Sink or swim? Sleep in highly trained adolescent swimmers during the in-season phase of training

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Abstract

Sleep is vital to the physiological and cognitive functioning in humans, however, disruption to sleep is a growing issue. Requirements of training in high performing adolescent athletes is increasing but it is largely unknown what effect this has upon their sleep. Extra-curricular activities such as sport, music, and part-time work are all contributing factors to the sleep disturbances adolescents' experience. Until now, limited research has been available on high performing adolescent athletes sleep as most research has focused on sleep in elite adult athletes. Research to date has illustrated that elite adult athletes experience disruptions to their sleep due to training and competitions which subsequently impacts their recovery, performance and fatigue. The few studies to investigate adolescent athletes have found that sleep has significant effects on injury occurrence, academic performance, mental health, and obesity, as discussed in the literature review in the first chapter of this thesis. Furthermore, through the limited previous research, it has been found that adolescent athletes sleep is disrupted on nights preceding early morning training sessions. The second chapter of this thesis includes an original study investigating the sleep of highly trained adolescent swimmers. Fifteen adolescent swimmers volunteered to participate in this study, where their sleep was measured via subjective and objective measures over a two-week 'normal' in-season training phase. Participants subjectively recorded their total sleep time (TST), sleep latency (SL), and wake episodes (WE) through a daily sleep diary. In conjunction, objective sleep indices (TST, SL, WE, total time in bed (TTB), wake after sleep onset (WASO), sleep efficiency (SE), sleep onset time (SOT), and wake time (WT) were measured through a wrist actigraph device. Analysis revealed that participants significantly overestimated their sleep duration by approximately one hour per night compared to their objective TST. Furthermore, on evenings preceding early morning training (EARLY), participants TST and TTB was significantly less compared to nights preceding day trainings (DAY) and rest days (REST). Finally, the third chapter of this thesis summarises the overall findings of the thesis, as well as highlighting practical applications, and potential future research directions.

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Abbreviations

- TST – Total Sleep Time
- TTB – Total Time in Bed
- SL – Sleep Latency
- SE – Sleep Efficiency
- WASO – Wake After Sleep Onset
- WT – Wake Time
- SOT – Sleep Onset Time
- WE – Wake Episodes Per Night
- ASBQ – Athlete Sleep Behaviour Questionnaire
- SHI – Sleep Hygiene Index
- ESS – Epworth Sleepiness Scale
- PSQI – Pittsburgh Sleep Quality Index
- ASSQ – Athlete Sleep Screening Questionnaire
- EARLY – Pre 7am training
- DAY – Post 7am day training
- REST – Day with no training
- PSG – Polysomnography
- BMI – Body Mass Index
- h – hour
- min – minutes
- h:min – hours:minutes
- AASM – American Academy of Sleep Medicine
- REM – Rapid-Eye Movement
- NREM – Non-Rapid-Eye Movement

Thesis Organisation

The current thesis comprises of three chapters. Chapter One presents a review of the literature on the physiology of sleep, the importance of sleep, and the sleep disruptions and issues experienced by adolescent athletes. Chapter Two details an original study investigating the sleeping patterns of highly trained adolescent swimmers, comparing their subjective (perceived) and objective (wrist actigraphy) measures of sleep. This chapter is formatted in the required style of journal it was submitted to *The Journal of Sport and Exercise Science,* and consequently some information throughout the thesis may be repeated. Chapter Three provides a summary of the overall findings, along with practical applications, limitations and recommendations for future research.

Chapter One: Literature Review

Introduction

Disruption to sleep behaviour is becoming an increasing issue in the athletic population, with the added demand of training loads causing further disruption (Fullagar, Skorski, et al., 2015; Watson & Brickson, 2018). Sleep is considered to be a fundamental aspect for recovery in athletes (Leeder et al., 2012). Subsequently, if optimal sleep is not achieved it can then have significant impacts upon training and competition performance, motivation, perception of effort and cognition (Halson, 2014a). Sleep is also vital for adolescents as there are many factors that influence their sleep/wake cycle, most commonly known is their delayed circadian rhythm due to three (biological, psychological and socio-cultural) contributing factors (Carskadon, 2011; Carskadon et al., 1993; Crowley et al., 2007; Garcia et al., 2001; Watson et al., 2017). Therefore, sleep quality and quantity are important factors for adolescent's health and wellbeing including their cognitive and physical health (Leeder et al., 2012; Moore & Meltzer, 2008; Park, 2011; Sarchiapone et al., 2014).

