared to during the week, as has been reported for other New Zealand adolescents (Dorofaeff & Denny, 2006; Skidmore *et al.,* 2013; and Galland *et al.,* 2017). The same trend was observed in the basketballers monitored in Estivill-Domènech *et al*, (2018). The hallmarks of social jetlag were less pronounced in the rowers on nights prior to weekend morning trainings. These findings echo those of Brand *et al*, (2010) who found less variability in sleep from weekday to weekend in an adolescent athlete group who had weekend sporting commitments, when compared to a sedentary control group. The circadian disruption caused by accruing a sleep dept throughout the week and then ‘catching up’ sleep over the weekend has been well documented to have negative outcomes for metabolic and psychological health and academic outcomes for adolescents (Dorofaeff & Denny, 2006; Díaz-Morales & Escribano. 2015; and Malone *et al.,* 2016). What is yet to be established, however, is the effect of repeatedly truncating sleep throughout the week as a result of intermittent early morning training. It is currently unclear whether the additional disruption to sleeping patterns as evidenced in Chapter 3 further exacerbates these health and academic issues for adolescent athletes.

The changing physiological preference for later bed and wake times is associated with a shift towards being more ‘evening type’ as puberty progresses (Giannotti *et al.,* 2002; Kim *et al.,* 2002; Roenneberg *et al.,* 2004; Roenneberg *et al.,* 2007; and Randler & Bilger, 2009). The findings presented in Chapter 3, however, show that the swimmers and rowers in these studies tended towards being “morning type”, based on both the MEC and the ASSQ. Again, the results of Estivill-Domènech *et al*, (2018) show a similar trend with only 2 of their 12 basketballers being rated as evening types on the compound morningness scale (CMS), while 50% were morning types and the rest intermediate types. These findings are thus counter to the chronotype changes typically found in general populations of adolescents (Carskadon, 2011; and Carskadon, Vieira & Acebo, 2018).

There are several possible explanations. It is possible that adolescents who choose to participate in sports with early morning training and continue to do so throughout adolescence without dropping out, are more inclined to be morning types. Adult studies investigating chronotype in athlete populations provide evidence to support this hypothesis, with more adult athletes tending to be morning types (Lastella *et al.,* 2016; and Vitale & Weydahl, 2017). An additional explanation may be that the chronotype measuring tools used in this thesis have not yet been validated specifically in adolescent athlete groups. It is possible that the questions on the scales do not accurately measure chronotype in adolescent athletes because early morning wake ups are so ingrained in their daily routines that this skews how they answers the items on these tools. To test these hypotheses, validated chronotype tools for adolescent athlete populations are needed within these populations

6.1.2 Swimmers' intervention

The main finding from the intervention study with the swimmers documented in Chapter 4 was that sleep education and training rescheduling, while feasible, did not significantly alter objective measures of sleep duration and swimming performance or subjective measures of mood in this particular intervention. However, there was evidence of improvement in the sleep behaviour of the swimmers, specifically around use of electronic devices before bedtime.

School-based sleep education interventions within adolescent populations (reviewed in Chung *et al.,* 2017) and young adult athletes (Kaier *et al.,* 2016; and Van Rywyk *et al.,* 2017) typically result in short-term weekday and weekend sleep extensions which revert to control levels at follow-up. This contrasts with the findings of Chapter 4. One explanation for the lack of change in the current intervention could be that the sleep education used did not motivate behavioural change in the swimmers. Against this, however, is the evidence of significant reductions in electronic device use before bedtime throughout the intervention. Device use in the hour before bedtime fell significantly from

91% of nights during baseline to 79% during the first half of the intervention and to 67% during the second half of the intervention. Sleep education does not seem to elicit such a change universally. Kaier *et al*, (2016) failed to see any positive behavioural change in athletes' sleep/wake behaviour following sleep education. These findings suggest that the current intervention may have been successful in motivating changes to sleep/wake behaviour.

It is thought likely that the swimmers' schedules simply did not have the flexibility to allow for substantial changes to sleep timing that would result in sleep extension, regardless of how motivated they were by the sleep education they received. Indeed, this was assumed when designing the intervention and was the reason for the addition of training rescheduling. Ideally, an early morning training session would have been rescheduled to later in the day. However, the swimmers already had afternoon swim training daily during the week and school schedules limited when training sessions could take place. Although the current intervention did not significantly change sleep duration or subjective mood measures, it is possible that significant changes might be found in a larger sample, if the effect sizes were small.

6.1.3 Rower's intervention

The intervention for rowers included blue light blocking glasses to supplement their sleep education. As with the swimmers, the intervention with the rowers resulted in no measurable change to sleep duration, perceived sleep quality or stress. Across the intervention period, however, the rowers showed a reduction in subjective measures of fatigue and muscle soreness in the morning.

Compliance using the actiwatches, sleep diaries and blue light blocking glasses during the intervention was sporadic. A sizeable number of participants (27%) had over 40% of data missing and had to be excluded from final analyses. Compliance using the blue light blocking glasses averaged only 61% in the final sample. These results call into question the feasibility of such long interventions in populations of adolescent elite athletes. In contrast to the findings in Chapter 4, previous studies have shown that blue light blocking interventions in male adolescents and adult athletes can improve subjective measures of sleep quality and mood while also decreasing sleep onset latency (Bender *et al.,* 2017; Knufinke *et al.,* 2019; and Knufinke *et al.,* 2020). This difference may be attributable, at least in part, to the inconsistent use of the blue light-blocking glasses by the rowers. However, the significant reductions in fatigue and muscle soreness were similar on nights when rowers did or did not use the blue light-blocking glasses prior to bedtime. Another potential explanation is that the reductions in subjective fatigue and muscle soreness may reflect an unreported reduction in training load, which could not be controlled.

6.2 Limitations

The limitations of the baseline data collection, as well as the intervention studies, have been addressed in Chapters 3, 4 & 5. Limitations that apply to the research as a whole, and comparisons of the interventions, are considered here.

The pilot interventions described in this thesis took place in the real world, which is both a strength and a limitation. The main strength is that the feasibility of the interventions was examined outside strictly controlled conditions. The limitations arise from uncontrolled factors that may have confounded the study findings.

One potential confounding factor was the training load. Ideally, training intensity and duration would have been kept consistent throughout the monitoring periods for both the rowers and swimmers. While the coaches were asked to try and do this as best as they could, the reality is that all the athletes and coaches were working towards competitions during their competitive seasons. To find 2 months in elite adolescent athletes' schedules free from competition, school holidays and major academic examinations is a logistical improbability and compromises had to be made. Ideally, if training load could not be controlled, it should have been measured. However, this would have placed additional data recording demands on coaches and/or athletes and it was decided that this would be a disincentive for deciding to participate, or for completing the required data collection tasks. Athletes' perceptions of training load also have limitations in accuracy and reliability. Another potential confound was that several of the athletes participated in other sporting and extracurricular activities. However, if this had been an exclusion criterion, the sample of possible participants would have been too small.

The small sample sizes in the interventions are another limitation. This was in part because elite adolescent athletes from a single sporting code are a limited population. It was potentially possible to recruit from several clubs or teams, however, this would also add variability to the sample, associated with different geographical locations, schooling requirements, training loads, and training schedules. Two teams were recruited for the rowers' intervention and some of these issues were present.

Building rapport with the rowers was harder than with the swimmers from a researcher's perspective. Typically, all the swimmers and their coach were present at each visit by the researcher, which continually built the relationship with the participants. In contrast, the rowers had a variety of schedules and were seldom present at researcher visits. The rowers also had multiple coaches who were part-time compared to the swimmers' one full-time coach. These differences affected how the logistics of the interventions played out.

Another difference was that the majority of the squad of swimmers took part in the intervention, whereas only 22 out of 73 rowers volunteered to participate. The swimmers and their coach, by virtue of their training being the same for everyone, were effectively participating as a group as well as individuals. It is possible that the swimmers as a group kept each other accountable and motivated in the study, leading to better retention and compliance rates than among the rowers, who did not have the same group commitment to the intervention.

Another factor that could have caused differences in the rapport between participants and the researcher was that performance testing only occurred with the swimmers. This meant the researcher made more frequent contact with the swimmers and spent more time in their early morning training. The absence of performance testing for the rowers is also a limitation since no inferences could be made about how the intervention may have affected their performance. However, performance testing of the rowers was not feasible because it was not possible to conduct repeated tests with all of the participants from both teams on the same day of the week at the same time.

6.3 Implications of findings

6.3.1 A message for sporting organisations and coaches

The findings of this thesis highlight the challenge that early morning training poses for the sleep of adolescent athletes. The adverse consequences of inadequate and disrupted sleep patterns during adolescence are well documented and confirm that significant attention should be paid to optimising the scheduling of training for adolescent athletes. The high prevalence of early morning training sessions is the result of tradition and overloaded adolescent schedules. Creative and careful solutions need to be found to reduce the need for early morning training sessions.

Recovery is a major component of athletic training and performance. Coaches must take an active role in teaching and implementing scientifically backed recovery strategies that include ensuring adequate sleep according to accepted recommendations. Coaches should also be monitoring their athletes' recovery and sleep just as they would injury risk from overtraining. Inadequate sleep increases the likelihood of injury and illness in adolescent athletes, making it a vital measure to routinely monitor.

Sporting organisations should also carefully consider scheduling major events to minimise negative effects on adolescent athlete sleep. Sleep and recovery should be championed as an essential component in coach development programs as well as athlete wellbeing programs such as the Sport New Zealand 'Balance is Better' campaign.

6.3.2 A message for parents

Parents need to understand the impact that puberty has on sleep regulation. The changes that the homeostatic sleep process and circadian timing system undergo across puberty result in a preference for later bed and wake times. Understanding this physiological transition is the first step in engaging with this aspect of their children's lives, rather than thinking that teenagers are being lazy or oppositional in their sleep timing.

As shown in this thesis, social and training commitments can be at odds with adolescents' physiologically preferred sleep times and result in a sleep restriction. Regular and persistent inadequate sleep can have consequences on mood, health academic and sporting performance. Informed parents can provide an informed voice advocating for their youngsters' sleep, for example on school boards or sport club committees.

6.3.3 A message for health practitioners

Whether dealing with the mental or physical wellbeing of an adolescent athlete, a crucial factor that needs to be taken into consideration is their sleep/wake behaviour and its relationship to training schedules. Monitoring tools that only show average sleep over a week do not provide a nuanced enough picture of the fluctuations that adolescent athlete sleep may undergo with changing training schedules.

6.4 Recommendations for future research

A clear message from this thesis is that a lot more work needs to be done to optimise the training schedules of adolescent athletes in relation to their sleep opportunities. The findings of Chapter 3 add to a limited body of previous research examining how sleep duration and timing can vary over a week interspersed with early morning training in adolescent athlete groups. Additional work is needed to identify the influence of age (across pubertal stages) and sex on the impact of training schedules on the sleep of adolescent athletes. The sample sizes in the studies in this thesis were not large enough to address these issues.

Working with multiple sporting codes, clubs and teams also illuminated the fact that intervention in adolescent athlete populations cannot be a one-size-fits-all approach. Any intervention aiming to improve sleep/wake behaviour in adolescent athlete cohorts needs extensive co-design with, and commitment from, the athletes and their support networks, including coaches and parents.

The interventions piloted in this thesis provided mixed results. The swimmers' intervention showed strong signs of being sustainable and feasible with high retention and compliance, as well as evidence of positive sleep/wake behavioural change in decreased bedtime device use. Indeed, the swimmers' coach reported in informal catchup with the researcher a year after the study that many of the swimmers had started programming their smartphones to automatically switch to "do not disturb" mode when connected to their home WIFI networks. This strategy could be a novel way to try and reduce nighttime device interaction in adolescents in general, not just athletes, and should be investigated further.

The rowers' study by contrast had lower retention and compliance rates. Some of the potential reasons for this have been described above, and there are lessons to be learned for future interventions. Understanding the dynamics of a sporting group is critical when designing an intervention. Stakeholder engagement is vital for both design and implementation of interventions because of the unique aspects of each sporting club or team.

Future studies examining the efficacy of sleep education coupled with blue light-blocking glasses should be undertaken to answer some of the questions arising from this thesis. One issue that needs to be addressed is whether consistent use of blue light-blocking glasses on consecutive nights is more effective for altering sleep/wake behaviour than sporadic use. Another finding that deserves further investigation is why, given the same sleep education material, the swimmers decreased their device use while the rowers did not. It is possible that giving the rowers the blue light-blocking glasses from the outset may have given them a false sense of protection from the effects of device use before bed, and potentially even promoted device use. If this is indeed the case, then the preferred approach with adolescent athletes may be to start with sleep education and only introduce blue light-blocking glasses if sleep education alone does not result in behavioural change.

The findings of this thesis also raise the question of the necessity for early morning training. With evidence now showing an increased risk of illness, injury, and burnout in athletes with poor sleep patterns, the cost-benefit of early morning training should be thoroughly analysed. Research into the performance benefits as well as health detriments of early morning training should be compared to training schedules that avoid early morning training. Optimal training schedules should be designed to maximise performance improvements while limiting the impact on sleep/wake patterns.

6.5 Conclusion

The findings of this thesis add to the understanding of the bidirectional interplay between athletic training and sleep patterns. The novel aspect of this thesis is that it highlights just how critical it is to present the night-to-night variability of sleeping patterns in adolescent athletes rather than reporting average weekly sleep, which is commonplace in previous literature. Restricted sleep is a consequence of early morning training. The next critical question is how we fix or improve the situation.

Chapters 4 & 5 trialled unique and tailored sleep interventions and both highlight the complexity of intervening in the overloaded schedules of adolescent athletes. Both the swimming team and rowing teams were receptive to piloting interventions around athlete sleep as they acknowledge the problems that early morning training creates. The swimmers in particular were highly motivated to make changes, as evidenced by their coach being willing to alter training sessions and by the swimmers' significant decrease in electronic device use before bedtime. Despite this, changes in objective sleep measurements were not found during the intervention for either the swimmers or rowers. It should be kept in mind however that the small sample sizes in these pilot studies would have limited their ability to identify changes with small effect sizes.

To reduce morning training and keep the training load consistent, a massive rescheduling commitment would need to be undertaken by all stakeholders in the adolescents' lives. This would include the schooling system, the coaches and sporting regulatory bodies, parents and guardians, friends, family, and most of all the athletes themselves.

REFERENCE LIST

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. Sports medicine, 38(3), 239-252.

Abeln, V., Kleinert, J., Strüder, H. K., & Schneider, S. (2014). Brainwave entrainment for better sleep and post-sleep state of young elite soccer players–A pilot study. European journal of sport science, 14(5), 393-402.

Akerstedt, T., Ingre, M., Broman, J. E., & Kecklund, G. (2008). Disturbed sleep in shift workers, day workers, and insomniacs. Chronobiology International; 25: 333–348.

Allen, S. V., & Hopkins, W. G. (2015). Age of peak competitive performance of elite athletes: a systematic review. Sports Medicine, 45(10), 1431-1441.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. Sleep; 26 (3): 342–92.

Arora, T., Albahri, A., Omar, O. M., Sharara, A., & Taheri, S. (2018). The Prospective Association Between Electronic Device Use Before Bedtime and Academic Attainment in Adolescents. Journal of Adolescent Health, 63(4), 451–458. https://doi.org/10.1016/j.jadohealth.2018.04.007

Astiz, M., Heyde, I., & Oster, H. (2019). Mechanisms of communication in the Mammalian Circadian timing system. International Journal of Molecular Sciences, 20(2). https://doi.org/10.3390/ijms20020343

Atkins, R., Lam, W. K., Scanlan, A. T., Beaven, C. M., & Driller, M. (2020). Lower-body compression garments worn following exercise improves perceived recovery but not subsequent performance in basketball athletes. Journal of Sports Sciences, 38(9), 961-969.

Balkin, T. J., Rupp, T., Picchioni, D., & Wesensten, N. J. (2008). Sleep loss and sleepiness: current issues. Chest; 134: 653-660.

Balilionis, G., Nepocatych, S., Ellis, C. M., Richardson, M. T., Neggers, Y. H., & Bishop, P. A. (2012). Effects of different types of warm-up on swimming performance, reaction time, and dive distance. The Journal of Strength & Conditioning Research, 26(12), 3297-3303.

Bartel, K. A., Gradisar, M., & Williamson, P. (2015). Protective and risk factors for adolescent sleep: a meta-analytic review. Sleep medicine reviews, 21, 72-85.

Beijamini, F., & Louzada, F. M. (2012). Are educational interventions able to prevent excessive daytime sleepiness in adolescents?. Biological Rhythm Research, 43(6), 603-613.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., & Redmond, D. P. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. Journal of Sleep Research; 1–12.

Bender, A. M., Lawson, D., Werthner, P., & Samuels, C. H. (2018). The clinical validation of the athlete sleep screening questionnaire: an instrument to identify athletes that need further sleep assessment. Sports medicine-open, 4(1), 1-8.

Bender, A. M., Van Dongen, H. P., & Samuels, C. H. (2018). Sleep quality and chronotype differences between elite athletes and non-athlete controls. Clocks & Sleep, 1(1), 3-12.

Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., ... & Engebretsen, L. (2015). International Olympic Committee consensus statement on youth athletic development. British journal of sports medicine, 49(13), 843-851.

Besedovsky, L., Lange, T., & Born, J. (2012). Sleep and immune function. Pflügers Archiv-European Journal of Physiology, 463(1), 121-137.

Bixler, E. O., Vgontzas, A. N., Liao, D., Chrousos, G. P., & Vela-Bueno, A. (2009). Insomnia with objective short sleep duration is associated with a high risk for hypertension. Sleep; 32(4): 491.

Blanchfield, A. W., Lewis-Jones, T. M., Wignall, J. R., Roberts, J. B., & Oliver, S. J. (2018). The influence of an afternoon nap on the endurance performance of trained runners. European journal of sport science, 18(9), 1177-1184.

Blood, M. L., Sack, R. L., Percy, D. C., & Pen, J. C. (1997). A comparison of sleep detection by wrist actigraphy, behavioral response, and polysomnography. Sleep, 20(6), 388-395.

Bonato, M., Merati, G., La Torre, A., Saresella, M., Marvetano, I., Banfi, G., & Vitale, J. A. (2020). Effect of acute sleep hygiene on salivary cortisol level following a late night soccer-specific training session. Journal of sports science & medicine, 19(1), 235.

Bonnar, D., Bartel, K., Kakoschke, N., & Lang, C. (2018). Sleep interventions designed to improve athletic performance and recovery: a systematic review of current approaches. Sports medicine, 48(3), 683-703.

Bootzin, R. R., & Nicassio, P. M. (1978). Behavioral treatments for insomnia. In: Hersen, M., Eissler, R., & Miller, P., eds. Progress in behavior modification. Vol 6. New York: Academic Press: 1-45.

Bootzin, R. R., & Engle-Friedman, M. (1981). The assessment of insomnia. Behavioral Assessment; 3: 107-26.

Borbély, A. A. (1982). A two process model of sleep regulation. Human neurobiology; 1(3): 195-204.

Borbély, A. A., & Achermann, P. (1999). Sleep homeostasis and models of sleep regulation. Journal of Biological Rhythms; 14(6): 557–68.

Borg, G. (1990). Psychophysical scaling with applications in physical work and the perception of exertion. Scandinavian journal of work, environment & health, 55-58. http://www.jstor.org/stable/40965845.

Borg, G. (1998). Borg's perceived exertion and pain scales. Human kinetics.

Brand, S., Gerber, M., Beck, J., Hatzinger, M., Pühse, U. W. E., & Holsboer-Trachsler, E. (2010). Exercising, sleep-EEG patterns, and psychological functioning are related among adolescents. The World Journal of Biological Psychiatry, 11(2), 129-140.

Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., & Rollag, M. D. (2001). Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. Journal of Neuroscience, 21(16), 6405-6412.

Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Lichstein, K. L., & Morin, C. M. (2006). Recommendations for a standard research assessment of insomnia. Sleep; 29:1155-73.

Cain, S. W., Dennison, C. F., Zeiter, J. M., Guzik, A. M., & Khalsa, S. S. (2010). Sex differences in phase angle of entrainment and melatonin amplitude in humans. Journal of Biological Rhythms; 25(4): 288–296.

Cain, N., & Gradisar, M. (2010). Electronic media use and sleep in school-aged children and adolescents: A review. Sleep medicine, 11(8), 735-742.