A major factor impacting adolescents sleep behaviour is their involvement in various extra-curricular activities, such as, part-time work, sport, music lessons and social lives which makes it challenging to achieve the later sleep offset required (Carskadon et al., 1998; Copenhaver & Diamond, 2017; Moore & Meltzer, 2008; Suppiah et al., 2015; Watson et al., 2017). In particular many adolescents are heavily involved in sporting activities which increases the need for quality sleep hygiene practices and schedules. With training requirements for adolescent athletes increasing such as high training loads, early/late trainings and competitions, sleep disturbances are occurring more commonly in this population (Copenhaver & Diamond, 2017; Ng et al., 2009). Therefore, the purpose of this review is to provide a background on the role of sleep, the importance of sleep in the athletic population and the effect that training, and performance requirements have on sleep. Furthermore, providing a background on the role of sleep behaviours for adolescents and more specifically adolescent athletes. A secondary aim is to review the different ways of measuring sleep behaviours in the adolescent athlete population.

Sleep Physiology

The circadian rhythm is the 24-hour internal clock of a human's body that has to be reset every 24 hours, and in most adults the circadian rhythm follows the same patterns (Aschoff, 1998; Beersma & Gordijn, 2007; Zee et al., 2013). Many physiological variables are influenced by the circadian rhythm in humans, but most commonly known is the duration and timing of the sleep and wake cycle (Aschoff, 1998). Sleep in America Polls (2018, 2020) reported that only 10% of adults prioritise sleep over other aspects of daily living including physical fitness, work, and hobbies, and 72% reported feeling sleepy between two and seven days per week. If the recommended 7-8 hours of sleep per night is not obtained by adults, abnormal sleep/wake cycles may occur (National Sleep Foundation, 2014; Paruthi et al., 2016), with the potential to result in sleep disorders such as; insomnia, sleep apnoea, sleep disordered breathing, restless leg syndrome, and REM sleep-behaviour disorder (Crowley, 2011; Zee et al., 2013). Insomnia can be associated with an abnormal timing of the biological clock resulting in an impairment of daytime functioning often diagnosed after one month of difficulty falling asleep (Crowley, 2011; Zee et al., 2013). Furthermore, reduced daytime functioning can cause a lack of concentration, decrease in memory, poor attention and slower reaction times (Halson, 2014b). Crowley (2011) also reports that sleep apnoea can result in poor quality sleep, oxygen desaturation and excessive daytime sleepiness. While disruption to sleep can be a result of many factors, the current literature demonstrates the importance of sleep and the value in following sleep recommendations for overall health and wellbeing.

In comparison to adults, adolescents experience a delayed circadian rhythm due to varying factors including biological, psychological and socio-cultural influences. It is primarily a change in the biologic timing mechanism that causes a delay in sleep onset (Carskadon et al., 1993). A review by Garcia et al. (2001) showed that adolescents experienced a half hour longer prolonged circadian period (25 hours) compared to the general population (24.5 hours). The prolonged circadian period caused delayed sleep onset in adolescents and was found to be a result of biological factors including pubertal stage and phase delay (Garcia et al., 2001). Several other studies report that there is a delay in the sleep/wake cycle of adolescents mainly occurring because of biological maturational processes. Data from Carskadon et al. (1993) identifies adolescents who had higher puberty scores (were further developed) resulted in a significantly later bedtime on weekdays due to their preferred later phase during pubertal maturation. Carskadon and colleagues (1993) research suggest that there may be a potential link between melatonin to circadian rhythms and maturational processes. Furthermore, Giannotti et al. (2002) suggests that there is a link between circadian rhythms and pubertal timing throughout pubertal development due to melatonin secretion. Melatonin is the hormone naturally produced by the pineal gland in the brain which is then released into the bloodstream to help initiate sleep onset (Arendt, 2000; Zhdanova & Tucci, 2003). The pineal gland is prompted by darkness to start producing melatonin, whilst production is stopped when light is present. Evidence has shown that the phase delay of melatonin secretion is significantly correlated with maturation ($r = .62$) and age ($r = .62$) (Carskadon et al., 1997; Giannotti et al., 2002). Therefore, a 'healthy' night of sleep for adolescents has been recommended to be 8-10 hours for optimal functioning (Paruthi et al., 2016; Watson et al., 2017).