Cappuccio, F. P., Taggart, F. M., Kandala, N., Currie, A., Peile, E., & Miller, M. A. (2007). Meta-Analysis of Short Sleep Duration and Obesity in Children and Adults. Sleep; 31(5): 619-626.

Carney, C. E., Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Krystal, A. D., Lichstein, K. L., & Morin, C. M. (2012). The consensus sleep diary: standardizing prospective sleep self-monitoring. Sleep; 35(2): 287–302.

Carskadon, M. A. (2008). Maturation of processes regulating sleep in adolescents. In Sleep in children (pp. 125-144). CRC Press.

Carskadon, M. A. (2011). Sleep in adolescents: the perfect storm. Pediatric Clinics, 58(3), 637-647.

Carskadon, M. A., Acebo, C., & Arnedt, J. T. (2002, April). Failure to identify pubertally-mediated melatonin sensitivity to light in adolescents. In Sleep (Vol. 25, pp. A191-A191). 6301 BANDEL RD, STE 101, ROCHESTER, MN 55901 USA: AMER ACAD SLEEP MEDICINE.

Carskadon, M. A., Acebo, C., & Jenni, O. G. (2004). Regulation of adolescent sleep: implications for behavior. Annals of the New York Academy of Sciences, 1021(1), 276-291.

Carskadon, M. A., Acebo, C., Richardson, G. S., Tate, B. A., & Seifer, R. (1997). An approach to studying circadian rhythms of adolescent humans. Journal of biological rhythms, 12(3), 278-289.

Carskadon, M. A., & Dement, W. C. (1987). Daytime sleepiness: quantification of a behavioral state. Neuroscience & Biobehavioral Reviews, 11(3), 307-317.

Carskadon, M. A., & Dement, W. C. (2017). Normal human sleep: An overview. In M. Kryger, T. Roth & W. C. Dement (Eds.), Principles and practice of sleep medicine (6th ed., pp. 15–24). Elsevier.

Carskadon, M. A., Harvey, K., & Dement, W. C. (1981). Acute Restriction of Nocturnal Sleep in Children. Perceptual and Motor Skills, 53(1), 103–112. https://doi.org/10.2466/pms.1981.53.1.103

Carskadon, M. A., Vieira, C., & Acebo, C. (1993). Association between puberty and delayed phase preference. Sleep, 16(3), 258-262.

Carskadon, M. A., Wolfson, A. R., Acebo, C., Tzischinsky, O., & Seifer, R. (1998). Adolescent sleep patterns, circadian timing, and sleepiness at a transition to early school days. Sleep, 21(8), 871-881.

Catrett, C. D., & Gaultney, J. F. (2009). Possible insomnia predicts some risky behaviors among adolescents when controlling for depressive symptoms. The Journal of genetic psychology, 170(4), 287-309.

Chang, A. M., Aeschbach, D., Duffy, J. F., & Czeisler, C. A. (2015). Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. Proceedings of the National Academy of Sciences, 112(4), 1232-1237.

Chatard, J. C., & Stewart, A. M. (2011). Training load and performance in swimming. World Book of Swimming: From Science to Performance, January, 359–373.

Chen, M. Y., Wang, E. K., & Jeng, Y. J. (2006). Adequate sleep among adolescents is positively associated with health status and health-related behaviors. BMC public health, 6(1), 1-8.

Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: a reciprocal issue?. Sleep medicine reviews, 20, 59-72.

Choi, Y., Sadamune, R., Nakamura, Y., Suita, M., Miyakawa, S., & Maeda, S. (2018). The effect of sleep on motor skill learning in young badminton players aged 6–9 years. Sleep and Biological Rhythms, 16(1), 141-147.

Chung, K. F., Chan, M. S., Lam, Y. Y., Lai, C. S. Y., & Yeung, W. F. (2017). School-Based Sleep Education Programs for Short Sleep Duration in Adolescents: A Systematic Review and Meta-Analysis. Journal of school health, 87(6), 401-408.

Cohen, R. A., & Albers, H. E. (1991). Disruption of human circadian and cognitive regulation following a discrete hypothalamic lesion: a case study. Neurology; 41: 726–729.

Cole, R. J., Kripke, D. F., Gruen, W., Mullaney, D. J., & Gillin, J. C. (1992). Automatic sleep/wake identification from wrist activity. Sleep, 15(5), 461–469. https://doi.org/10.1093/sleep/15.5.461

Crowley, S. J. (2009). Weekend recovery sleep in adolescents: Can it occur without a circadian phase delay?. Brown University.

Crowley, S. J., Acebo, C., & Carskadon, M. A. (2007). Sleep, circadian rhythms, and delayed phase in adolescence. Sleep Medicine; 8(6): 602–12.

Crowley, S. J., Acebo, C., Fallone, G., & Carskadon, M. A. (2006). Estimating dim light melatonin onset (DLMO) phase in adolescents using summer or school-year sleep/wake schedules. Sleep, 29(12), 1632-1641.

Crowley, S. J., Cain, S. W., Burns, A. C., Acebo, C., & Carskadon, M. A. (2015). Increased sensitivity of the circadian system to light in early/mid-puberty. The Journal of Clinical Endocrinology & Metabolism, 100(11), 4067-4073.

Crowley, S. J., & Eastman, C. I. (2018). 0248 Sleep and the Forbidden Zone: Trouble for Teens. Sleep, 41, A96.

Crowley, S. J., Tarokh, L., & Carskadon, M. A. (2014). Sleep during adolescence. Principles and practice of pediatric sleep medicine, 45-51.

Crowley, S. J., Wolfson, A. R., Tarokh, L., & Carskadon, M. A. (2018). An update on adolescent sleep: New evidence informing the perfect storm model. Journal of adolescence, 67, 55-65.

Cumming, G. (2014). The new statistics: Why and how. Psychological Science; 25(1): 7–29.

Czeisler, C. A. & Wright, K. P. (1999). Influence of light on circadian rhythmicity in humans. In: Regulation of Sleep and Circadian Rhythms, edited by Turek, F. W. & Zee, P. C. New York: Marcel Dekker; p. 149–180.

Daan, S. (2000). The Colin S Pittendrigh Lecture, Colin Pittendrigh, Jürgen Aschoff, and the Natural Entrainment of Circadian Systems. Journal of Biological Rhythms; 15(3): 195–207.

Daan, S., Beersma, D. G., & Borbély, A. A. (1984). Timing of human sleep: recovery process gated by a circadian pacemaker. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology; 246(2): R161-R183.

Darchia, N. & Cervena, K. (2014). The journey through the world of adolescent sleep. Reviews in the Neurosciences, 25(4), 585-604. https://doi.org/10.1515/revneuro-2013-0065

Davies, D. J., Graham, K. S., & Chow, C. M. (2010). The effect of prior endurance training on nap sleep patterns. International Journal of Sports Physiology and Performance, 5(1), 87-97.

Díaz-Morales, J. F., & Escribano, C. (2015). Social jetlag, academic achievement and cognitive performance: Understanding gender/sex differences. Chronobiology international, 32(6), 822-831.

Dijk, D. J., & Czeisler, C. A. (1995). Contribution of the circadian pacemaker and the sleep homeostat to sleep propensity, sleep structure, electroencephalographic slow waves, and sleep spindle activity in humans. Journal of Neuroscience, 15(5), 3526-3538.

Dijk, D. J., & Lockley, S. W. (2002). Integration of human sleep-wake regulation and circadian rhythmicity. Journal of Applied Physiology; 92(2): 852–862.

Dorofaeff, T. F., & Denny, S. (2006). Sleep and adolescence. Do New Zealand teenagers get enough?. Journal of paediatrics and child health, 42(9), 515-520.

Douzi, W., Dupuy, O., Theurot, D., Boucard, G., & Dugué, B. (2019). Partial-body cryostimulation after training improves sleep quality in professional soccer players. BMC Research Notes, 12(1), 1-5.

Driller, M. W., Lastella, M., & Sharp, A. P. (2019). Individualized sleep education improves subjective and objective sleep indices in elite cricket athletes: A pilot study. Journal of sports sciences, 37(17), 2021-2025.

Duffy, J. F., Cain, S. W., Chang, A., Phillips, A. J. K., Munch, M. Y., Gronfier, C., et al. (2011). Sex difference in the near-24-hour intrinsic period of the human circadian timing system. Proceedings of the National Academy of Sciences; 108(Suppl 3): 15602–15608.

Durmer, J. S., & Dinges, D. F. (2005). Neurocognitive consequences of sleep deprivation. In Seminars in neurology; 25(1):117-129.

Eisenstein, M. (2013). Chronobiology: stepping out of time. Nature, 497(7450), S10-S12.

Emmanuel M, Bokor BR. Tanner Stages. 2021 Dec 15. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan–. PMID: 29262142.

Erlacher, D., Ehrlenspiel, F., Adegbesan, O. A., & El-din, H. G. (2011). Sleep habits in German athletes before important competitions or games. Journal of Sports Sciences; 29(8): 37–41.

Erlacher, D., & Ehrlenspiel, F. (2017). Sleep, dreams, and athletic performance. Sport, Recovery, and Performance, 168-182.

Estivill-Domènech, C., Galilea, B., Rodríguez-Morilla, B., de Yzaguirre, I., Estivill, E., López, E., ... & Segarra, F. (2018). Do elite athletes sleep well?. Apunts. Medicina de l'Esport, 53(198), 47-54.

Field, A., Miles, J., & Field, Z. (2012). Discovering statistics using R. Sage publications.

Ferrara, M., & De Gennaro, L. (2001). How much sleep do we need? Sleep Medicine Reviews; 5(2): 155–179.

Fullagar, H. H., Duffield, R., Skorski, S., Coutts, A. J., Julian, R., & Meyer, T. (2015). Sleep and recovery in team sport: current sleep-related issues facing professional team-sport athletes. International journal of sports physiology and performance, 10(8), 950-957.

Fox, J. L., Scanlan, A. T., Stanton, R., & Sargent, C. (2020). Insufficient sleep in young athletes? Causes, consequences, and potential treatments. Sports Medicine, 50(3), 461-470.

Galland, B. C., Gray, A. R., Penno, J., Smith, C., Lobb, C., & Taylor, R. W. (2017). Gender differences in sleep hygiene practices and sleep quality in New Zealand adolescents aged 15 to 17 years. Sleep Health, 3(2), 77-83.

Gangwisch, J. E. (2009). Epidemiological evidence for the links between sleep, circadian rhythms and metabolism. Obesity Reviews; 10: 37–45.

Garaulet, M., Ortega, F. B., Ruiz, J. R., Rey-López, J. P., Béghin, L., Manios, Y., ... & Moreno, L. A. (2011). Short sleep duration is associated with increased obesity markers in European adolescents: effect of physical activity and dietary habits. The HELENA study. International journal of obesity, 35(10), 1308-1317.

Gerber, M., Best, S., Meerstetter, F., Isoard-Gautheur, S., Gustafsson, H., Bianchi, R., ... & Brand, S. (2018). Cross-sectional and longitudinal associations between athlete burnout, insomnia, and polysomnographic indices in young elite athletes. Journal of Sport and Exercise Psychology, 40(6), 312-324.

Giannotti, F., Cortesi, F., Sebastiani, T., & Ottaviano, S. (2002). Circadian preference, sleep and daytime behaviour in adolescence. Journal of sleep research, 11(3), 191-199.

Girschik, J. C., Fritschi, L., Heyworth, J., & Waters, F. A. (2012). Validation of self-reported sleep against actigraphy. Journal of Epidemiology; 22: 462–468.

Godber, K. (2012). The Life-worlds of Elite Young Athletes : A Lens on their School / Sport Balancing Act. 17, 1–13.

Gradisar, M., Gardner, G., & Dohnt, H. (2011). Recent worldwide sleep patterns and problems during adolescence: a review and meta-analysis of age, region, and sleep. Sleep medicine, 12(2), 110-118.

Gradisar, M., Wolfson, A. R., Harvey, A. G., Hale, L., Rosenberg, R., & Czeisler, C. A. (2013). The sleep and technology use of Americans: findings from the National Sleep Foundation's 2011 Sleep in America poll. Journal of Clinical Sleep Medicine, 9(12), 1291-1299.

Grainger, A., Comfort, P., & Heffernan, S. (2020). No effect of partial-body cryotherapy on restoration of countermovement jump or well-being performance in elite rugby union players during the competitive phase of the season. International Journal of Sports Physiology and Performance, 15(1), 98-104.

Greene, R. W., Bjorness, T. E., & Suzuki, A. (2017). The adenosine-mediated, neuronal-glial, homeostatic sleep response. Current opinion in neurobiology, 44, 236-242.

Gudmundsdottir, S. L. (2019). Training Schedule and Sleep in Adolescent Swimmers. Pediatric Exercise Science, 1–7. https://doi.org/10.1123/pes.2019-0067

Gupta, L., Morgan, K., & Gilchrist, S. (2017). Does elite sport degrade sleep quality? A systematic review. Sports Medicine, 47(7), 1317-1333.

Gwyther, K., Rice, S., Purcell, R., Pilkington, V., Santesteban-Echarri, O., Bailey, A., & Walton, C. C. (2022). Sleep interventions for performance, mood and sleep outcomes in athletes: A systematic review and meta-analysis. Psychology of Sport and Exercise, 58, 102094.

Hagenauer, M. H., Perryman, J. I., Lee, T. M., & Carskadon, M. A. (2009). Adolescent changes in the homeostatic and circadian regulation of sleep. Developmental neuroscience, 31(4), 276-284.

Hall, M. H., Muldoon, M. F., & Manuck, S. B. (2008). Self-reported sleep duration is associated with the metabolic syndrome in midlife adults. Sleep; 31(5): 635-643.

Halson, S. L. (2014). Sleep in elite athletes and nutritional interventions to enhance sleep. Sports Medicine; 44(1): S13-S23.

Hamblin, D. L., & Wood, A. W. (2002). Effects of mobile phone emissions on human brain activity and sleep variables. International journal of radiation biology, 78(8), 659-669.

Hankins, M. W., & Lucas, R. J. (2002). The primary visual pathway in humans is regulated according to long-term light exposure through the action of a nonclassical photopigment. Current Biology, 12(3), 191-198.

Hankins, M. W., Peirson, S. N., & Foster, R. G. (2008). Melanopsin: an exciting photopigment. Trends in neurosciences, 31(1), 27-36.

Harada, T., Wada, K., Tsuji, F., Krejci, M., Kawada, T., Noji, T., ... & Takeuchi, H. (2016). Intervention study using a leaflet entitled ‘three benefits of “go to bed early! get up early! and intake nutritionally rich breakfast!” a message for athletes’ to improve the soccer performance of university soccer team. Sleep and Biological Rhythms, 14(1), 65-74.

Hausswirth, C., Louis, J., Aubry, A., Bonnet, G., Duffield, R. O. B., & Le Meur, Y. (2014). Evidence of disturbed sleep and increased illness in overreached endurance athletes. Medicine and science in sports and exercise.

Hayes, L. D., Bickerstaff, G. F., & Baker, J. S. (2010). Review article interactions of cortisol, testosterone, and resistance training: influence of circadian rhythms. Chronobiology International; 27(4): 675–705.

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O’Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., Ware, J. C., & Adams Hillard, P. J. (2015). National sleep foundation’s sleep time duration recommendations: Methodology and results summary. Sleep Health, 1(1), 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Hooper, S. L., Mackinnon, L. T., Howard, A. L. F., Gordon, R. D., & Bachmann, A. W. (1995). Markers for monitoring overtraining and recovery. Medicine & Science in Sports & Exercise, 27(1), 106-112. http://www.ncbi.nlm.nih.gov/pubmed/7898325

Hosea, T. M., & Hannafin, J. A. (2012). Rowing injuries. Sports health, 4(3), 236-245.

Hublin, C., Kaprio, J., Partinen, M., & Koskenvuo, M. (2007). Sleep and mortality: a population based 22 year follow up study. Sleep; 30(10): 1245-1253

Illingworth, G. (2020). The challenges of adolescent sleep. Interface focus, 10(3), 20190080.

Jean-Louis, G., Williams, N. J., Sarpong, D., Pandey, A., Youngstedt, S., Zizi, F., Ogedegbe, G. (2014). Associations between inadequate sleep and obesity in the US adult population: analysis of the national health interview survey (1977-2009). BMC Public Health; 14: 290.

Jean-Louis, G., von Gizycki, H., Zizi, F., Fookson, J., Spielman, A., Nunes, J., ... & Taub, H. (1996). Determination of sleep and wakefulness with the actigraph data analysis software (ADAS). Sleep, 19(9), 739-743.

Jenni, O. G., Van Reen, E., & Carskadon, M. A. (2005). Regional differences of the sleep electroencephalogram in adolescents. Journal of sleep research, 14(2), 141-147.

Juliff, L. E., Halson, S. L., & Peiffer, J. J. (2015). Understanding sleep disturbance in athletes prior to important competitions. Journal of Science and Medicine in Sport; 18(1): 13–18.

Kahn-Greene, E. T., Killgore, D. B., Kamimori, G. H., Balkin, T. J., & Killgore, W. D. (2007). The effects of sleep deprivation on symptoms of psychopathology in healthy adults. Sleep medicine, 8(3), 215-221.

Kaier, E., Zanotti, D., Davis, J. L., Strunk, K., & Cromer, L. D. (2016). Addressing the problem of student-athlete sleepiness: feasibility of implementing an interactive sleep workshop at a Division I school. Journal of Clinical Sport Psychology, 10(3), 237-247.

Karacan, I., & Moore, C. A. (1979). Genetics and human sleep. Psychiatric Annals, 9(7), 11-23.

Kecklund, G., & Akerstedt, T. (1995). Effects of timing of shifts on sleepiness and sleep duration. Journal of Sleep Research; 4: 47–50.

Kelley, P., Lockley, S. W., Foster, R. G., & Kelley, J. (2015). Synchronizing education to adolescent biology:‘let teens sleep, start school later’. Learning, Media and Technology, 40(2), 210-226.

Kiernan, K. (2018). Insights into using the GLIMMIX procedure to model categorical outcomes with random effects. Cary: SAS Institute Inc. paper SAS2179.

Killgore, W. D. S. (2010). Effects of sleep deprivation on cognition. Progress in Brain Research; 185 (617): 105–29.

Kira, G., Maddison, R., Hull, M., Blunden, S., & Olds, T. (2014). Sleep education improves the sleep duration of adolescents: a randomized controlled pilot study. Journal of Clinical Sleep Medicine, 10(7), 787-792.

Kirschen, G. W., Jones, J. J., & Hale, L. (2020). The impact of sleep duration on performance among competitive athletes: a systematic literature review. Clinical journal of sport medicine, 30(5), 503-512.

Kline, C. E., Durstine, J. L., Davis, J. M., Moore, T. A., Devlin, T. M., Zielinski, M. R., & Youngstedt, S. D. (2007). Circadian variation in swim performance. Journal of Applied Physiology, 102(2), 641–649. https://doi.org/10.1152/japplphysiol.00910.2006

Knufinke, M., Nieuwenhuys, A., Geurts, S. A., Møst, E. I., Moen, M. H., Maase, K., ... & Kompier, M. A. (2021). Dim light, sleep tight, and wake up bright–Sleep optimization in athletes by means of light regulation. European Journal of Sport Science, 21(1), 7-15.

Knufinke, M., Nieuwenhuys, A., Maase, K., Moen, M. H., Geurts, S. A., Coenen, A. M., & Kompier, M. A. (2018). Effects of natural between-days variation in sleep on elite athletes' psychomotor vigilance and sport-specific measures of performance. Journal of Sports Science & Medicine, 17(4), 515.

Kopasz, M., Loessl, B., Valerius, G., Koenig, E., Matthaeas, N., Hornyak, M., Kloepfer, C., Nissen, C., Riemann, D., & Voderholzer, U. (2010). No persisting effect of partial sleep curtailment on cognitive performance and declarative memory recall in adolescents. Journal of Sleep Research, 19(1 PART. 1), 71–79. https://doi.org/10.1111/j.1365-2869.2009.00742.x

Kölling, S., Steinacker, J. M., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016). The longer the better: sleep–wake patterns during preparation of the world rowing junior championships. Chronobiology international, 33(1), 73-84.

Krause, A. J., Simon, E. B., Mander, B. A., Greer, S. M., Saletin, J. M., Goldstein-Piekarski, A. N., & Walker, M. P. (2017). The sleep-deprived human brain. Nature Reviews Neuroscience, 18(7), 404-418.

Kripke, D. F., Garfinkel, L., Wingard, D. L., Klauber, M. R., & Marler, M. R. (2002). Mortality associated with sleep duration and insomnia. Archives Of General Psychology; 59(2):131-136

Kronholm, E., Partonen, T., Laatikainen, T., Peltonen, M., Härmä, M., Hublin, C., Kaprio, J., Aro, A. R., Partinen, M., Fogelholm, M., Valve, R., Vahtera, J., Oksanen, T., Kivimäki, M., Koskenvuo, M. & Sutela, H. (2008). Trends in self-reported sleep duration and insomnia-related symptoms in Finland from 1972 to 2005: a comparative review and re-analysis of Finnish population samples. Journal of Sleep Research; 17: 54–62.

Krueger, M., Costello, J. T., Stenzel, M., Mester, J., & Wahl, P. (2020). The physiological effects of daily cold-water immersion on 5-day tournament performance in international standard youth field-hockey players. European journal of applied physiology, 120(1), 295-305.

Kundermann, B., Krieg, J. C., Schreiber, W., & Lautenbacher, S. (2004). The effects of sleep deprivation on pain. Pain Research and Management, 9(1), 25-32.

Lastella, M., Lovell, G. P., & Sargent, C. (2014). Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. European Journal of Sport Science; 14 (1): S123–30.

Lastella, M., Roach, G. D., Halson, S. L., & Sargent, C. (2015a). Sleep/wake behaviours of elite athletes from individual and team sports. European Journal of Sport Science; 1–7.

Lastella, M., Roach, G. D., Halson, S. L., Martin, D. T., West, N. P., & Sargent, C. (2015b). Sleep/wake behaviour of endurance cyclists before and during competition. Journal of Sports Sciences; 33(3): 293–9.

Lastella, M., Roach, G. D., Halson, S. L., & Sargent, C. (2016). The chronotype of elite athletes. Journal of human kinetics, 54(1), 219-225.

Lavie, P. (1986). Ultrashort sleep-waking schedule. III.'Gates' and 'forbidden zones' for sleep. Electroencephalography and clinical neurophysiology, 63(5), 414-425. https://doi.org/10.1016/0013-4694(86)90123-9

Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J., & Pedlar, C. (2012). Sleep duration and quality in elite athletes measured using wristwatch actigraphy. Journal of Sport Sciences; 30(6): 541-545.

Leger, D., Beck, F., Richard, J. B., & Godeau, E. (2012). Total Sleep Time Severely Drops during Adolescence. PLoS ONE, 7(10), e45204.

Letton, A., Vissman, S., Cidral-Filho, F., & Martins, D. F. (2018). Nighttime use of farinfrared emitting ceramic shirts increases quality of sleep in young baseball players. Global Advances in Health and Medicine, 7, 208. https://doi.org/10.1177/2164956118773837

Levene, H. (1960). In Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling, I. Olkin et al. eds., Stanford University Press, pp. 278-292.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Oliver, S. (2006). SAS for mixed models. SAS publishing.

Littner, M., Kushida, C. A., Anderson, W. M., Bailey, D., Berry, R. B., Davila, D. G., ... & Johnson, S. F. (2003). Practice parameters for the role of actigraphy in the study of sleep and circadian rhythms: an update for 2002. Sleep, 26(3), 337-341.

Liu, X. (2004). Sleep and Adolescent Suicidal Behavior. Sleep; 27(7): 1351-1358.

Liu, X., & Buysse, D. J. (2006). Sleep and youth suicidal behavior: a neglected field. Current Opinion in Psychiatry, 19(3), 288-293.

Logan, R. W., & McClung, C. A. (2019). Rhythms of life: circadian disruption and brain disorders across the lifespan. Nature Reviews Neuroscience, 20(1), 49-65.

Lo, J. C., Ong, J. L., Leong, R. L., Gooley, J. J., & Chee, M. W. (2016). Cognitive performance, sleepiness, and mood in partially sleep deprived adolescents: the need for sleep study. Sleep, 39(3), 687-698.

Loturco, I., Abad, C. C. C., Nakamura, F. Y., Ramos, S. P., Kobal, R., Gil, S., ... & Tricoli, V. (2016). Effects of far infrared rays emitting clothing on recovery after an intense plyometric exercise bout applied to elite soccer players: a randomized double-blind placebo-controlled trial. Biology of sport, 33(3), 277-283.

Loughran, S. P., Wood, A. W., Barton, J. M., Croft, R. J., Thompson, B., & Stough, C. (2005). The effect of electromagnetic fields emitted by mobile phones on human sleep. Neuroreport, 16(17), 1973-1976.

Mah, C. D., Mah, K. E., & Dement, W. C. (2009, January). Athletic performance improvements and sleep extension in collegiate tennis players. In Sleep (Vol. 32, pp. A155-A155). ONE WESTBROOK CORPORATE CTR, STE 920, WESTCHESTER, IL 60154 USA: AMER ACAD SLEEP MEDICINE.

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. Sleep, 34(7), 943-950.

Malhotra, R. K., & Avidan, A. Y. (2013). Sleep stages and scoring technique. Atlas of sleep medicine, 77-99.

Malone, S. K., Zemel, B., Compher, C., Souders, M., Chittams, J., Thompson, A. L., ... & Lipman, T. H. (2016). Social jet lag, chronotype and body mass index in 14–17-year-old adolescents. Chronobiology international, 33(9), 1255-1266.

Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance?. European journal of applied physiology, 104(5), 929-931.

Maslowsky, J., & Ozer, E. J. (2014). Developmental trends in sleep duration in adolescence and young adulthood: evidence from a national United States sample. Journal of Adolescent Health, 54(6), 691-697.

Mazzardo-Martins, L., Vissman, S., Cidral-Filho, F. J., & Martins, D. (2016). Effect of far-infrared emitting ceramics apparel on young baseball players: a double-blind, placebo controlled trial. J Altern Complement Med (New York, NY), 22(6), A84.

Meier-Ewert, H. K., Ridker, P. M., Rifali, N., Regan, M. M., Price, N. J., Dinges, D. F., & Mullington, J. M. (2004). Effects of sleep loss on C Reactive protein, an inflammatory marker for cardiovascular risk. Journal of the American College of Cardiology; 43(4): 678-683.

Meltzer, L. J., Walsh, C. M., Traylor, J., & Westin, A. M. L. (2012). Direct Comparison of Two New Actigraphs and Polysomnography in Children and Adolescents. Sleep, 12–15. https://doi.org/10.5665/sleep.1608

Moseley, L., & Gradisar, M. (2009). Evaluation of a school-based intervention for adolescent sleep problems. Sleep, 32(3), 334-341.

Mullington, J. M., Haack, M., Toth, M., Serrador, J. M., & Meier-Ewert, H. K. (2009). Cardiovascular, inflammatory, and metabolic consequences of sleep deprivation. Progress in cardiovascular diseases, 51(4), 294-302.

Nunes, R. F., Cidral-Filho, F. J., Flores, L. J., Nakamura, F. Y., Rodriguez, H. F., Bobinski, F., ... & Guglielmo, L. G. (2020). Effects of far-infrared emitting ceramic materials on recovery during 2-week preseason of elite futsal players. The Journal of Strength & Conditioning Research, 34(1), 235-248.

O'Brien, E. M., & Mindell, J. A. (2005). Sleep and risk-taking behavior in adolescents. Behavioral sleep medicine, 3(3), 113-133.

O'Donnell, S., & Driller, M. W. (2017). Sleep-hygiene Education improves Sleep Indices in Elite Female Athletes. International journal of exercise science, 10(4), 522-530.

Ohayon, M. M., Carskadon, M. A., Guilleminault, C., & Vitiello, M. V. (2004). Meta-Analysis of Quantitative Sleep Parameters From Childhood to Old Age in Healthy Individuals: Developing Normative Sleep Values Across the Human Lifespan. SLEEP, 27(7), 1255-1273. https://doi.org/https://doi.org.ezproxy.massey.ac.nz/10.1093/sleep/27.7.1255

Olds, T., Blunden, S., Petkov, J., & Forchino, F. (2010). The relationships between sex, age, geography and time in bed in adolescents: a meta-analysis of data from 23 countries. Sleep medicine reviews, 14(6), 371-378.

Oliver, S. J., Costa, R. J. S., Walsh, N. P., Laing, S. J., & Bilzon, J. L. J. (2009). One night of sleep deprivation decreases treadmill endurance performance. European Journal of Applied Physiology; 107(2): 155–161.

Owens, H., Christian, B., & Polivka, B. (2017). Sleep behaviors in traditional-age college students: A state of the science review with implications for practice. Journal of the American Association of Nurse Practitioners, 29(11), 695-703.

Patel, S. R., Malhotra, A., White, D. P., Gottlieb, D.J. &, Hu FB (2006). Association between reduced sleep and weight gain in women. American Journal of Epidemiology; 164: 947–954.

Patel, S. R. & Hu, F. B. (2008). Short Sleep Duration and Weight Gain: A Systematic Review. Obesity, 16: 643–653.

Paruthi, S., Brooks, L. J., D'Ambrosio, C., Hall, W. A., Kotagal, S., Lloyd, R. M., ... & Wise, M. S. (2016). Consensus statement of the American Academy of Sleep Medicine on the recommended amount of sleep for healthy children: methodology and discussion. Journal of clinical sleep medicine, 12(11), 1549-1561.

Petit, E., Mougin, F., Bourdin, H., Tio, G., & Haffen, E. (2014). A 20-min nap in athletes changes subsequent sleep architecture but does not alter physical performances after normal sleep or 5-h phase-advance conditions. European journal of applied physiology, 114(2), 305-315.

Ramos-Campo, D. J., Ávila-Gandía, V., Luque, A. J., & Rubio-Arias, J. Á. (2019). Effects of hour of training and exercise intensity on nocturnal autonomic modulation and sleep quality of amateur ultra-endurance runners. Physiology & behavior, 198, 134-139.

Randler, C., Bilger, S., & Díaz-Morales, J. F. (2009). Associations among sleep, chronotype, parental monitoring, and pubertal development among German adolescents. The Journal of Psychology, 143(5), 509-520.

Reilly, T., & Edwards, B. (2007). Altered sleep – wake cycles and physical performance in athletes. Physiology & Behavior; 90: 274–284.

Roach, G. D., Schmidt, W. F., Aughey, R. J., Bourdon, P. C., Soria, R., Claros, J. C. J., ... & Sargent, C. (2013). The sleep of elite athletes at sea level and high altitude: a comparison of sea-level natives and high-altitude natives (ISA3600). British journal of sports medicine, 47(Suppl 1), i114-i120.

Roenneberg, T., Kuehnle, T., Juda, M., Kantermann, T., Allebrandt, K., Gordijn, M., & Merrow, M. (2007). Epidemiology of the human circadian clock. Sleep medicine reviews, 11(6), 429-438.

Roenneberg, T., Kuehnle, T., Pramstaller, P. P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. Current biology, 14(24), R1038-R1039.

Romyn, G., Lastella, M., Miller, D. J., Versey, N. G., Roach, G. D., & Sargent, C. (2018). Daytime naps can be used to supplement night-time sleep in athletes. Chronobiology International, 35(6), 865-868.

Romyn, G., Robey, E., Dimmock, J. A., Halson, S. L., & Peeling, P. (2016). Sleep, anxiety and electronic device use by athletes in the training and competition environments. European journal of sport science, 16(3), 301-308.

Samuels, C., James, L., Lawson, D., & Meeuwisse, W. (2016). The athlete sleep screening questionnaire: a new tool for assessing and managing sleep in elite athletes. British journal of sports medicine, 50(7), 418-422.

Sargent, C., Darwent, D., Ferguson, S. A., Kennaway, D. J., & Roach, G. D. (2012). Sleep restriction masks the influence of the circadian process on sleep propensity. Chronobiology international, 29(5), 565-571.

Sargent, C., Halson, S., & Roach, G. D. (2014a). Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. European Journal of Sport Science, 14(SUPPL.1), 310–315. https://doi.org/10.1080/17461391.2012.696711

Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2014b). The impact of training schedules on the sleep and fatigue of elite athletes. Chronobiology international, 31(10), 1160-1168.

Schaal, K., Le Meur, Y., Louis, J., Filliard, J. R., Hellard, P., Casazza, G., & Hausswirth, C. (2015). Whole-body cryostimulation limits overreaching in elite synchronized swimmers. Med Sci Sports Exerc, 47(7), 1416-1425.

Shechter, A., Kim, E. W., St-Onge, M. P., & Westwood, A. J. (2018). Blocking nocturnal blue light for insomnia: A randomized controlled trial. Journal of psychiatric research, 96, 196-202.

Schmidt, C., Collette, F., Cajochen, C., & Peigneux, P. (2007). A time to think: circadian rhythms in human cognition. Cognitive neuropsychology, 24(7), 755-789.

Schwartz, W. J., Busis, N. A., & Hedley-Whyte, E. T. (1986). A discrete lesion of ventral hypothalamus and optic chiasm that disturbed the daily temperature rhythm. Journal of Neurology; 233: 1–4.

Schwartz, J., & Simon Jr, R. D. (2015). Sleep extension improves serving accuracy: A study with college varsity tennis players. Physiology & behavior, 151, 541-544.

Secher, N. H., & Volianitis, S. (Eds.). (2009). The Handbook of Sports Medicine and Science: Rowing. John Wiley & Sons.

Sekine, M., Chandola, T., Martikainen, P., Marmot, M. & Kagamimori, S. (2006). Work and family characteristics as determinants of socioeconomic and sex inequalities in sleep: The Japanese Civil Servants Study. Sleep; 29(2): 206-216.

Shekleton, J. A., Rajaratnam, S. M., Gooley, J. J., Van Reen, E., Czeisler, C. A., & Lockley, S. W. (2013). Improved neurobehavioral performance during the wake maintenance zone. Journal of Clinical Sleep Medicine, 9(4), 353-362.

Short, M. A., Weber, N., Reynolds, C., Coussens, S., & Carskadon, M. A. (2018). Estimating adolescent sleep need using dose-response modeling. Sleep, 41(4), zsy011.

Sisk, C. L., & Foster, D. L. (2004). The neural basis of puberty and adolescence. Nature neuroscience, 7(10), 1040-1047.

Skein, M., Duffield, R., Edge, J., Short, M. J., & Mündel, T. (2011). Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. Medicine and Science in Sports and Exercise; 43(7): 1301–1311.

Skidmore, P. M., Howe, A. S., Polak, M. A., Wong, J. E., Lubransky, A., Williams, S. M., & Black, K. E. (2013). Sleep duration and adiposity in older adolescents from Otago, New Zealand: relationships differ between boys and girls and are independent of food choice. Nutrition journal, 12(1), 1-10.

Slater, J. A., Botsis, T., Walsh, J., King, S., Straker, L. M., & Eastwood, P. R. (2015). Assessing sleep using hip and wrist actigraphy. Sleep and Biological Rhythms, 13(2), 172-180.

Sport New Zealand. (2012). Sport and recreation in the lives of young New Zealanders. Retrieved from http://www.sportnz.org.nz/yps

Staunton, C., Gordon, B., Custovic, E., Stanger, J., & Kingsley, M. (2017). Sleep patterns and match performance in elite Australian basketball athletes. Journal of Science and Medicine in Sport, 20(8), 786-789.

Steenekamp, T., Zaslona, J., Gander, P., Rowlands, D., & Signal, T. L. (2021). Sleep/wake behaviour of competitive adolescent athletes in New Zealand: insight into the impact of early morning training. Sleep Medicine, 77, 88-95. https://doi.org/10.1016/j.sleep.2020.11.023

St-Onge, M. P., Grandner, M. A., Brown, D., Conroy, M. B., Jean-Louis, G., Coons, M., & Bhatt, D. L. (2016). Sleep duration and quality: impact on lifestyle behaviors and cardiometabolic health: a scientific statement from the American Heart Association. Circulation, 134(18), e367-e386.

Strogatz, S. H., Kronauer, R. E., & Czeisler, C. A. (1987). Circadian pacemaker interferes with sleep onset at specific times each day: role in insomnia. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 253(1), R172-R178. https://doi.org/10.1152/ajpregu.1987.253.1.R172

Suppiah, H. T., Low, C. Y., & Chia, M. (2015). Effects of sports training on sleep characteristics of Asian adolescent athletes. Biological rhythm research, 46(4), 523-536.

Suppiah, H. T., Low, C. Y., & Chia, M. (2016). Effects of sport-specific training intensity on sleep patterns and psychomotor performance in adolescent athletes. Pediatric exercise science, 28(4), 588-595.

Suppiah, H. T., Low, C. Y., Choong, G., & Chia, M. (2019). Effects of a short daytime nap on shooting and sprint performance in high-level adolescent athletes. International Journal of Sports Physiology and Performance, 14(1), 76-82.

Tabachnick, B. G., & Fidell, L. S. (2013). Using multivariate statistics, 6th edn Boston. Ma: Pearson.

Taylor, D. J., Jenni, O. G., Acebo, C., & Carskadon, M. A. (2005). Sleep tendency during extended wakefulness: insights into adolescent sleep regulation and behavior. Journal of sleep research, 14(3), 239-244.

Temesi, J., Arnal, P. J., Davranche, K., Bonnefoy, R., Levy, P., Verges, S., & Millet, G. Y. (2013). Does central fatigue explain reduced cycling after complete sleep deprivation? Medicine and Science in Sports and Exercise; 45(12): 2243–2253.

Tempesta, D., Salfi, F., De Gennaro, L., & Ferrara, M. (2020). The impact of five nights of sleep restriction on emotional reactivity. Journal of Sleep Research, 29(5), e13022.

Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. The Journal of physiology, 535(1), 261-267.

Thun, E., Bjorvatn, B., Flo, E., Harris, A., & Pallesen, S. (2015). Sleep, circadian rhythms, and athletic performance. Sleep medicine reviews, 23, 1-9.

Trinder, J., Paxton, S. J., Montgomery, J., & Fraser, G. (1985). Endurance as opposed to power training: their effect on sleep. Psychophysiology, 22(6), 668-673.

Tucker, R. (2009). The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. British journal of sports medicine, 43(6), 392-400.

Tuomilehto, H., Vuorinen, V. P., Penttilä, E., Kivimäki, M., Vuorenmaa, M., Venojärvi, M., ... & Pihlajamäki, J. (2017). Sleep of professional athletes: underexploited potential to improve health and performance. Journal of Sports Sciences, 35(7), 704-710.

Vaeyens, R., Güllich, A., Warr, C. R., & Philippaerts, R. (2009). Talent identification and promotion programmes of olympic athletes. Journal of Sports Sciences, 27(13), 1367–1380. https://doi.org/10.1080/02640410903110974

Van Cauter, E., Spiegel, K., Tasali, E., & Leproult, R. (2008). Metabolic consequences of sleep and sleep loss. Sleep Medicine; 9(1): S23-S28.

Van den Bulck, J. (2004). Television viewing, computer game playing, and Internet use and self-reported time to bed and time out of bed in secondary-school children. Sleep, 27(1): 101-104.

Van der Lely, S., Frey, S., Garbazza, C., Wirz-Justice, A., Jenni, O. G., Steiner, R., ... & Schmidt, C. (2015). Blue blocker glasses as a countermeasure for alerting effects of evening light-emitting diode screen exposure in male teenagers. Journal of Adolescent Health, 56(1), 113-119.

Van Dongen, H. P. A, Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep; 26(2): 117–26.

Van Ryswyk, E., Weeks, R., Bandick, L., O'Keefe, M., Vakulin, A., Catcheside, P., ... & Antic, N. A. (2017). A novel sleep optimisation programme to improve athletes' well-being and performance. European Journal of Sport Science, 17(2), 144-151.

Vitale, K. C., Owens, R., Hopkins, S. R., & Malhotra, A. (2019). Sleep hygiene for optimizing recovery in athletes: review and recommendations. International journal of sports medicine, 40(08), 535-543.

Vitale, J. A., & Weydahl, A. (2017). Chronotype, physical activity, and sport performance: a systematic review. Sports Medicine, 47(9), 1859-1868.

Vlahoyiannis, A., Aphamis, G., Bogdanis, G. C., Sakkas, G. K., Andreou, E., & Giannaki, C. D. (2021). Deconstructing athletes' sleep: A systematic review of the influence of age, sex, athletic expertise, sport type, and season on sleep characteristics. Journal of Sport and Health Science, 10(4), 387-402.

Volianitis, S., Yoshiga, C. C., & Secher, N. H. (2020). The physiology of rowing with perspective on training and health. European Journal of Applied Physiology, 120(9), 1943-1963.