Elite athletes also experience differing sleep behaviours to the general population and with the training requirements of this population steadily increasing, sleep is being recognised as essential for recovery due to the psychological and physiological functions that occur during sleep (Nedelec et al., 2018). Sleep is divided into two stages, non-rapid eye movement (NREM) and rapid eye movement (REM) to comprise of approximately 90-120 minutes sleep which humans continuously cycle through throughout the night (Fullagar, Duffield, et al., 2015). NREM sleep is further divided into four stages where during stages three and four, slow wave (deep) sleep occurs and it is thought that physiological growth and repair peaks during this slow wave sleep due to metabolic activity being at its lowest point (Venter, 2012). During NREM sleep the body is also actively repairing and restoring itself due to the release of growth hormone, which is vital to recovery in athletes as more than 95% of growth hormone is released during NREM sleep (Gunning, 2001; Venter, 2012). The release of growth hormone influences athletic recovery as muscle growth, repair, and bone building are all vital for recovery following strenuous exercise (O'Donnell et al., 2018a).

NREM sleep is followed by REM sleep where the brain begins to reactivate, and cognitive restoration occurs (Belenky et al., 2003; Hobson, 2005). Often known as 'dream sleep' (the stage where dreams occur), it is thought that REM sleep forms 20-25% of adults sleep each night (Venter, 2012). Whilst in REM sleep, periodic brain activation, localised recuperative processes and emotional regulation take part (Fullagar, Skorski, et al., 2015). REM sleep is thought to be important for memory consolidation and is therefore important when learning new complex techniques or tactics and when new motor skills are being acquired (Venter, 2012). Both physiological and psychological recovery after exercise can be impaired by disturbances to the timing of sleep phases or the quality and duration of sleep within NREM and REM sleep phases (Samuels, 2008). Therefore, sleep plays a vital role in ensuring athletes are fully recovered and performance ready for both trainings and competitions (Copenhaver & Diamond, 2017; Leeder et al., 2012; Sargent, Lastella, et al., 2014).

Measuring Sleep in Adolescent Athletes

Polysomnography

Polysomnography (PSG) is an objective measure considered the "gold standard" for measuring sleep architecture, sleep indices and diagnosing sleep disorders in humans (Halson, 2014a; Meltzer et al., 2012). Electrodes attached to the skin on the scalp monitor brain activity (electroencephalogram), eye movements (electrooculogram), muscle activity (electromyogram), and cardiac activity (electrocardiogram) (Halson, 2014a). However, several factors such as the large financial costs, only providing 1-2 nights worth of sleep information, and an insufficient number of sleep labs being prepared to test young people (Meltzer et al., 2012), means using PSG in children and adolescent populations is difficult and limiting. It therefore makes it an impracticable option to measure sleep in adolescents. PSG may also not be the preferred option of measuring sleep in athletes. While PSG is useful in suspected sleep disorder research, athletes already experience many stressors and anxiety in their lives so minimising this and monitoring sleep through less invasive strategies would be the preferred option (Halson, 2019). However, if a medical sleep disorder is suspected it is recommended that athletes should be referred to a sleep physician for more in depth monitoring (Halson, 2019). Measuring sleep through PSG is also highly impracticable for athletes in the sport setting due to the sleep laboratory requirements not being the same as their usual sleep environments, making it difficult to draw conclusions in this population (O'Donnell et al., 2018a).

Actigraphy

A commonly used objective method for assessing sleep is through an actigraph wrist-watch device. Actigraphy is a much less invasive and more accessible strategy compared to PSG (Short et al., 2012). Sleep and wake is measured through the detection of movement the actigraph device picks up over a period of time (Short et al., 2012). Actigraphy devices main measurements of sleep include: total sleep time (TST), total time in bed (TTB), sleep efficiency (SE), number of wake episodes per night (WE), wake after sleep onset (WASO), sleep latency (SL), sleep onset time (SOT) and wake time (WT) (Table 4.) (Halson, 2014a; O'Donnell et al., 2018a). Research has shown that actigraphy can provide reliable, important information in good sleeping populations but it should not replace PSG (Ancoli-Israel et al., 2003; Sadeh, 2011). A study by Driller et al. (2016) showed the Readiband actigraph device to have high levels of intra-device reliability. However, due to the inaccurate measurement of time at lights out, caution should be taken when using sleep latency, sleep efficiency, and wake after sleep onset results from actigraph devices, as it was reported to significantly underestimate or overestimate depending on the indices compared to PSG (Dunican et al., 2017).