Von Rosen, P., Frohm, A., Kottorp, A., Friden, C., & Heijne, A. (2017). Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. Scandinavian journal of medicine & science in sports, 27(11), 1364-1371.

Wada, K., Yata, S., Akimitsu, O., Krejci, M., Noji, T., Nakade, M., ... & Harada, T. (2013). A tryptophan-rich breakfast and exposure to light with low color temperature at night improve sleep and salivary melatonin level in Japanese students. Journal of Circadian Rhythms, 11(1), 1-9.

Walsh, J. A., Sanders, D., Hamilton, D. L., & Walshe, I. (2019). Sleep profiles of elite swimmers during different training phases. The Journal of Strength & Conditioning Research, 33(3), 811-818.

Walters, S. R., Beattie, R., Oldham, A. R., & Millar, S. K. (2017). Attrition in school rowing in New Zealand: A qualitative descriptive study. The Qualitative Report, 22(10), 2785-2804.

Watson, Badr, M. S., Belenky, G., Bliwise, D. L., & Buxton, O. M. (2015). SLEEP - Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society. Sleep, 38(6), 843–844. https://doi.org/10.5664/jcsm.4758

Wing, Y. K., Chan, N. Y., Man Yu, M. W., Lam, S. P., Zhang, J., Li, S. X., ... & Li, A. M. (2015). A school-based sleep education program for adolescents: a cluster randomized trial. Pediatrics, 135(3), e635-e643.

Wittmann, M., Dinich, J., Merrow, M., & Roenneberg, T. (2006). Social jetlag: Misalignment of biological and social time. Chronobiology International, 23(1–2), 497–509. https://doi.org/10.1080/07420520500545979

Wong, M. M., Brower, K. J., Fitzgerald, H. E., & Zucker, R. A. (2004). Sleep Problems in Early Childhood and Early Onset of Alcohol and Other Drug Use in Adolescence. Alcoholism: Clinical & Experimental Research; 28(4): 578–587.

Wood, A. W., Loughran, S. P., & Stough, C. (2006). Does evening exposure to mobile phone radiation affect subsequent melatonin production?. International journal of radiation biology, 82(2), 69-76.

Wood, B., Rea, M. S., Plitnick, B., & Figueiro, M. G. (2013). Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. Applied Ergonomics, 44(2), 237–240. https://doi.org/10.1016/j.apergo.2012.07.008

Wyatt, J. K. (2007). Circadian rhythm sleep disorders in children and adolescents. Sleep Medicine Clinics, 2(3), 387-396.

Yang, C. K., Kim, J. K., Patel, S. R., & Lee, J. H. (2005). Age-related changes in sleep/wake patterns among Korean teenagers. Pediatrics, 115(Supplement_1), 250-256.

Yu, Y., Lu, B. S., Wang, B., Wang, H., Yang, J., Li, Z., et al. (2007). Short Sleep Duration and Adiposity in Chinese Adolescents. Sleep; 30(12): 1688-1697.

Zhao, J., Tian, Y., Nie, J., Xu, J., & Liu, D. (2012). Red light and the sleep quality and endurance performance of Chinese female basketball players. Journal of athletic training, 47(6), 673-678.

APPENDIX 1 INFORMATION LETTERS FOR SWIMMERS

Effects of sleep education and training rescheduling on the sleep and swimming performance of elite adolescent athletes

ATHLETE INFORMATION SHEET

Introduction

- The aim of this study is find out about junior swimmers' sleep and swimming performance.
- You are at a stage in your life where your body naturally wants to go to sleep later and wake up later.
- Science tells us that your early morning training schedules might be cutting your sleep short. This can affect your health and may affect your ability to do your best in the pool.
- Our plan is to teach you some more about sleep, and to reschedule some of your morning training later in the day to see if we can improve your sleep.

Project Description

- We will monitor your sleep for eight weeks. To do this, you will need to fill in a daily sleep diary and wear an actigraph (a small watch that measures how much you move).
- Your performance will be measured by timing you in a race. You will need to swim a race during your Friday morning training session once every two weeks (five races over the eight weeks).
- The eight-week study will be broken up into two time periods. The first two weeks will be during your normal training and the next six weeks will be after we teach you about sleep and change your training times.
- A researcher will teach you about sleep at the beginning of the intervention. You will also receive a booklet with sleep information in it. Half way through the intervention, you will meet again with the researcher for another sleep lesson.
- The researcher and your coach will change your training times so that you have two mornings in a row without training. You will still train the same amount during the week, just at different times than usual.
- Your sleep and performance measures will be compared before and after you learn more about sleep and change your training schedule.

Participant Recruitment

- You may be invited to participate in the study after hearing about it from your coach or your parents.
- **Taking part in the study is your choice and no one can force you to be involved.**
- You can only take part in the study if you:
    - ✓ Are between (and including) the ages of 14 and 18.
    - ✓ Have been chosen to compete or have competed in a national level swimming competition.
    - ✓ Swim for Capital Swimming Club or Raumati Raptors.
    - ✓ Are not injured at the time of recruitment and attend 90% of their weekly training sessions.

- ✓ Have not been diagnosed with a sleep or mood disorder.
- ✓ Are not taking medication known to effect sleep.
- ✓ Non-smokers

Project Procedures

- If you would like to take part in this study, you and your parents (if you are younger than 16 years of age) will have to give written consent using the form provided with this information sheet.
- All information you provide will be confidential. The research team (the people named at the bottom of this page) will give you a participant identification number that will be attached to all your data. During your data collection, we will use your name and your contact details (including phone and email) to stay in touch with you. Once you have finished data collection we will delete your contact information and only keep your participant ID number.

If you decide to participate, you will be asked to do the following:

Sleep measures

- You will need to fill in a questionnaire that will take about 15 minutes. The questionnaire collects basic information about: you (age, sex, information about your usual sleep and swimming, and contact details); whether you meet all the criteria for being in the study.
- You will meet with a researcher who will give you an actigraph, and a sleep diary and explain how to use them (photo of actigraph shown below). The sleep diary will also include a questionnaire to tell whether you are a morning or an evening person (your 'chronotype').
- You will need to wear the actigraph continuously (except when you are in contact with water for a long time, like during swimming or taking a bath/shower) and complete the sleep diary every day for 8 weeks.
    - ➢ The actigraph is the size of a watch and is worn on your non-dominant wrist. It measures movement, light, temperature of the actigraph case (to detect when it is worn), and keeps track of when you press a button (you're asked to press this when you get into and out of bed). The actigraph does not collect any other information and cannot tell the researchers what you are doing. It cannot transmit data until it is handed back to the researchers. When you return the actigraph, the information is analysed with a computer program to say when and for how long you have slept. The sleep diary asks when you try to sleep, how often you wake, and has space for you to rate how well you slept and any important notes, such as when you took the watch off.

- Every week you will receive a phone call, text, or email message from a researcher to check to see if you have any questions or need help with the study.

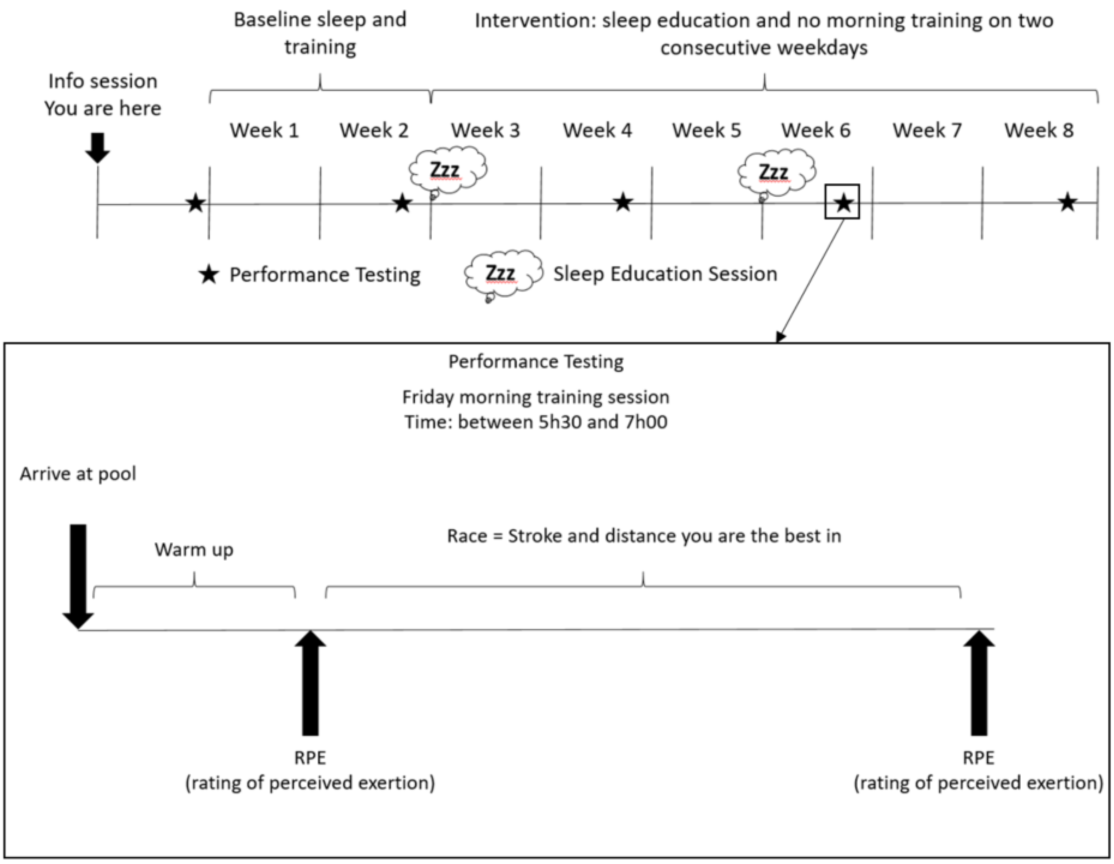
Intervention

- You will need to come to a session on sleep that your parents are also invited to attend. It will be a 45-minute talk where you will learn more about sleep, why it is important for your health and swimming performance, and ways to help improve your sleep.

- You will receive a sleep information booklet to keep. It will have the information from the lesson plus some extra details.
- Three weeks into the intervention, you will have to come to another session with the researcher. At this session, the group will get feedback on everyone's usual sleep. You will also get feedback on your own sleep (but this will not be shared with the group). At this session, you can also tell the researcher how the study is going and if you have any problems.
- After two weeks in the study, some of your training times will be changed to give you two mornings in a row without training. You will still do the same amount of training in a week, only the times of the training sessions will be changed.

Performance measures

- You will need to swim five races at training during the study.
- You will swim a race every two weeks during your Friday morning training session.
- Before each race, your coach will take you through a warm-up to get you ready (the warm-up your coach would normally do with you before a real race).
- The race you swim will be in the stroke and distance that you are best in (your coach will help you decide if you are not sure).
- Your race time will be taken and your performance will be compared over the weeks you are in the study. You will also be asked how your body feels (called a rating of perceived exertion) after your warm up and after your race.



Data Management

- Your sleep and performance information will be analysed by researchers from the Sleep/Wake Research Centre.
- None of the information collected will have your name attached to it. Instead, it will be labelled with an identification number. Your individual information will only be given to you and your parents (if you are under 16 years of age) and no one else will have access to your information without your permission. No information that could personally identify you will be used in any reports on the study.
- The findings of the study will be published in scientific papers and presentations and as part of Travis Steenekemp's doctoral thesis. You will receive a summary of the findings of the study and have access to this on the Sleep/Wake Research Centre website.
- You have the right to ask that any of your information only be used by the current study and not again in the future.
- All data will be stored in secure facilities at the Sleep/Wake Research Centre, Massey University. The signed consent form will be kept for 5 years then destroyed. Hard copy data will be kept for 10 years after the study has been completed then securely destroyed. Digital data (labelled with ID numbers only) will be kept indefinitely, or until you ask us to delete it. If you want us to delete your data, you will need to remember your participant ID number since it will not be labelled with your name.

Risks, Inconveniences, and Benefits

Risks. Taking part in physical training always involves the risk of injury. The study has been designed to try make sure that you are not asked to do more or less physical training than you would usually do in a week. Major increases or decreases in training, or when you are asked to do something you are not used to doing, are typically the most likely times for getting injured. For this reason, the performance test you will be asked to do is a swimming race in your best event. Being a national level swimmer, your body should be used to the stress a swimming race would put on it.

Inconveniences. Wearing the actigraph might feel uncomfortable at times. There is a chance that the watch might irritate you, especially at night if you do not usually wear a watch while you sleep. There is also a chance that the watch might irritate your skin. If this happens, let the researcher know as soon as possible. Filling in the sleep diary will take a few minutes each day across the 8-week study. The diary has been kept as short as possible to make it quick and easy for you to use. Changing your training times may also cause inconvenience to you or your parents. The change in times may mean that how you get to the pool and school will also have to change during the study.

Benefits. By being a part of this study, you will add to what we know about the sleep of junior elite swimmers. You will also have the chance to learn more about how your body works. You will learn about how you sleep, why sleep is important and how sleep is linked to athletic performance. Once you are finished with the study, you will get feedback on your own results (e.g., to see a chart of your sleep during the entire study). To identify your data, you will need to remember and give the researchers your participant identification number.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Participant's Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time and take your data;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used in reports (a participant ID number is used instead);
- be given access to a summary of the project findings when it is concluded.

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application SOA 18/36. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 9099 x 85094, email humanethicsoutha@massey.ac.nz

Project Contacts

If you have any questions about this project, please do not hesitate to contact the researcher:

Travis Steenekamp T.Steenekamp@massey.ac.nz [redacted]

This study is being undertaken as part of the researcher's PhD. You may contact the project supervisors if you have any questions or issues with the study:

Primary supervisor: Associate Professor Leigh Signal **T.L.Signal@massey.ac.nz**

Co-supervisor: Dr Jennifer Zaslona **J.Zaslona@massey.ac.nz**

Co-supervisor: Professor David Rowlands **D.S.Rowlands@massey.ac.nz**

Co-supervisor: Professor Philippa Gander **P.H.Gander@massey.ac.nz**

- **Effects of sleep education and training rescheduling on the sleep and performance of elite adolescent athletes**

PARENTS INFORMATION SHEET

Introduction

- The aim of this study is find out about junior swimmers' sleep and swimming performance.
- Adolescents are at a stage in your life where your body naturally wants to go to sleep later and wake up later.
- Science tells us that their early morning training schedules might be cutting sleep short. This can affect aspects of health and may affect their ability to do their best in the pool.
- Our plan is to teach swimmers some more about sleep, and to reschedule some of your morning training later in the day to see if we can improve their sleep.

Project Description

- Your child's sleep will be monitored using diaries and actigraphy (small watch-like device to measure wrist movement) for eight weeks: two baseline weeks followed by a six-week intervention.
- During Friday morning training session at two-week intervals, he/she will swim a timed race in their best stroke and distance, with appropriate warm-up and supervision from the coach (five testing sessions altogether).
- The intervention will include two sleep education sessions and changes to the timing sessions.
- The sleep education will include a group seminar with the researcher at the beginning of the intervention; a sleep education booklet designed specifically for junior elite swimmers and their parents; and a follow up face-to-face meeting half way through the intervention.
- Training rescheduling will be arranged with your child's coaches, to allow him/her to have two consecutive weekday mornings free from training. This will give them a chance to sleep in while keeping the overall training load for the week the same.
- Sleep and swimming performance measures will be compared before and after the intervention period.

Participant Recruitment

- You and your child may be invited to participate in the study after hearing about it from your child's coach.
- **Participation is voluntary and there are no disadvantages if you choose not to participate.**
- Swimmers will be eligible to take part in the study if they are:
    - ✓ Between (and including) the ages of 14 and 18.
    - ✓ Junior elite swimmers who have been chosen to compete or have competed in a national level swimming competition.
    - ✓ Swim for a club whose coach is willing to be involved in the study.
    - ✓ Not injured at the time of recruitment and attend 90% of their weekly training sessions.
    - ✓ Have not been diagnosed with a sleep or mood disorder.
    - ✓ Are not taking medication known to effect on sleep.
    - ✓ Non-smokers

Project Procedures

- If your child decides to participate and is less than 16 years of age, they will only be allowed to do so if you provide written consent using the consent form provided with this information sheet.
- All information you and your child provide will be confidential and will be labelled and saved only with a participant identification number (not your names). We will use your name and your contact details (including phone and email) during data collection to stay in touch with you, but once we have finished data collection we will delete your contact information and only keep your child's participant ID number.

If your child decides to participate, they will be asked to do the following:

Sleep measures

- They will need to fill in a questionnaire that will take about 15 minutes. The questionnaire collects basic information about: them (age, sex, information about their usual sleep and swimming, and contact details); whether they meet all the criteria for being in the study.
- They will meet with a researcher who will give them an actigraph, and a sleep diary and explain how to use it (photo of actigraph shown below). The sleep diary will also include a questionnaire to tell whether they are a morning or an evening person (their 'chronotype').
- They will need to wear the actigraph continuously (except when they are in contact with water for a long time, like during swimming or taking a bath/shower) and complete the sleep diary every day for 8 weeks.
    - ➢ The actigraph is the size of a watch and is worn on the non-dominant wrist. It measures movement, light intensity, the temperature of the actigraph case (to detect when it is worn), and keeps track of when you press a button (the swimmers are asked to press this when they get into and out of bed). The actigraph does not collect any other information and cannot tell the researchers what they are doing. It cannot transmit data until it is handed back to the researchers. When they return the actigraph, data are analysed with a computer program to estimate when and for how long they have slept. The sleep diary asks when they try to sleep, how often they wake, and has space for them to rate how well they slept and any important notes, such as when they took the watch off. The diary is short and concise and should only take a few minutes to fill out daily.

- Every week they will receive a phone call, text, or email message from a researcher to check to see if they have any questions or need help with the study.

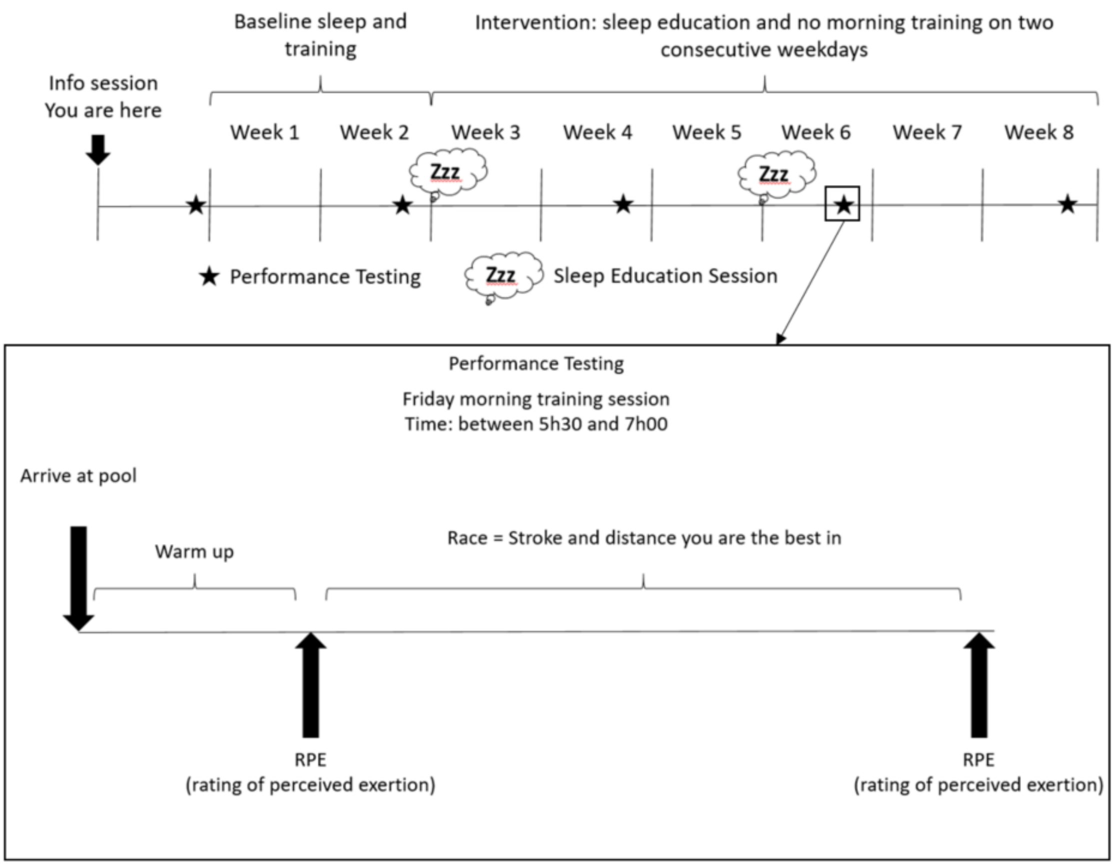
Intervention

- Your child will need to attend a sleep education session that you as their parents are invited to attend. This session will take place after the two baseline weeks. This will be a 45-minute seminar where you will learn about sleep, why it is important for your child's health and performance, and ways they could improve their sleep (and maybe yours too!).