Table 1. Definitions of each sleep variable measured through wrist-actigraphy. Adapted from M. Driller, J. McQuillan, and S. O'Donnell, 2016.\.

Sleep Indices	**Units**	**Description**
Total Sleep Time (TST)	Minutes	Total time spent asleep
Sleep Efficiency (SE)	%	Total time in bed divided by total sleep time
Total Time in Bed (TTB)	Minutes	Total time spent in bed
Sleep Latency (SL)	Minutes	Time taken for sleep onset
Wake Episodes per Night (WE)	Number count	Total number of awakenings per night
Sleep Onset Variance (SOV)	Minutes	Sleep onset consistency relative to mean
Wake Variance (WV)	Minutes	Wake time consistency relative to mean
Wake Episode Duration (WED)	Minutes	Mean wake episode duration
Sleep Onset Time (SOT)	Time of day	Time of transition from wakefulness into sleep
Wake Time (WT)	Time of day	Wake up time for the sleep period
Wake After Sleep Onset (WASO)	Minutes	Time spent awake after sleep onset per night

A study by Short et al. (2012) evaluated 385 perceived sleep patterns between sleep diaries and an actigraph device. Sleep diary estimates of both WASO and TST were substantially less than what the actigraphy device reported (Short et al., 2012). Furthermore, a study by de Zambotti et al. (2015) found that in 65 adolescents, a night time fitness tracker showed good agreement with PSG for TST, SE and WASO. Actigraphy devices provide a cost-effective alternative to

PSG and allow for sleep monitoring to occur in a person's own sleep environment, making it a more practical option.

Sleep Diaries and Questionnaires

Sleep diaries and sleep questionnaires are both subjective measures recorded or filled out by individuals to give their perception of sleep quality and quantity, which can then be evaluated. In regards to sleep diaries, a study by Short et al. (2013) investigated the comparison of 308 adolescents' individually recorded sleep diaries to the data of an actigraph device over a seven day period. Adolescents significantly estimated their bedtimes earlier than they were, had later wake up times on weekends, and significantly overestimated how much sleep they were obtaining (Short et al., 2013). Similarly, a study by Wolfson et al. (2003) evaluated the validity of the Sleep Habits Survey of 302 adolescents, discovering that the sleep estimates adolescents gave in the survey were similar to sleep diary and actigraph measures. While sleep diaries are an affordable, accessible option to evaluate sleep, caution should be taken when interpreting the results, and where possible, using actigraph devices in combination with sleep diaries to improve the accuracy of the results.

There are a variety of sleep questionnaires and surveys used in sleep research including but not limited to, the Pittsburgh Sleep Quality Index (PSQI), which assesses sleep quality and disturbances over a one month period to give a global score relating to overall sleep quality (Buysse et al., 1989); the Epworth Sleepiness Scale (ESS), which provides a measurement for general daytime sleepiness rated on a scale of 0-3 for eight everyday different activities (Johns, 1991); and the Sleep Hygiene Index (SHI), which is a 13 question self-administered questionnaire that assesses sleep behaviour and habits thought to compromise sleep hygiene (Mastin et al., 2006). These three questionnaires have been commonly used in sleep research, but it has been suggested that these are not specific to athletes and the unique challenges they experience. However, two recent questionnaires have been developed that are representative of the challenges and environments experienced by athletes and thus the impacts these have on their sleep (O'Donnell et al., 2018a). These are the Athlete Sleep Behaviour Questionnaire (ASBQ), which is an 18 question questionnaire that focuses on the specific challenges to the sleeping behaviours of athletes (Driller et al., 2018); and the Athlete Sleep Screening Questionnaire (ASSQ), which has 15 questions used to assess athletes sleep in four critical domains (TST, insomnia, sleep quality, and chronotype) (Samuels et al., 2016). It would be advantageous for sport practitioners working with athletes to use the ASBQ and ASSQ questionnaires specifically designed for athletes as the situations experienced are unique to this population (Driller et al., 2018; Samuels et al., 2016). These questionnaires include questions relating to the use of stimulants for training/competition, traveling for sport, training/competing late at night, and thinking/worrying about sporting performance in bed, all of which relate specifically to athletes. Sleep questionnaires and surveys are also widely used amongst sleep research in adolescents due to them being accessible and easy for participants to use.

Finally, a point of interest in sleep monitoring is the lack of agreement between the quality of the PSQI and the 'gold-standard' PSG, despite subjective sleep measures such as the PSQI being quick and easy to use (Landry et al., 2015). Dunican and colleagues (2017) assessment of sleep efficiency in actigraphs showed that the devices overestimated sleep efficiency by 13%. Therefore, it can be difficult to quantify the quality of sleep in both subjective and objective monitoring tools (Dunican et al., 2017; Landry et al., 2015) and caution is recommended when using the term sleep quality.

Table 2. Studies examining sleep measures in adolescents

Study	Subjects (*n*)	Topic	Population	Results
Arora et al. (2013)	225	Actigraphy vs. self-reported	Adolescents (11-13 years)	Self-reported TST = acceptable agreement with actigraphy
de Zambotti et al. (2015)	65	Actigraphy vs. PSG	Healthy adolescents (15.8 ± 2.5 years)	Actigraph = good agreement with PSG for TST & WASO
Lee and Sibley (2019)	58	Actigraphy vs. PSG	Adolescents (15-19 years)	Wearables comparable to actigraphs but not PSG
Meltzer et al. (2012)	115	PSG in adolescents	Youth (3-18 years)	Actigraph = good sensitivity but poor specificity compared to PSG
Short et al. (2012)	385	Actigraphy vs. self-reported	Adolescents (13-18 years)	TST ↓ & WASO increased in actigraph compared to perceived[#]
Wolfson et al. (2003)	302	Perceived vs. actual sleep	High school students (ANP)	Survey = valid compared to diaries & actigraphy

Notes: ↓ = decrease. [#]Statistically significant (p<0.05).
Abbreviations: PSG, polysomnography; TST, total sleep time; WASO, wake after sleep onset; ANP, age not provided

Importance of Sleep

Importance of Sleep for Athletes

Poor sleep behaviours are common in athletes and research has shown that athletes experience poorer sleep than the general population, especially those competing at higher levels (Andrade et al., 2019; Leeder et al., 2012; Mah et al., 2018). A review by Gupta et al. (2017) analysed a range of sleep indices attributed to sleep quality of elite athletes and concluded that high levels of sleep disturbance (longer sleep latencies, greater sleep fragmentation, non-restorative sleep, and excessive daytime fatigue) are commonly experienced by elite athletes. Leeder et al. (2012) also studied the sleeping patterns of 46 elite Great British national squad members from a variety of sports and found that although athletes appear to get similar sleep quantity to the general population, all other variables (time in bed, sleep latency, time awake, sleep efficiency, actual sleep percentage, moving minutes, percentage moving time, and fragmentation index) suggest that the disruption to sleep indices is much worse than that of the general population (sleep latency: 18.2 minutes in athletes vs. 5.0 minutes in control; time awake: 1:17 h:min in athletes vs. 0:50 h:min in control; sleep efficiency: 80.6% in athletes vs. 88.7% in control). A study by Mah et al. (2018) investigated the sleeping patterns of 628 collegiate athletes, finding that 42.4% of athletes experienced poor sleep quality. It was also found that 51% reported high levels of daytime sleepiness, while 39.1% of the athletes received less than seven hours of sleep on weeknights (Mah et al., 2018). Similar findings by Knufinke and colleagues (2018) showed that 41% of all athletes (98) could be classified as 'poor sleepers'. Another study that investigated the sleep complaints of 146 Olympic athletes found that 53% of all athletes reported a sleep complaint of some form, with insufficient sleep/waking up tired accounting for the most amount of complaints (32%), followed by snoring (21%), insomnia (19.2%), and excessive daytime sleepiness (8.8%) (Silva et al., 2019). Furthermore, a study by Andrade et al. (2019) found that of 1041 adult athletes, those who competed at an international level were 84% more likely to have poorer sleep compared to those who only competed at a regional level. The findings from the previous research highlights the prevalence of poor sleep behaviours in athletes, therefore warranting the need for continual research in this area.