- You will receive a sleep information booklet that you will be able to keep. It will include the information from the seminar, and additional helpful information.
- Three weeks into the intervention, they will be required to attend a follow up session with the researcher where they will receive individual feedback on their baseline sleep (their personal data will not be shared with the group). This will also be an occasion to let the researcher know how you and your child are finding the intervention.
- From the beginning of the intervention, their weekly training sessions will also be rescheduled. They will not have training on two consecutive weekday mornings for the six weeks of the intervention. Their training sessions will be moved but their overall training load will not change; only the time at which training takes place will change.

Performance measures

- They will be required to complete five performance testing sessions.
- Performance testing will take place during the Friday morning training session every two weeks.
- The performance test will include a fixed warm-up (the warm-up their coach would typically take them though before a real race) followed by a simulated race time trial.
- The race will be in the stroke and distance they are most competitive in (their coach will help them decide if they are not sure).
- Their race time will be recorded and their performance will be compared over the weeks they take part in the study. Their ratings of perceived exertion will be taken directly after their warm up and again after their race.



Data Management

- Data will be analysed by researchers from the Sleep/Wake Research Centre.
- None of the data collected will have your child's name attached to it. Instead, it will be labelled with an identification number. Individual data will only be made available to your child (and you if your child is under the age of 16). No one else will have access to their information without their permission. No material that could personally identify them will be used in any reports on the study.
- The findings of the study will be published in peer-reviewed papers and presentations. You will receive a summary of the findings of the study and have access to this via hard copy or on the Sleep/Wake Research Centre website.
- De-identified data may subsequently be used in conjunction with data from other studies to improve our understanding of sleep and circadian processes in young people. Your child (and you if your child is under the age of 16) retains the right to remove their data from subsequent analyses after the study ends.
- All data will be stored in secure facilities at the Sleep/Wake Research Centre, Massey University. The signed consent forms will be kept for 5 years then destroyed. Hard copy data will be kept for 10 years after the study has been completed then securely destroyed. Digital data (labelled with ID numbers only) will be kept indefinitely, or until you or your child asks us to delete it. If they want us to delete their data, they will need to remember their participant ID number since it will not be labelled with their name.

Risks, Inconveniences, and Benefits

Risks. Taking part in physical training always involves the risk of injury. The study has been designed to ensure that your child is not asked to do more or less physical training than they would typically do in a week. Major spikes or dips in training load are typically the most likely times when athletes get injured. Keeping their training load consistent will therefore minimise the risk of them getting injured during the intervention period even though their training times are being altered. Injuries commonly occur when introducing an unfamiliar stressor into training. For this reason, the performance test they will perform is one that they will be accustomed to as an elite swimmer. The training load and performance measures they will encounter during the study are no different to what they would experience in their normal swimming routines.

Inconveniences. Wearing the actigraph may be considered an inconvenience. There is a possibility that the actigraph can cause them some discomfort particularly if they do not usually wear a watch when sleeping. If as a result of wearing the actiwatch they experience a skin irritation, please notify the researcher so that corrective measures can be taken. Keeping the sleep diary will take a few minutes each day across the 8-week study. The diary has been kept as concise as possible to minimise its inconvenience to the user. However, the change in their training times may be inconvenient to them or to you. The change in training days may mean you have to adjust your routine for getting them to the pool and to school.

Benefits. By participating in this project, they will contribute to an improved understanding of the sleep of junior elite swimmers. You and your child will also have the opportunity to gain insight into the workings of the human body. They will gain a better understanding of their sleep patterns and sleep needs as well as how their body reacts to the amount of sleep they get. Once their participation is complete, they may contact the researchers to receive feedback on their individual data (e.g., to see a chart of their sleep during the entire study). To identify their data, they will need to remember and provide the researchers with their participant identification number.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Participant's Rights

You are under no obligation to accept this invitation. If you and your child decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time and take your data;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your names will not be used in reports (a participant ID number is used instead) unless you give permission to the researcher;

be given access to a summary of the project findings when it is concluded.

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application SOA 18/36. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 9099 x 85094, email humanethicsoutha@massey.ac.nz

Project Contacts

If you have any questions about this project, please do not hesitate to contact the researcher:

Travis Steenekamp T.Steenekamp@massey.ac.nz [redacted]

This study is being undertaken as part of the researcher's PhD. You may contact the project supervisors if you have any questions or issues with the study:

Primary supervisor: Associate Professor Leigh Signal **T.L.Signal@massey.ac.nz**

Co-supervisor: Dr Jennifer Zaslona **J.Zaslona@massey.ac.nz**

Co-supervisor: Professor David Rowlands **D.S.Rowlands@massey.ac.nz**

Co-supervisor: Professor Philippa Gander **P.H.Gander@massey.ac.nz**

APPENDIX 2 SCREENING QUESTIONNAIRE

"Effects of sleep education and training restructuring on the sleep and swimming performance of elite adolescent athletes"

Screening questionnaire

Please read each question carefully and answer ALL of the questions in this booklet.

Please remember that all of the information you provide for this study is strictly confidential.
Your name is not kept with this information and so you cannot be identified.

If you have any questions or concerns please ask a researcher.

HEALTH CHECKLIST

GENERAL

What sex are you? *(Please tick)* ☐ Male ☐ Female ☐
Non binary

What is your date of birth? .... /............ /...........

(day) (month) (year)

Have you traveled overseas in the last four weeks? 1☐ Yes 0☐No

If yes, where did you travel? ....

SMOKING

Do you describe yourself as a:

1☐ Regular smoker

(I smoke one or more cigarettes per day)

2☐ Occasional smoker

(I do not smoke every day)

3☐ Ex-smoker

(I used to smoke but not any more)

4☐ Non-smoker

(I have never smoked regularly)

STRESS

Are you currently experiencing a greater than your normal amount of stress? (e.g. a sick relative, relationship break-up, writing exams, etc.) 1☐ Yes 0☐No

Do you have any academic or other test scheduled for one week before and during the study?

1☐ Yes 0☐No

In general, would you say your health is?

0☐Excellent 1☐Very good 2☐Good 3☐Fair 4☐Poor

<u>GENERAL HEALTH</u> (please use the back of this sheet if you require more space.

Have you ever been diagnosed with a sleeping problem? 1☐ Yes 0☐No

If yes, please describe

....

....

Are you currently on any medication?

(prescription <u>or</u> over the counter) 1☐ Yes 0☐No

If so, what medication? ....………

Have you been on any medication in the past week? 1☐ Yes 0☐No

(prescription <u>or</u> over the counter)

If so, what medication? ....………

Do you currently have any physical illness? 1☐ Yes 0☐No

If yes, what illness(es)? ....………

Have you ever been diagnosed with a mood or mental health disorder? 1☐ Yes 0☐No

If yes, what disorders? ....………

Are you currently being treated for this disorder? 1☐ Yes 0☐No

If yes, how is it being treated? ....…..

Do you have any personal or family history of respiratory problems?

(e.g. asthma, allergies, bronchitis) $_1$☐ Yes $_0$☐No

If so, what illness(es)? ....………

Do you have any personal or family history of a mental illness? $_1$☐ Yes $_0$☐No

If so, what illness(es)? ....………

List the types of exercise you do for an average week ....

....

How much exercise do you do, on average per week? ....**hours**

How many swimming sessions are you expected to attend, on average per week? ....

How many of these sessions do you go to, on average per week? ....

Have you been injured in the past month? $_1$☐ Yes $_0$☐No

If so, has this injury stopped you from being able to train normally? …………………

………………………………………………………………………………………….

Athlete Sleep Screening Questionnaire

INSTRUCTIONS

The following questions relate to your sleep habits. Please circle the best answer which you think represents your typical sleep habits over the recent past. For all questions, circle a letter from 'a' to 'e' unless otherwise specified.

1. During the recent past, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

a) 5 to 6 hours
b) 6 to 7 hours
c) 7 to 8 hours
d) 8 to 9 hours
e) more than 9 hours

2. How many naps per week do you take?

a) none
b) once or twice
c) three or four times
d) five to seven times

3. How satisfied/dissatisfied are you with the quality of your sleep?

a) very satisfied
b) somewhat satisfied
c) neither satisfied nor dissatisfied
d) somewhat dissatisfied
e) very dissatisfied

4. During the recent past, how long has it usually taken you to fall asleep each night?

a) 15 minutes or less
b) 16 – 30 minutes
c) 31 – 60 minutes
d) longer than 60 minutes

5. How often do you have trouble staying asleep?

a) none
b) once or twice per week
c) three or four times per week
d) five to seven days per week

6. During the recent past, how often have you taken medicine to help you sleep (prescribed or over-the-counter)?

a) none
b) once or twice per week
c) three or four times per week
d) five to seven times per week

7. Considering only your own "feeling best" rhythm, at what time would you get up if you were entirely free to plan your day?

a) 5:00 am – 6:30 am
b) 6:30 am – 7:45 am
c) 7:45 am – 9:45 am
d) 9:45 am – 11:00 am
e) 11:00 am – 12:00 pm (noon)

8. How alert do you feel during the first half-hour after having awakened?

a) not at all alert
b) slightly alert
c) fairly alert
d) very alert

9. Do you consider yourself to be a morning type person or an evening type person?

a) definitely a morning type
b) more a morning type than an evening type
c) more an evening type than a morning type
d) definitely an evening type

10. Considering your own "feeling best" rhythm, at what time would you go to bed if you were entirely free to plan your evening?

a) 8:00 pm – 9:00 pm
b) 9:00 pm – 10:15 pm
c) 10:15 pm – 12:30 am
d) 12:30 am – 1:45 am
e) 1:45 am – 3:00 am

11. When you are travelling for your sport, do you experience sleep disturbance?

a) Yes
b) No

12. When you are travelling for your sport, do you experience daytime dysfunction (feeling generally unwell or having poor performance)?

a) Yes
b) No

13. Are you typically a loud snorer?

a) Yes
b) No

14. Have you been told that you choke, gasp, or stop breathing for periods of time during sleep?

a) Yes
b) No

15. On average, how many caffeinated products (caffeine pills, coffee, tea, soda, energy drinks) do you have per day? For coffee and tea, one drink = 6-8oz/177-237ml; for caffeinated soda, one drink = 1 can (12oz/355ml)?

a) Less than 1 per day
b) 1-2 per day
c) 3 per day
d) 4 per day
e) 5 or more per day

16. Over the recent past, how often do you use an electronic device (example: cell phone, computer, tablet, T.V. etc.) within 1 hour of going to bed?

a) Not at all
b) 1-3 times per week
c) 4-6 times per week
d) Every day

Please provide your contact details below. These details will be kept separately from the information you have provided in this questionnaire and will be destroyed once your participation in this study has been completed.

Name: ______________________________

Swimming club: ______________________________

____

Telephone number: ______________________ **(home)**

____

______________________ **(mobile)**

E-mail: ______________________

THANK-YOU FOR COMPLETING THIS QUESTIONNAIRE.

APPENDIX 3 ATHLETE CONSENT FORM

Effects of sleep education and training rescheduling on the sleep and swimming performance of elite adolescent athletes - consent form

If you are under the age of 16, you will not be allowed to participate if a parent does not sign this form as well!

This form will be securely held by the Sleep/Wake Research Centre for five (5) years.

Researchers from the Sleep/Wake Research Centre have adequately answered any and all questions I have about this data collection effort, my participation, and the procedures involved. I understand that I may contact researchers from the Sleep/Wake Research Centre to answer additional questions at any time during my participation.

I understand that records of my participation will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this project.

I understand that I may withdraw from participation at any time without penalty. I also understand that the researcher may stop my participation in the study or exclude my data if I no longer meet study criteria.

I wish/do not wish to be contacted in the eventuality that the researchers design a follow-up study to further their understanding of the long-term efficacy of the current investigation.

I understand that de-identified data from all participants in this study may subsequently be used in conjunction with data from other studies to improve our understanding of sleep in adolescent athletes.

I wish/do not wish to have de-identified data placed in an official archive. *Note there is no currently identified external archive in which to place data, though it is possible that in the future such an archive will become available.*

I have read and received a copy the study Information Sheet and had the details of the study explained to me. I understand its contents, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: ______________________ **Date:** __________

Full Name - printed ______________________

Parental Signature: ______________________ **Date:** __________

Full Name - printed ______________________

APPENDIX 4 SLEEP EDUCATION MANUAL

More Zzzz's for faster PB's

A SLEEP GUIDE FOR YOUNG ATHLETES AND THEIR PARENTS

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

SLEEP~WAKE research centre
MOE TIKA~MOE PAI

CONTENTS

Welcome

Back to basics

- What is sleep?
- How do our bodies regulate sleep?
- Different types of sleep
- How much sleep do we need?
- How is sleep different for teens?
- What happens if we do not sleep enough?

Sleep and athletes

- Why is sleep important to athletes?
- Health
- Performance

Sleep stealers

Sleep tips

Final thoughts

How to keep up to date with science and helpful resources

Welcome

You are at an incredibly exciting time of your life; you are young, ambitious, talented, full of potential and…probably sleepy. As a teenager, you face so many pressures in your daily life. You have to keep up with school, stay connected with your friends and maintain a social life. As an athlete, you have the added pressure of training and competing too. Let's not forget that you also need some time to relax, have fun and just be young! With the long list of pressures you need to be juggling, it is no surprise that a good night's sleep is sometimes forgotten about or simply not a priority. In fact, some research has found that only 15% of teenagers get the recommended amount of sleep on weeknights. But wait, what is the recommended amount of sleep for teens? How important is that good night's sleep you might be missing out on? How does it affect your everyday life? How does it affect your health and performance?

If you don't know the answers to these questions, it's okay! That's why this booklet is here to help. After reading this booklet you should have a better understanding of what sleep is, why it is important and what activities are good or bad for sleep. Perhaps most importantly, it will explain how sleep affects physical performance and why sleep should be a major priority for any athlete.

Back to basics

What is sleep

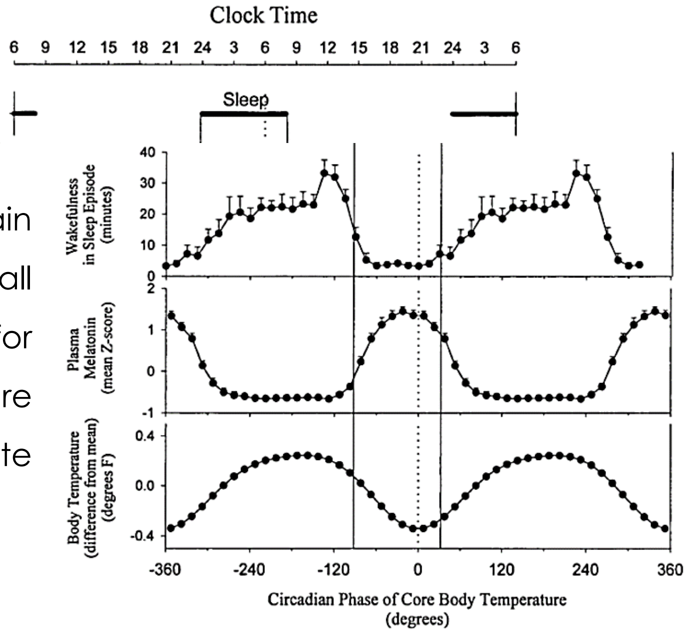
When we sleep, we become less responsive to what is going on around us but our brains and bodies continue doing really important tasks. Sleep is vital for recovery from the previous period of wakefulness and for preparing the body for the upcoming time awake. Three aspects need to kept in mind when thinking about healthy sleep. The first is **sleep duration**: how long you slept. The second is **sleep quality**: how free of disruptions your sleep was and how refreshed you feel when you wake up. The last component of good sleep is **sleep timing**: how consistent your bedtimes and rise times are from night to night. Getting enough, good quality sleep at the right time of day is important for our brains and bodies to function properly.

How do our bodies control when we sleep?

Two main factors control when we sleep and when we are awake. These are:

1. The circadian body clock and;
2. The sleep drive

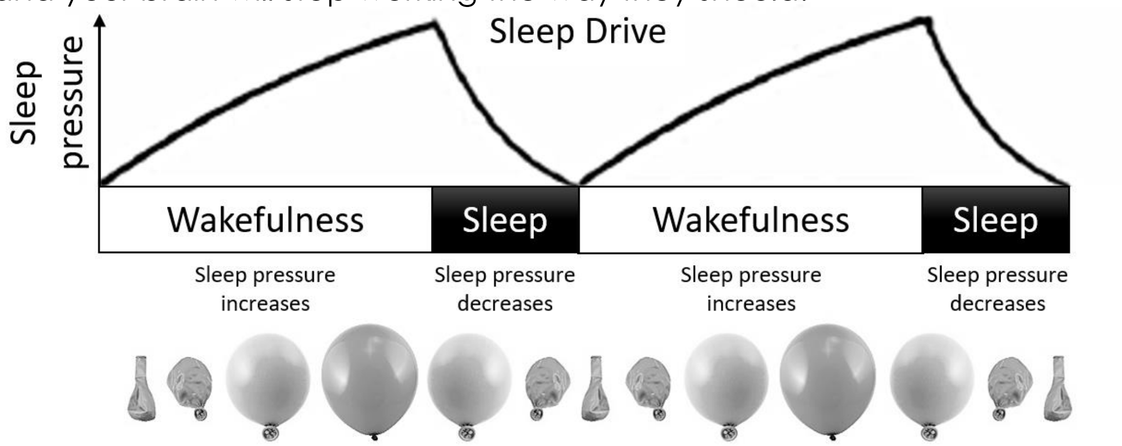
Most of the biological processes in the body follow a **circadian rhythm**, meaning they have a 24-hour pattern of activity. Deep inside our brains is a small group of cells that act as an internal clock. They control many processes in our bodies including the rise and fall of certain hormones, body temperature and our ability to fall asleep. We even have circadian rhythms for physical and cognitive performance. We are usually best at tasks that rely on being accurate



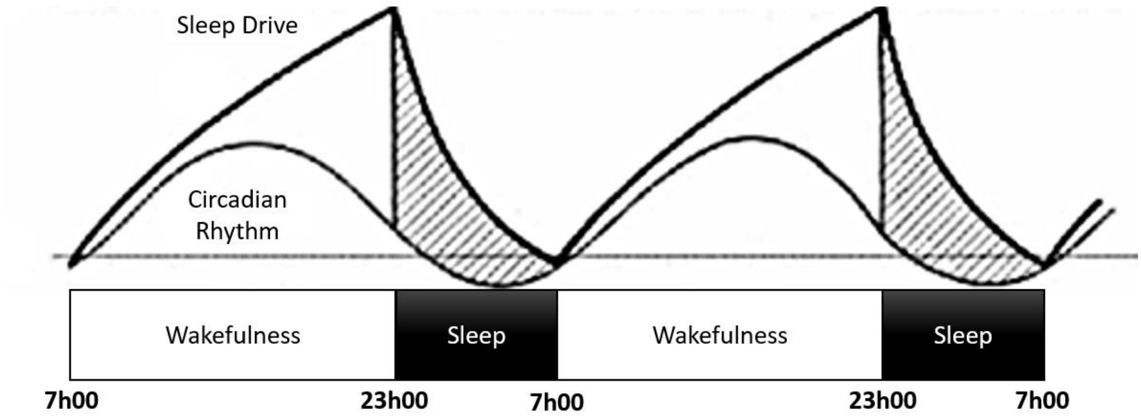
early in the day, whereas, we are strongest and fastest in the late afternoon.

Our body clocks are not the only thing that control when we sleep and when we are awake. The other factor is called the **sleep drive**. The sleep drive simply means that the longer you are awake, the sleepier you get.

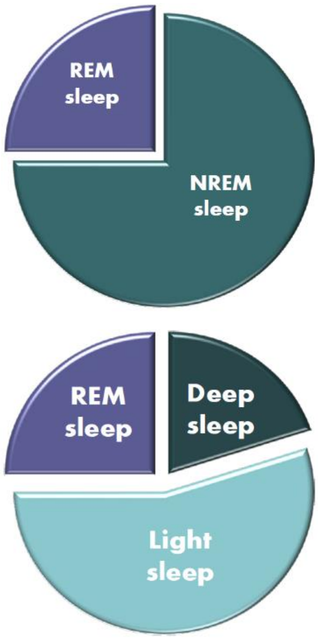
The sleep drive is like blowing up a balloon. Every hour you are awake is like one breath into the balloon. Once the balloon is full (which is like being awake an entire day or about 16 hours) there is a lot of pressure built up inside the balloon. The only way to get rid of the pressure is to let the air out (for you, it is to sleep and this increased pressure will help you fall asleep). However, if you continue to blow air into the balloon (you stay awake longer than you should) eventually the balloon will pop. We promise that you won't 'pop' if you stay awake too long but your body and your brain will stop working the way they should.



The circadian rhythm and sleep drive work together to keep you awake during the day and get you to fall asleep and stay asleep at night. In the early evening our sleep drive is high but our circadian clock is telling us to stay awake. This stops us falling asleep at dinner time. Our circadian clock then stops telling us to stay awake and we are able to fall asleep. During sleep, the sleep pressure (or drive) is released (the air in the balloon has been let out). We wake-up in the morning when the circadian clock starts telling us to be awake.



Different types of sleep



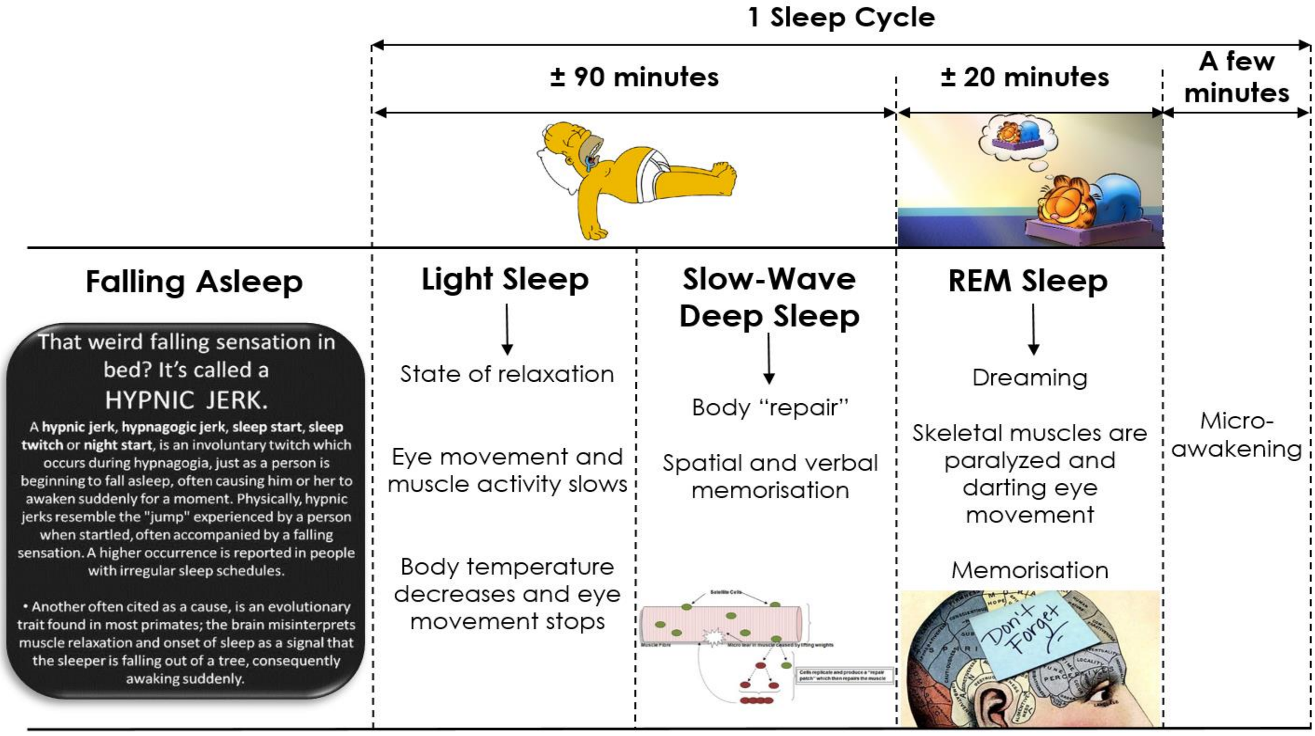
Did you know that not all sleep is the same? During a normal night, we have different types of sleep. The two different types of sleep are **non-rapid eye movement sleep (NREM)** and **rapid eye movement sleep (REM).**

Non-rapid eye movement sleep can be further broken down into **light sleep** and **deep sleep**. During light sleep, our brain activity and heart rate slows, and our muscles relax. It is not difficult to wake someone from light sleep.

Deep sleep is a time of repair and growth. Blood flow to our muscles increase, hormones for growth and development are released and our energy stores in our muscles are topped up. It can be difficult to wake someone up from deep sleep.

During rapid eye movement sleep our brains are very active. This is the stage of sleep when we dream. Our eyes move quickly from side to side and our brain activity and heart rate increases. Most of our muscles are told by our brains to stop working during rapid eye movement sleep. We think this happens so that we don't hurt ourselves while we are dreaming.

Going from light sleep into deep sleep and then into REM sleep is one **sleep cycle**. One full sleep cycle lasts about 90 to 110 minutes and we usually go through five sleep cycles a night.



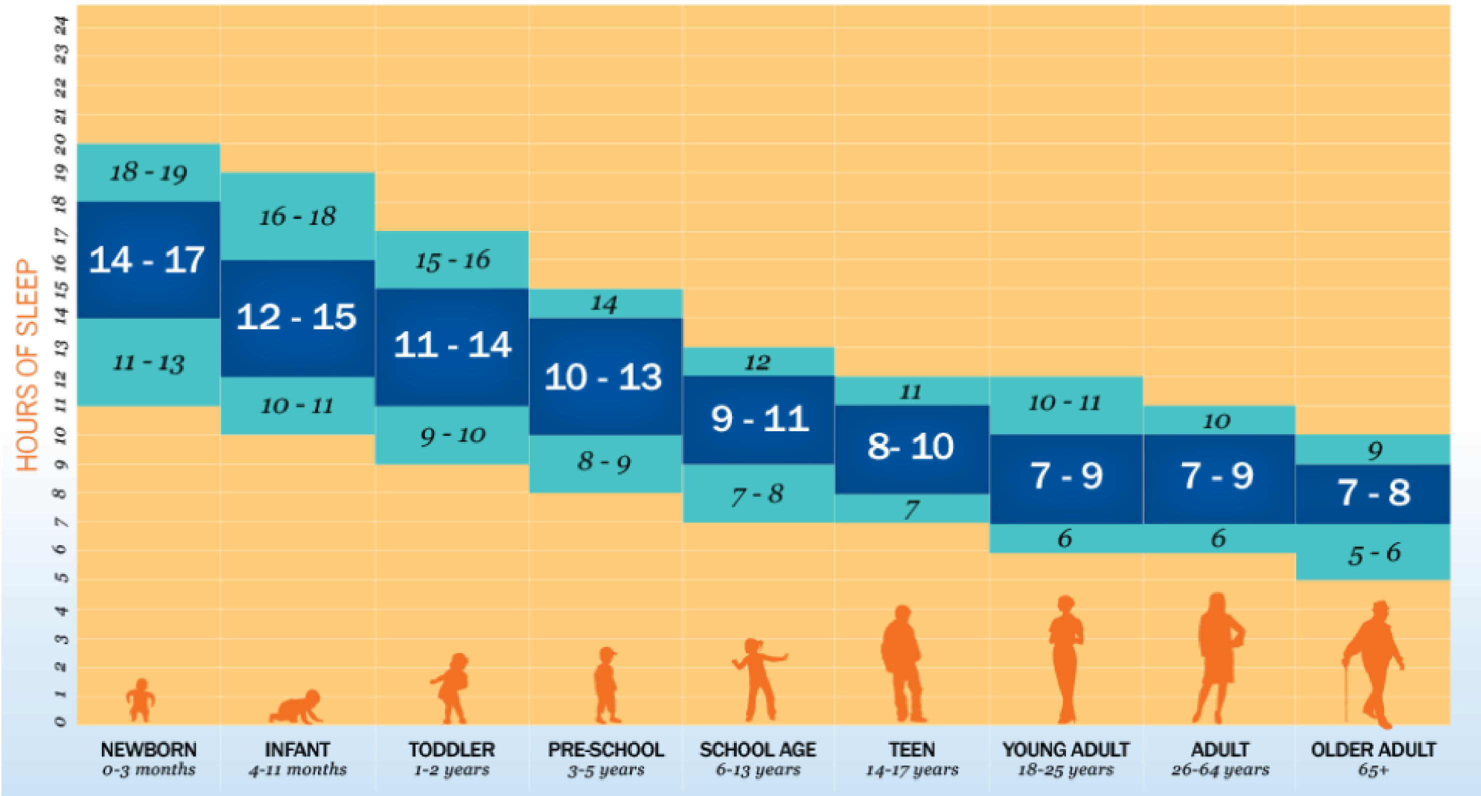
How much sleep do we need?

So…how much sleep do you think you need? Don't look down! That's cheating!

Well I guess by now you've looked at the picture…and yes, that's right, almost all teenagers need between **eight and ten hours of sleep a night**. You might be wondering why you need so much sleep. As a teenager your body is still growing and developing and sleep is really important for this to happen. Sleep is also incredibly important for storing information and memories. High school is an important time of your life for learning and without sleep, the

information you learn during the day will not be stored properly.

Think of yourself as a flash drive. The things you learn during the day are pieces of information you're collecting from the world. Good sleep helps file that information on your main computer (your brain) and makes it easy to find and remember it when you need to. Sleep also helps clear your flash drive so there's enough space on it to learn new things the next day. But, if you don't sleep well or don't get enough sleep, the information on your flash drive may not be filed properly or saved at all onto your main computer!

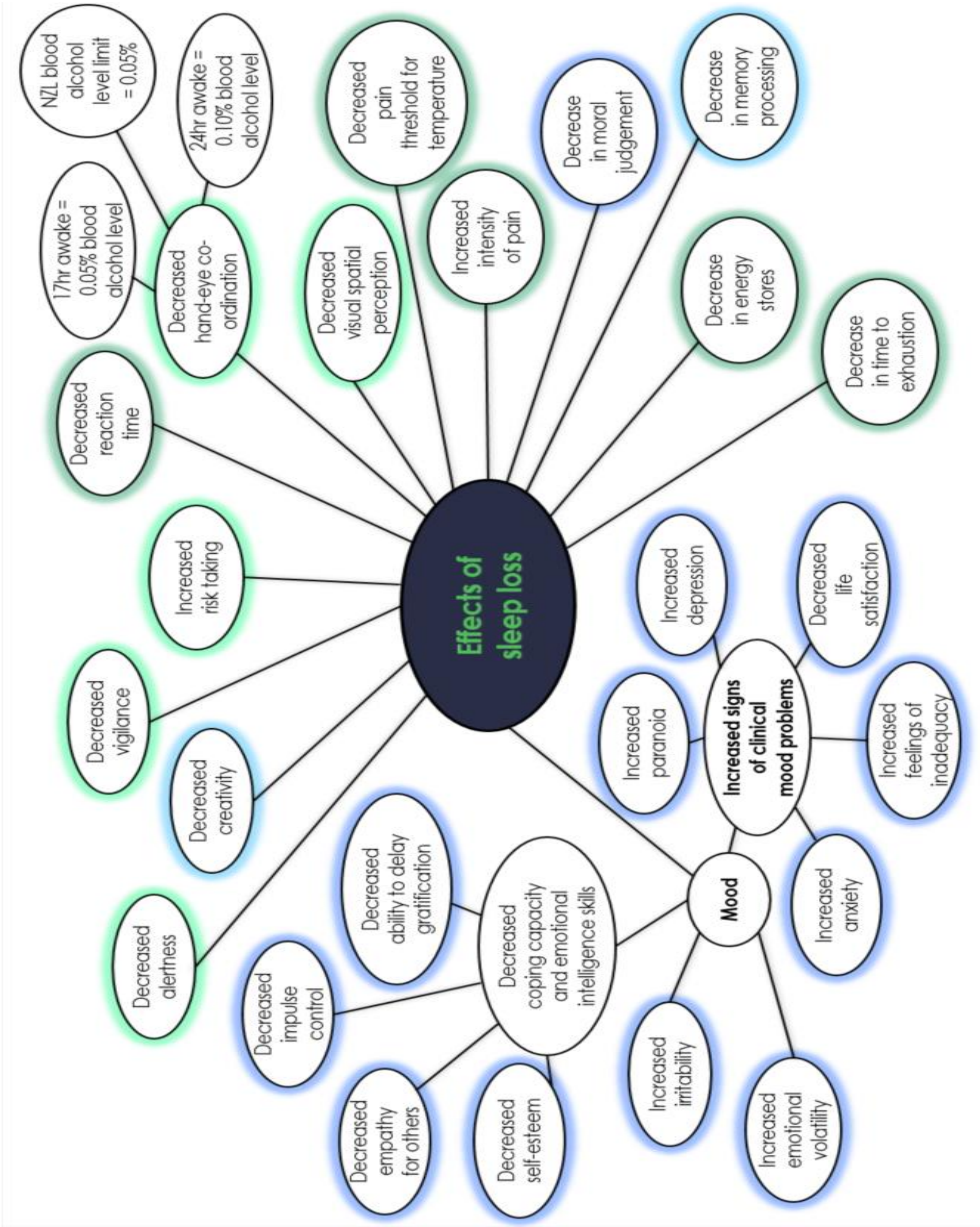


How is sleep different for teens?

As you've already seen, as a teenager you need less sleep than younger children but you need more sleep than adults because you are still growing and developing. But, this isn't the only way your sleep might be different from other age groups.

Remember the circadian body clock that was mentioned earlier…well the timing of a teenager's circadian body clock slightly differs to the timing of the circadian body clock at other life stages. During adolescence, one of the hormones that is linked to our sleep (called melatonin) is released slightly later by the brain. This means that teenagers often don't feel tired until later at night and also find it very difficult to wake up in the morning in time for school. Teenagers also often experience **social jetlag**. This is when we don't get enough sleep on weeknights but then go to bed later and sleep for longer on weekends (or other free days). Sleeping longer at the weekend seems like a good idea, as you're catching up on all the sleep you missed during your busy week. The problem is caused by going to bed later and waking up later than you would on a school night. Your body quickly adjusts to this new pattern of sleep, but the shift back to an earlier rise time on Monday morning is much harder. This is the same as going to Sydney for the weekend and then back to the Kapiti Coast on Monday morning. Shifting your bedtimes and rise times each weekend is the same as giving yourself jetlag each week. This is why it is called "social jetlag."

What happens if we do not sleep enough?

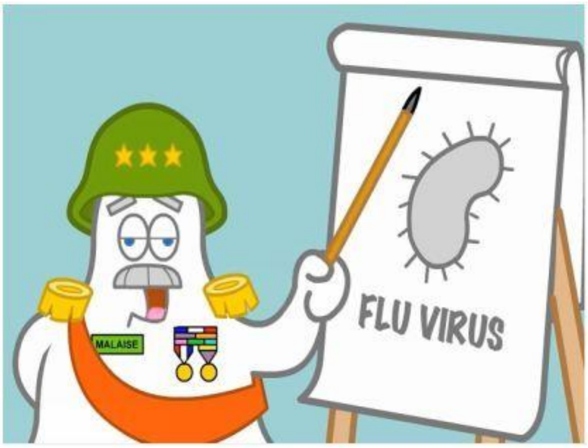


Sleep and athletes

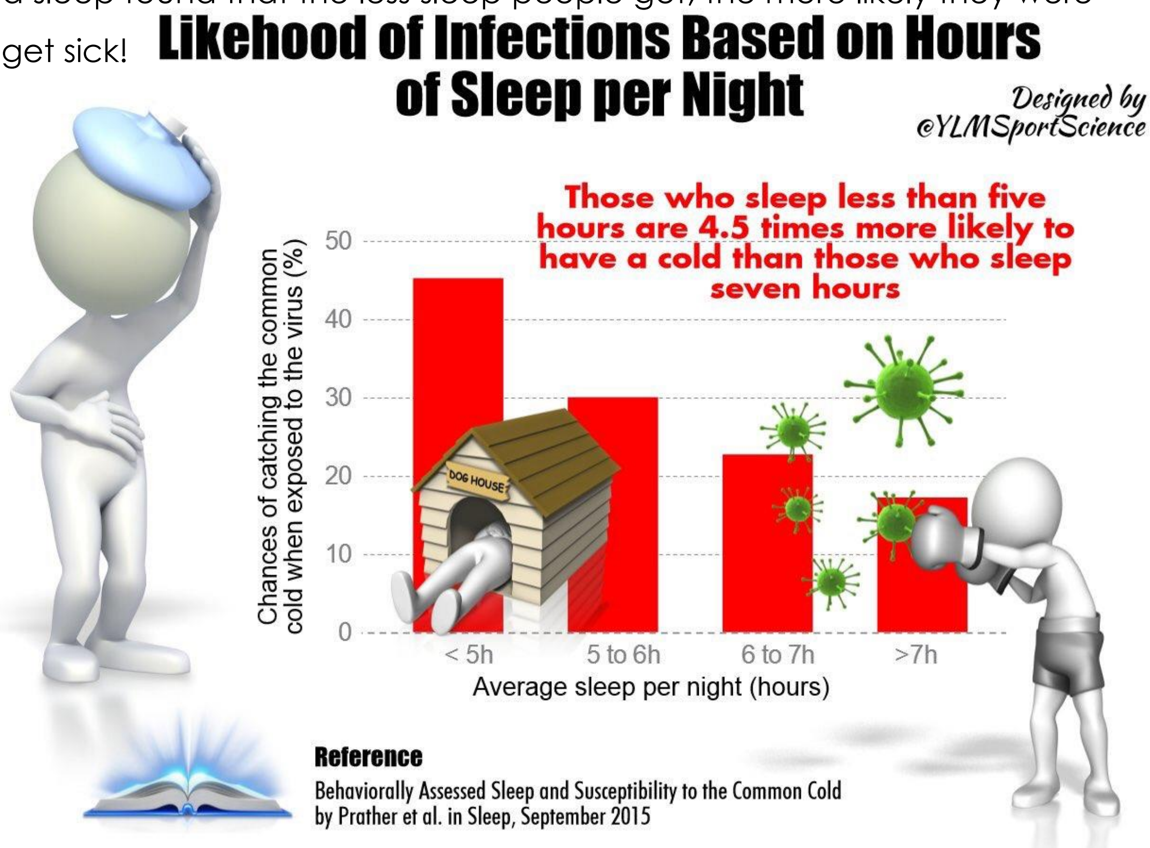
Why is sleep important to athletes?

Health

Athletes need to be healthy and happy, not only to compete at their best, but also to train at their best. Let's talk about sleep and being healthy first…



Our bodies are rather busy while we sleep. One thing they are busy with is launching an immune defence against things in our body that make us sick. This immune response also helps repair damaged tissue. These are both really important for athletes. You have to be healthy while you train in order to improve as much as you can while also staying well. As you can see in the picture below, a study looking at illness and sleep found that the less sleep people got, the more likely they were to get sick!

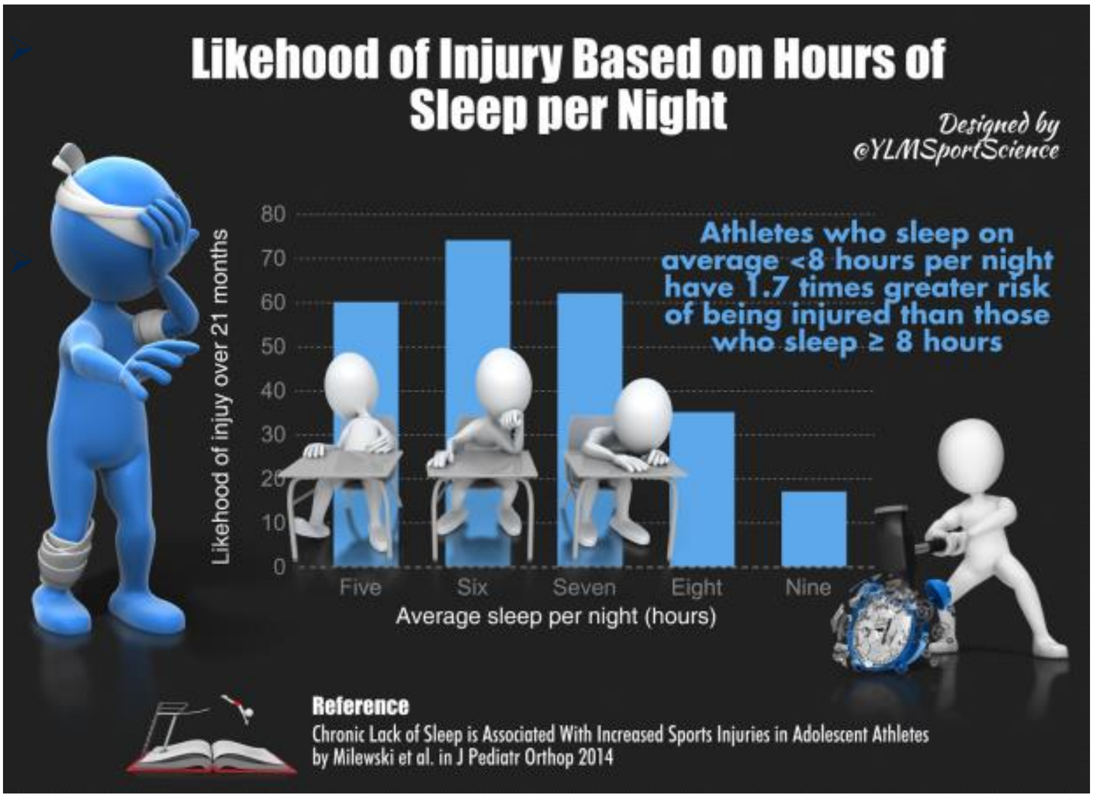


Did you know that when you exercise you actually break down your muscles? Your muscle gets little tears in it when you train. These little tears are then healed through your body's immune responses. If you continuously tear your muscles while doing the same thing (for example during training) your body starts to strengthen the muscles. This is your body's way of protecting itself. This is also the process that makes you faster and stronger, because every time your muscle breaks down, it's repaired to be better than it was before. Sleep is very important for this process! If you aren't getting enough sleep the tiny tears in your muscle don't repair as quickly, which might even mean you could get injured by exercising damaged muscle.

Sleep loss can lead to many other ways you might get injured:

- You are more likely to take risks
- Your reaction time is slower
- You are less alert
- You are more likely to let your form slip

These are all likely reasons why the study summarised in the picture below, found that junior athletes who got less sleep were more likely to get injured!



The other part of being healthy that we sometimes forget about is mental health. Being happy can be just as important to achieving our best on the sports field or in the pool. After all, when you're feeling down do you really train as hard as you could? And, if you aren't training as hard as possible, you aren't going to do as well as you want when it comes to competition

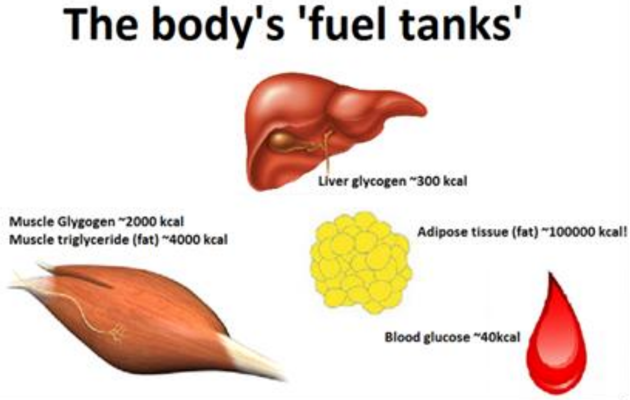
There is a link between poor sleep and many aspects of mental health, including an increased risk of depression, low self-esteem, anxiety and paranoia, irritability and feelings of inadequacy. So, sleep is just as important for your mental health as it is for your physical health!

Performance

Have you ever thought about what is behind the best possible athletic performance? Technically, we would say that sporting performance is dependent on how an athlete "paces" themselves. A winning "pacing strategy" is one where an athlete is pushing as hard as they can to finish the race in the fastest possible time while minimising the chance of fatiguing early. If you start a race too fast, you might get tired too early and not get the time you wanted. Similarly, if you start a race too slow because you're scared of getting tired, you also might not get the time you wanted. The ideal pacing strategy sits nicely in the middle.

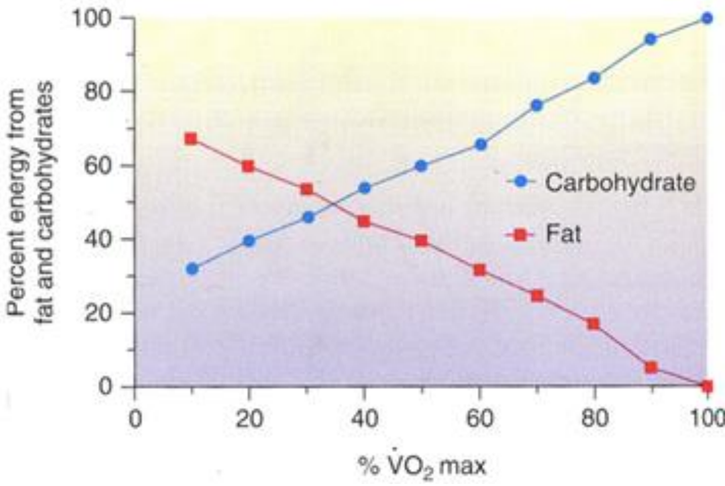
Why is this important for sleep? Well, not getting enough sleep can change processes in our body that affect our pacing in sport. Perhaps one of the most important components of pacing is an athlete's ability to accurately perceive how they feel before and during training or competition. We call this perception of effort. Sleep loss has been shown to lower our motivation levels and make us judge tasks as being harder than we would if we were properly rested. Our bodies are also more sensitive to pain, especially pain in response to extreme temperatures when we don't get enough sleep. Our ability to judge distance is poorer. Some studies even show that we are more likely to remember things that are negative when we are sleep deprived which leads to low levels of motivation and possibly even depression.

Another important component in athletic performance is having enough energy stored in our bodies before we train or compete. When we exercise, our muscles need to contract to make us move. But, our muscles need energy in order for them to contract. In terms of



athletic performance, our muscles need a constant energy supply for as long as possible in order for us to perform our best. The energy we use mainly comes from fats and carbohydrates which are stored in different places in the body.

What this graph shows us, is that we rely on different amounts of carbohydrates and fats depending on how hard we are exercising (higher the % or VO2max the harder the exercise). What you will notice from the graph, is that when we exercise really hard our muscles use a lot of carbohydrates.



One study made athletes train and then gave them either a normal night of sleep or no sleep. The study found that when they got no sleep after training they didn't recover their muscle glycogen (their main carbohydrate storage) as well as when they got the normal night of sleep. That means that sleep loss may lead to poorer energy storage even if you are eating a good diet! The same study also found that after not getting enough sleep the athletes sprint times were worse!

These are just some of the ways in which poor sleep could have a negative effect on your athletic performance!

Sleep stealers

We now know what sleep is, how our body regulates it, and some reasons why it's so important. Now it's time to learn what things might be bad for our sleep!

Artificial light and especially blue light (that is used in the screens of media devices) trick our bodies into thinking it's still daytime. The bright light does two things. Firstly, it makes you feel wide awake and alert. Secondly, the light shifts the timing of our circadian body clock. It delays the body clock and makes it hard to fall asleep until later at night! The content you are looking at can also make you more alert e.g. watching an action movie will be more alerting than reading a book on an e-reader.

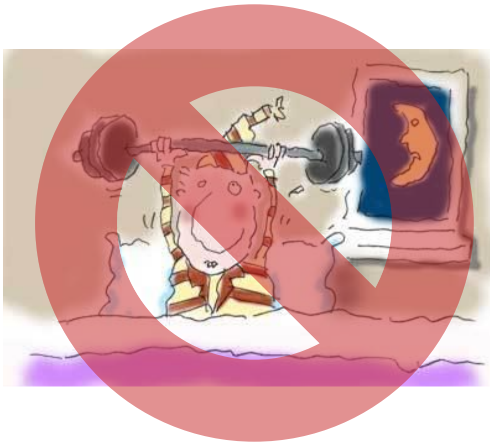
Ideally you should stop using devices that emit bright light at least an hour before bedtime if you want to sleep well (try it for a while and see how you feel!). If you can't turn off your phone, tablet or computer before bedtime for whatever reason, then you should at least try to filter out the blue light (f.lux is an app you can use on any device). There are many things we eat or drink that can also cause sleep issues. Caffeine is one we probably all know about! Caffeine is an ergogenic aid, which means it improves our performance by making us more alert. The problem is, if we make ourselves alert at the wrong time of the day it could mean we mess

up our ability to fall asleep! Ideally, you should avoid having caffeine at least 6 hours before bedtime. Caffeine doesn't mean just coffee. Caffeine is found in all sorts of food and drink. Something you need to be careful about as an athlete is energy drinks or supplements, most of which have caffeine in them. Make sure to check the labels of any sports drinks and supplements you use to check whether they have caffeine and try avoid using ones that do especially if you're using them before or after an afternoon/evening training session.

Some people use certain types of drugs to help them fall asleep, like alcohol or marijuana. One of the problems with these substances (there are lots of other problems that we won't talk about here) is that they stop us getting the normal amount of REM (or dreaming) sleep. Our brain then catches up on the REM sleep it has missed out on once the level of alcohol or marijuana in our body drops. This results in very disturbed sleep.

Other things that can stimulate our bodies and affect sleep include noise, eating too close to bedtime, exercising too close to bedtime and nicotine.

Avoid



Sleep tips

Now we know what we shouldn't do, it's time for what we should do!

- **Try and have a daily routine you stick to!** Our bodies like routine! When possible, try to go to bed and wake up about the same time each day. This can be really hard if you have early morning training but at least try and keep your bedtimes the same each night.

  Having a bedtime routine is also a great way to get your body ready for bed at night.

- **Reading** a book (a real one not on a device!) can be a great addition to your bedtime routine. Reading can relax us and you should read with a warm (yellow) light rather than the blue light from devices.
- **Taking a warm shower** is another good thing to add to a bedtime routine. Our bodies find it hard to go to sleep if it's too hot, in fact, our body temperature drops naturally when our body is preparing to go to sleep. So why a warm shower if our bodies like it cool before bed? Well, the warm water causes something called vasodilation. This is when our blood vessels get wider to allow more blood to flow around the surface of our bodies. Our bodies do this to cool our blood down and to make sure we don't overheat. This happens when we exercise too! When you get out of the shower your blood has moved to the surface and cools down because of the cold air.

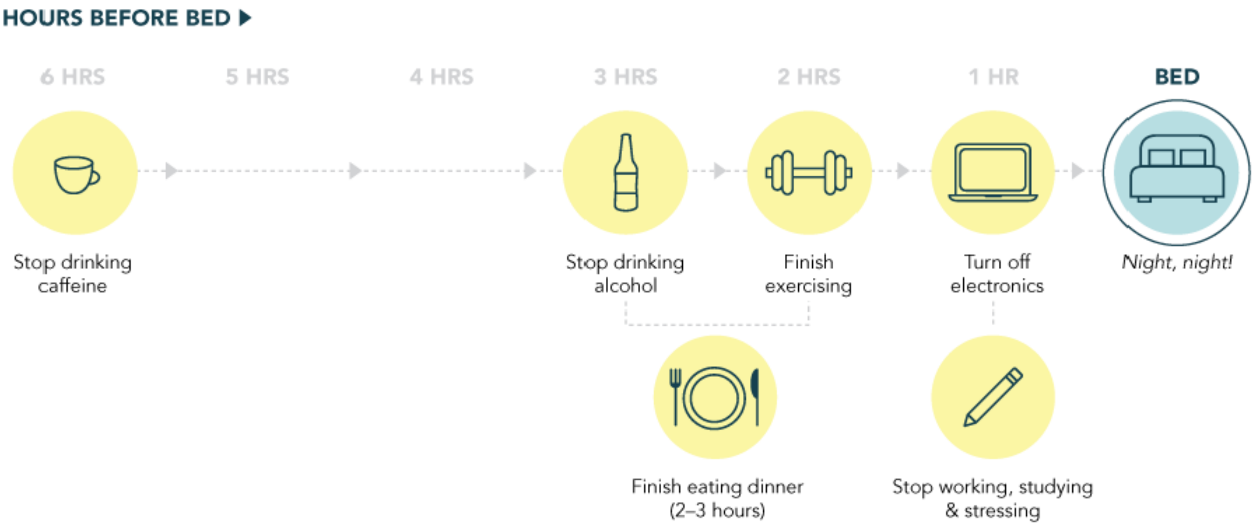
When it circulates around your body your core temperature then drops which gets us primed for sleep! If you took a cold shower, your extremities (arms and legs) would get cold but your blood vessels would constrict (get smaller) stopping cold blood circulation to your core. Your body is a pretty smart cookie!

- **Relaxation techniques** are also a good way to wind down. We really struggle to fall asleep when we are nervous or anxious. That's why athletes sometimes struggle to sleep before competitions! Try and find a nice quiet activity that relaxes you. Again, try and make sure it's not something that involves too much light or noise (Netflix isn't on the approved list!). Some suggestions would be meditation or breathing exercises, journaling or maybe reading as mentioned earlier. Find what works best for you and try adding it to your routine!

- **Avoid going to bed late and oversleeping on weekends!** Catching up on sleep over the weekend can feel like a good thing….until Monday morning hits! If you go to bed late and oversleep or wake up super late on the weekend, you shift the timing of your circadian body clock. When you have to wake up early on Monday morning again your body is out of sync and you can feel even more tired than you did at the end of last week!

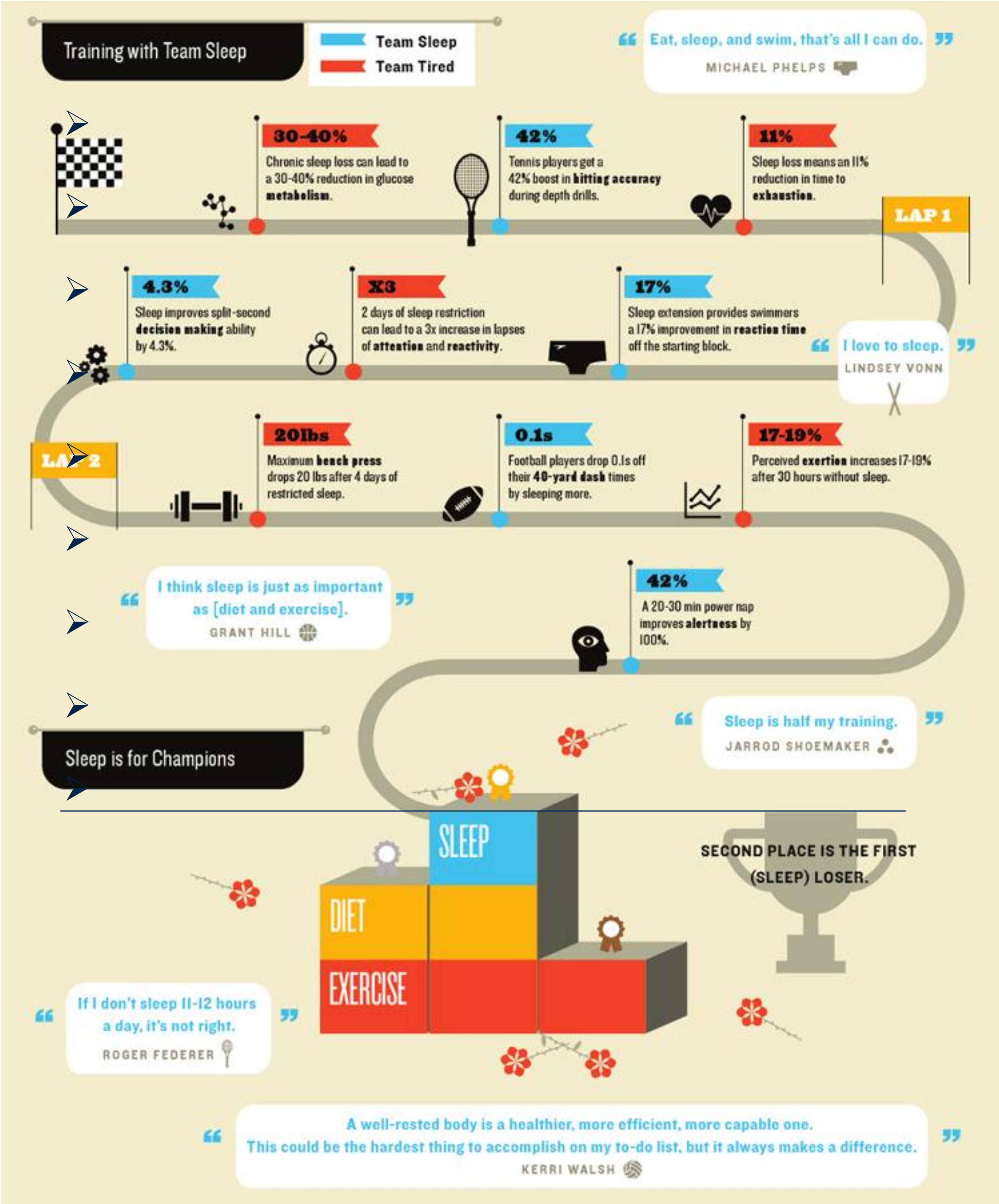
- **Comfy is best!** It might seem obvious, but being comfortable is important for the best sleep possible. Find what sleeping conditions you like the best, do you like a soft, hard or medium mattress? What smells relax you and make you feel at home? What smells are off putting and would bug you? What sort of pillows do you like? Try and find all the little combinations for your bedroom that make you feel like you're in your own little heaven! This could be really important if you're competing away from home. We all struggle the first few nights in a new place. If you have the space, pack your favorite blanky, pillow and anything else that will make you feel a little more at home in a different bed.

- **Afraid of the dark….it's actually your friend!** We already covered that light should be avoided before sleep, but you should also try to make sure your room is as dark as possible when you sleep. Even those little LED lights can be enough of a bother that they can delay falling asleep. Some athletes have reported travelling with blackout tape when they compete to cover lights on hotel TVs or phones. Some tape down curtains where little cracks of light come through. The smallest thing can be really irritating the night before a big race! Consider travelling with eye shades or ear plugs if you struggle with noise and light!



Final thoughts

I hope this booklet has helped you learn more about sleep and given you the motivation and tools to get the sleep you deserve! Remember…training is important for doing your best in your sport, but you can only train properly when you are well rested. Don't sacrifice all your hard work by not recovering properly!



How to keep up to date with science and helpful resources:

- You can follow me on twitter: @TravistyRSA

Other scientists who you should consider following are (there are so many but this is a good start!):

Matt Walker
@sleepdiplomat

Professor of Neuroscience at UC Berkeley; Sleep Scientist at Google; Author: Why We Sleep

California, USA

sleepdiplomat.com

YLMSportScience
@YLMSportScience

Scientific advisor of AS Monaco FC 💡🏆 To find out a snapshot of what is new in Sports Sciences 📊

Monaco / France

YLMSportScience.com

Dr. Amy M. Bender, PhD
@Sleep4Sport

Mom of 3 | Ironman | Bball HOF | Adjunct Kinesiology Prof | Research Scientist on a mission to promote sleep for better health + performance | #sleepwelltowin

Calgary, Alberta, Canada

linkedin.com/in/amy-m-bende...

Some helpful websites to visit are:

https://sleepfoundation.org/

https://www.sleephealthfoundation.org.au/

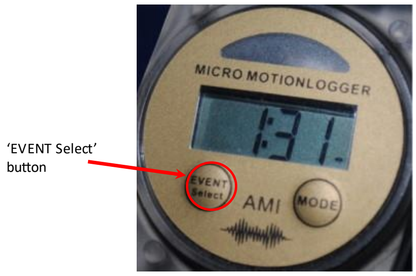
APPENDIX 5 SLEEP DIARY INSTRUCTIONS

SLEEP/TRAINING DIARY INSTRUCTIONS

INFORMATION ABOUT WEARING THE ACTIGRAPH

The small watch-sized object you will be wearing on your wrist is an actigraph. It contains an accelerometer and memory chip and records movement. The data from the actigraph is analysed along with the information from the sleep diary to determine sleep duration.

1. Wear the actigraph on your non-dominant wrist (the hand you don't write with). It is important that you do not change wrists as this may change the information that we get from the actigraph.
2. The actigraph should be attached reasonably firmly so that it does not move about on your wrist. If it does move about, tighten the strap slightly.
3. The actigraph must be removed for any contact with water (e.g. showering, swimming), but it is important that you put it back on again afterwards.
4. If you take the actigraph off for any reason (for showering, to take a swim etc) then please note this in your sleep diary.
5. If you forget to put the actigraph back on at any stage then put it on as soon as you remember. Please write in the diary the time when you put the actigraph back on.
6. **We cannot tell what you are doing from the actigraphy data. We can only tell whether you are moving or not.**
7. On the front of the actigraph there are two small buttons. The left one, labelled 'EVENT Select', is the event marker. If you push this, a small mark will appear on the data output. It does not stop or start the actigraph. The actigraph will keep recording the entire time you are wearing it.
8. We would like you to push the event marker when you start trying to sleep and again when you stop trying to sleep. Please do this whenever you intend to sleep for **10 minutes or longer**.



INFORMATION ABOUT COMPLETING THE SLEEP/TRAINING DIARY

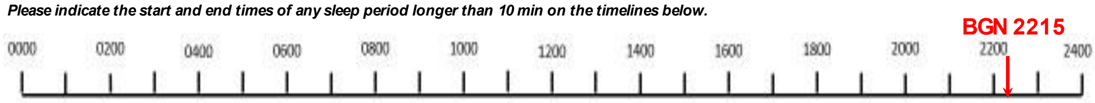
Information about filling out the sleep/training diary

1. We are interested in **any** sleep that is 10 minutes or longer. It does not matter whether this is during the day or during the night.
2. The information that is important to us is the times that you **begin trying to sleep** and when you **finish trying to sleep** for any sleep that is **10 minutes or longer.**
3. **Record all times in local time, using the 24-hour clock.**
4. When you are about to **begin trying to sleep:**
   a. Mark the time on the timeline with an arrow and record the time above/below it.
   b. Beginning (BGN) is the time when you begin trying to sleep. Some people may get into bed and read etc, but we do not need to know this, we only need to know when you begin trying to go to sleep.
5. When you have **finished trying to sleep:**
   a. Mark the time on the timeline with an arrow and record the time above/below it.
   b. Finished (FSH) is when you wake up and are no longer trying to sleep. At this time you may either get out of bed or begin to read etc, but you are no longer trying to sleep.
6. **Beginning** and **Finish** are the times we would like you to push the event marker on the actigraph.
7. If you wake up during your sleep to get a drink, go to the toilet etc, you do not need to write anything in the duty/sleep diary. If you get up for **more than 10 minutes** then please treat any later sleep as a new sleep period.

Below is an example of a completed timeline. 'FSH' indicates the time the participant woke up on that day while the 'BGN' indicates the time that the participant went to bed that day. Times are written next to the arrows to provide more accurate bed and wake up times.

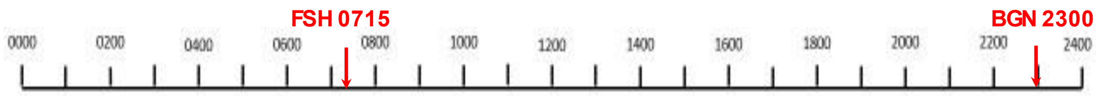
Date: 10 / 02 / 2018

Please indicate the start and end times of any sleep period longer than 10 min on the timelines below.



Date: 11 / 02 / 2018

Please indicate the start and end times of any sleep period longer than 10 min on the timelines below.



Information about filling out the sleep/training diary

1. The following section should be completed as soon as possible after you wake up in the morning.
2. The first question has to do with whether you used an electronic device 1 hour before bed the night before. There is no right or wrong answer, just be honest!

Did you use electronic devices 1 hour before bed? ☒ Yes ☐ No

1. We would like you to rate the quality of the sleep you have just woken up from. Clearly mark or indicate the phrase that most fits your sleep quality:

	1 - Very, very good	2 - Very good	3 - Good	4 - Average	5 - Bad	6 - Very bad	7 - Very, very bad
Sleep Quality			X				

1. Next, kindly mark how stressed you are feeling in your general life. This might include stress from school, training, competition, personal relationships etc.

	1 - Very, very low	2 - Very low	3 - Low	4 - Average	5 - High	6 - Very high	7 - Very, very high
Stress				X			

1. The third scale we would like you to fill out is how fatigued you feel. Do you feel tired? Does your body feel weak? This is where you would tell us that!

	1 - Very, very low	2 - Very low	3 - Low	4 - Average	5 - High	6 - Very high	7 - Very, very high
Fatique		X					

1. And the final scale you are being asked to fill out has to do with how sore your muscles are. Please indicate how much pain you feel.

	1 - Very, very low	2 - Very low	3 - Low	4 - Average	5 - High	6 - Very high	7 - Very, very high
Muscle Soreness						X	

1. The last thing we ask you fill out on your daily diary is a comment section. This section is where you can tell us how you slept, how training is going

Comments: **Had really weird dreams last night and couldn't fall asleep after that. But I felt really strong during training today! Broke my personal best!**

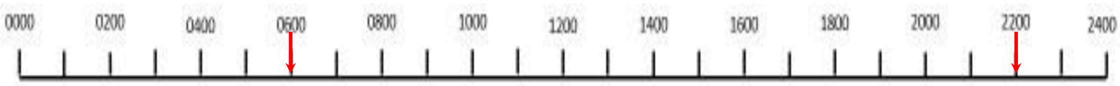
FULL EXAMPLE

Sleep diary

Date: 01/ 02 / 2018

Please indicate the start and end times of any sleep period longer than 10 min on the timelines below.

FSH 0600 BGN 2200



Did you use electronic devices 1 hour before bed? Yes ☐ No ☒

Cross out the most relevant response.

Sleep Quality	1 - Very, very good	2 - Very good	3 - Good	4 - Average	5 - Bad X	6 - Very bad	7 - Very, very bad
Stress	1 - Very, very low	2 - Very low	3 - Low	4 - Average X	5 - High	6 - Very high	7 - Very, very high
Fatique	1 - Very, very low	2 - Very low	3 - Low X	4 - Average	5 - High	6 - Very high	7 - Very, very high
Muscle Soreness	1 - Very, very low	2 - Very low	3 - Low	4 - Average	5 - High X	6 - Very high	7 - Very, very high

Comments: Think I am getting ill. I have a sore throat.

APPENDIX 6 INFORMATION LETTERS FOR SWIMMERS

Pilot interventions aimed at improving the sleep/wake patterns of junior rowers -

ATHLETE INFORMATION SHEET

Introduction

- This is a follow-on study looking at sleep interventions in junior athletes.
- The aim of this study is find out about junior rowers' sleep and rowing performance.
- You are at a stage in your life where your body naturally wants to go to sleep later and wake up later.
- Science tells us that your early morning training schedules and social lives might be cutting your sleep short. This can affect your health and may affect your ability to do your best in your sport.
- Our plan is to teach you some more about sleep and to see if we can improve your sleep by getting you to either wear blue light blocking glasses at night or by taking part in a goal setting exercise.

Project Description

- We will monitor your sleep for eight weeks. To do this, you will need to fill in a daily sleep diary and wear an actigraph (a small watch that measures how much you move).
- Your performance will be measured by timing you in ergometer time trials. You will need to do a 2km time trial once every two weeks (three time trials over the eight weeks).
- The eight-week study will be broken up into four time periods. The first two weeks will be during your normal training.
- The next four weeks (the intervention period) will be after we teach you about sleep. You will either be given a pair of blue light blocking glasses or asked to take part in a goal setting exercise for the intervention.
- After the intervention period will be the week of Maadi cup where we want to measure your sleep during competition.
- Finally, we also want to measure your sleep during the week after Maadi to see how your sleep changes during recovery from competition.
- A researcher will run two sessions to teach you about sleep during the project that you must attend. The first one will be at the start of the intervention period. At this session you will receive a 'sleep information' booklet. The second will be half way through the intervention period.
- You will be put into one of two groups, either in a blue light blocking glasses group or a goal setting group. The glasses group will be asked to wear glasses that limit the amount of blue light you see in the 2 hours before bed each night. The goal setting group will be asked to complete some questions that are aimed to motivate you to make changes to your sleep behaviour.
- Your sleep and performance measures will be compared before and after you learn more about sleep and go through the intervention.

Participant Recruitment

- You may be invited to participate in the study after hearing about it from your coach or your parents.
- **Taking part in the study is your choice and no one can force you to be involved. Deciding to participate will have no impact on your selection for future competitions.**
- You can only take part in the study if you:
  - ✓ Are between (and including) the ages of 13 and 18.
  - ✓ Have been chosen to compete or have competed in a national level rowing competition.
  - ✓ Row for a club that has agreed to take part in this study (ask your coach if you aren't sure).
  - ✓ Will be available to attend all the required intervention sessions.
  - ✓ Are not injured at the time of recruitment and attend 90% of their weekly training sessions.
  - ✓ Have not been diagnosed with a sleep or mood disorder.
  - ✓ Are not taking medication known to effect sleep. For example, sleeping tablets; some cold and flu medications; certain pain medications containing caffeine; antihistamines etc.
  - ✓ Non-smokers

Project Procedures

- If you would like to take part in this study, you and your parents (if you are younger than 16 years of age) will have to give written consent using the form provided with this information sheet.
- All information you provide will be confidential. The research team (the people named at the bottom of this page) will give you a participant identification number that will be attached to all your data. During your data collection, we will use your name and your contact details (including phone and email) to stay in touch with you. Once you have finished data collection we will delete your contact information and only keep your participant ID number.

If you decide to participate, you will be asked to do the following:

Sleep measures

- You will need to fill in a questionnaire that will take about 15 minutes. The questionnaire collects basic information about: you (age, gender, information about your usual sleep and rowing, and contact details); whether you meet all the criteria for being in the study.
- You will meet with a researcher who will give you an actigraph, and a sleep diary and explain how to use them (photo of actigraph shown below). The sleep diary will also include a questionnaire to tell whether you are a morning or an evening person (your 'chronotype').
- You will need to wear the actigraph continuously (except when you are in contact with water for a long time, like during rowing or taking a bath/shower) and complete the sleep diary every day for 8 weeks.

- ➢ The actigraph is the size of a watch and is worn on your non-dominant wrist. It measures movement, light, temperature of the actigraph case (to detect when it is worn), and keeps track of when you press a button (you're asked to press this when you get into and out of bed). The actigraph does not collect any other information and cannot tell the researchers what you are doing. It cannot transmit data until it is handed back to the researchers. When you return the actigraph, the information is analysed with a computer program to say when and for how long you have slept. The sleep diary asks when you try to sleep, how often you wake, and has space for you to rate how well you slept and any important notes, such as when you took the watch off.

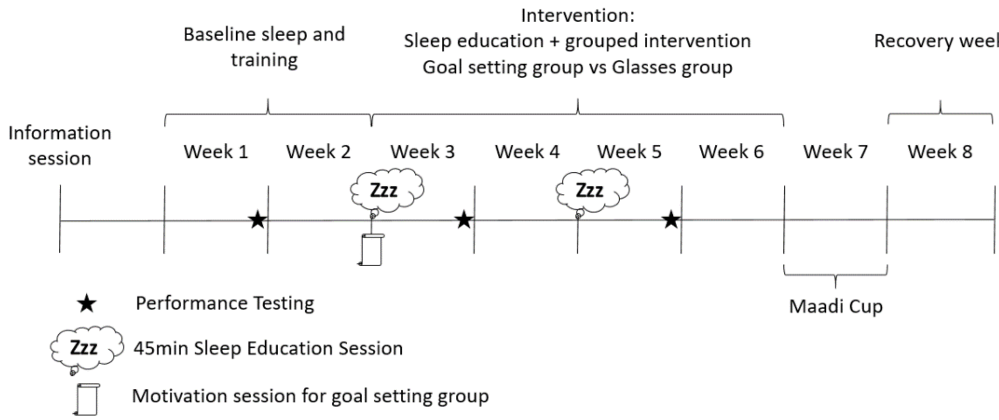
- Every week you will receive a phone call, text, or email message from a researcher to check to see if you have any questions or need help with the study.

Intervention

- You will need to come to a session on sleep that your parents are also invited to attend. It will be a 45-minute talk where you will learn more about sleep, why it is important for your health and rowing performance, and ways to help improve your sleep.
- You will receive a sleep information booklet to keep. It will have the information from the lesson plus some extra details.
- Two weeks into the intervention, you will have to come to another session with the researcher. At this session, the group will get feedback on everyone's usual sleep. You will also get feedback on your own sleep (but this will not be shared with the group). At this session, you can also tell the researcher how the study is going and if you have any problems.
- After two weeks in the study, you will be put in one of two groups. The one group will get blue light blocking glasses to wear each night before bed. The other group will do a goal setting program where you will do a writing exercise for 60-minutes. Both of these interventions are designed to help your sleep. You will also be given the intervention of the other group that you were not in once the study is over. This means that you won't miss out even if one is found to be better than the other!

Performance measures

- You will need to do three 2km time trials at training during the study.
- You will do your 2km time trial the same time of day and on the same day of the week each time.
- If you normally have something to eat before morning training please do so. We would like you to eat your usual breakfast and to do the same on all performance measure days.
- Before each time trial, your coach will take you through a warm-up to get you ready (the warm-up your coach would normally do with you before a real race).
- Your trial time will be taken and your performance will be compared over the weeks you are in the study. You will also be asked how your body feels (called a rating of perceived exertion) after your warm up and after your race.



Data Management

- Your sleep and performance information will be analysed by researchers from the Sleep/Wake Research Centre.
- The data from this study may be compared to previous study's results.
- None of the information collected will have your name attached to it. Instead, it will be labelled with an identification number. Your individual information will only be given to you and no one else will have access to your information without your permission. No information that could personally identify you will be used in any reports on the study.
- The findings of the study will be published in scientific papers and presentations and as part of Travis Steenekemp's doctoral thesis. You will receive a summary of the findings of the study and have access to this on the Sleep/Wake Research Centre website.
- You have the right to ask that any of your information only be used by the current study and not again in the future.
- All data will be stored in secure facilities at the Sleep/Wake Research Centre, Massey University. The signed consent form will be kept for 5 years then destroyed. Hard copy data will be kept for 10 years after the study has been completed then securely destroyed. Digital data (labelled with ID numbers only) will be kept for 10 years, or until you ask us to delete it. If you want us to delete your data, you will need to remember your participant ID number since it will not be labelled with your name.

Risks, Inconveniences, and Benefits

Risks. Taking part in physical training always involves the risk of injury. The study has been designed to try make sure that you are not asked to do more or less physical training than you would usually do in a week. Major increases or decreases in training, or when you are asked to do something you are not used to doing, are typically the most likely times for getting injured. For this reason, the performance test you will be asked to do is a rowing time trial. Being a competitive rower, your body should be used to the stress a rowing time trial would put on it.

Inconveniences. Wearing the actigraph might feel uncomfortable at times. There is a chance that the watch might irritate you, especially at night if you do not usually wear a watch while you sleep. There is also a chance that the watch might irritate your skin. If this happens, let the researcher know as soon as possible. Filling in the sleep diary will take a few minutes each day across the 8-week study. The diary has been kept as short as possible to make it quick and easy for you to use.

Benefits. By being a part of this study, you will add to what we know about the sleep of junior rowers. You will also have the chance to learn more about how your body works. You will learn about how you sleep, why sleep is important and how sleep is linked to athletic performance. After the study you will be offered the intervention that you were not a part of. Once you are finished with the study, you will get feedback on your own results (e.g., to see a chart of your sleep during the entire study). To identify your data, you will need to remember and give the researchers your participant identification number.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Participant's Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study at any time and take your data;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used in reports (a participant ID number is used instead) ;

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 18/86. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone + 646 356 9099 x 85094, email humanethicsoutha@massey.ac.nz .

Project Contacts

If you have any questions about this project, please do not hesitate to contact the researcher:

Travis Steenekamp T.Steenekamp@massey.ac.nz [redacted]

This study is being undertaken as part of the researcher's PhD. You may contact the project supervisors if you have any questions or issues with the study:

Primary supervisor: Associate Professor Leigh Signal **T.L.Signal@massey.ac.nz**

Co-supervisor: Dr Jennifer Zaslona J.Zaslona@massey.ac.nz

Co-supervisor: Professor David Rowlands D.S.Rowlands@massey.ac.nz

Co-supervisor: Professor Philippa Gander P.H.Gander@massey.ac.nz

APPENDIX 7 STATEMENTS OF CONTRIBUTION FOR CHAPTER 3-6

DRC 16

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Travis Steenekamp
Name/title of Primary Supervisor:	Prof Leigh Signal

In which chapter is the manuscript /published work: Chapter 3

Please select one of the following three options:

(●) The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

Steenekamp, T., Zaslona, J., Gander, P., Rowlands, D., & Signal, T. L. (2021). Sleep/wake behaviour of competitive adolescent athletes in New Zealand: insight into the impact of early morning training. Sleep Medicine, 77, 88-95. https://doi.org/10.1016/j.sleep.2020.11.023

( ) The manuscript is currently under review for publication – please indicate:

- The name of the journal:

- The percentage of the manuscript/published work that was contributed by the candidate: 80.00

- Describe the contribution that the candidate has made to the manuscript/published work:

CRediT author statement
Travis Steenekamp: Conceptualization, Methodology, Software, Formal Analysis, Writing - Original Draft, Writing - Review & Editing, Visualization
Jennifer Zaslona: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Supervision
David Rowlands: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing, Supervision
Philippa Gander: Conceptualization, Methodology, Writing - Review & Editing, Supervision
Leigh Signal: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing, Supervision

( ) It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Travis Steenekamp
Date:	30-Oct-2022
Primary Supervisor's Signature:	[signature]
Date:	31-Oct-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

GRS Version 5 – 13 December 2019
DRC 19/09/10

DRC 16

MASSEY UNIVERSITY TE KUNENGA KI PŪREHUROA UNIVERSITY OF NEW ZEALAND | GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Travis Steenekamp
Name/title of Primary Supervisor:	Prof Leigh Signal
In which chapter is the manuscript /published work:	Chapter 4

Please select one of the following three options:

◯ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

◯ The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate: 80.00
- Describe the contribution that the candidate has made to the manuscript/published work:

CRediT author statement
Travis Steenekamp: Conceptualization, Methodology, Software, Formal Analysis, Writing - Original Draft, Writing - Review & Editing, Visualization
Jennifer Zaslona: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Supervision
David Rowlands: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing, Supervision
Philippa Gander: Conceptualization, Methodology, Writing - Review & Editing, Supervision
Leigh Signal: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing, Supervision

◉ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Travis Steenekamp
Date:	30-Oct-2022
Primary Supervisor's Signature:	[signature]
Date:	31-Oct-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

GRS Version 5 – 13 December 2019
DRC 19/09/10

DRC 16

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Travis Steenekamp
Name/title of Primary Supervisor:	Prof Leigh Signal
In which chapter is the manuscript /published work:	Chapter 5

Please select one of the following three options:

○ The manuscript/published work is published or in press

- Please provide the full reference of the Research Output:

○ The manuscript is currently under review for publication – please indicate:

- The name of the journal:
- The percentage of the manuscript/published work that was contributed by the candidate: 75.00
- Describe the contribution that the candidate has made to the manuscript/published work:

CRediT author statement
Travis Steenekamp: Conceptualization, Methodology, Software, Formal Analysis, Writing - Original Draft, Writing - Review & Editing, Visualization
Jennifer Zaslona: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Supervision
David Rowlands: Conceptualization, Methodology, Formal analysis, Writing - Review & Editing, Supervision
Philippa Gander: Conceptualization, Methodology, Writing - Review & Editing, Supervision
Leigh Signal: Conceptualization, Methodology, Writing - Original Draft, Writing - Review & Editing, Supervision

◉ It is intended that the manuscript will be published, but it has not yet been submitted to a journal

Candidate's Signature:	Travis Steenekamp
Date:	30-Oct-2022
Primary Supervisor's Signature:	[signature]
Date:	31-Oct-2022

This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis.

GRS Version 5 – 13 December 2019
DRC 19/09/10