Fatigue is also another result of poor sleep in athletes (Halson, 2014a; Sargent, Halson, et al., 2014). A study by Sargent and colleagues (2014) focused on 70 nationally ranked athletes, reporting that higher levels of pre-training fatigue were associated with shorter sleep durations

(p = 0.02). Similarly, a study by Dickinson and Hanrahan (2009) looked at 59 elite athlete scholarship holders from the Queensland Academy of Sport and the Australian Institute of Sport, and found that although athletes obtained a good quantity of sleep they were still affected by fatigue during the day which could be a result of poor sleep. Sleep is an essential part of reducing fatigue in elite athletes (Robson-Ansley et al., 2009). By increasing good sleep behaviours, the research has shown that fatigue can be largely eliminated (Dement, 2005; Derman et al., 1997).

Importance of Sleep in Adolescents

Academic Performance

Adolescents are often involved in numerous extra-curricular activities outside their regular school hours including sports, music, clubs and part-time work which may have an impact on their sleep. Early school start times require adolescents to wake up earlier, but it does not account for the delayed sleep/wake schedule that adolescents experience. Due to their delayed circadian rhythm it has been reported that many adolescents struggle to fall asleep before 11pm but despite needing to sleep till 7:30am or later, school start times do not allow for the later sleep offset (Watson et al., 2017). Therefore, the American Academy of Sleep Medicine (AASM) suggests school start times of 8:30am or later to allow adolescents to obtain enough sleep on school nights (Watson et al., 2017). A study by Wolfson et al. (2007) found that of 205 middle school students, the 129 students who started school later (8:37am) receiving 65 minutes more sleep on school nights, were academically advantaged compared to their peers who started school at an earlier time (7:15am). However, the results from this study only reported significance for grade 8 students, not grade 7 students, furthermore it was found that those students who were also athletes missed their last period of school due to sports trainings. Therefore, it is hard to draw conclusions as the results from the study were not a true representation of all middle school aged students and it is possible that athletes who missed their last period of school may be disadvantaged in their academic grades due to missing out on class time. Moreover, a study by Wahlstrom (2002) offers support to Wolfson and colleagues research, as they found that high school students with a later start time (8:40am) reported significantly less daytime sleepiness, less struggle to stay awake in class, less sleepiness while doing homework as well as significantly better attendance and less depressive feelings, resulting in a slight increase but non-significant in academic performance compared to students with an earlier school start time (7:15am). Similarly, Carrell et al. (2011) looked at the data of 6156 first year students at the United States Air Force Academy and found that, although not significant, students who were randomly assigned to a first period class performed worse and had lower academic performance throughout the day compared to those who did not have a first period class. Edwards' (2012) findings also suggest that a delay in school start time would increase academic performance. Delaying school start times by one hour leads to a three percentile point gain in both math and reading scores, which remained when re tested two years later (Edwards, 2012). As shown through the previous research, the conflicting results reported due to differing methods between the studies, make it difficult to draw definitive conclusions on how sleep impacts academic performance. Therefore, future research is warranted in this area, particularly for academic performance on later school start times where students were given the opportunity to sleep in but also complete a whole day at school.

Physical and Mental Health

Adolescents who obtain the recommended amount of sleep (8-10 hours) also have more positive associations with health promoting behaviours (Chen et al., 2006). Poor sleep in adolescents can also be linked to obesity (Beebe et al., 2013), poor diet choices (Beebe et al., 2013; Chen et al., 2006), severe mental health problems (Fredriksen et al., 2004; Sarchiapone et al., 2014), low mental toughness (Brand et al., 2014), pain (Palermo et al., 2007), violence (Hildenbrand et al., 2013), and a variety of sleep disorders (Yen et al., 2008). Furthermore, the likelihood of obesity occurring in adolescents increases by 6.5% when a one hour decrease in sleep occurs (Park, 2011). The increased risk of obesity occurs as foods with a higher glycemic index are more likely to be consumed when sleep restriction occurs (Beebe et al., 2013). Park (2011) analysed the survey data of 73,836 Korean adolescents finding that body mass index (BMI) was highest amongst those who slept less than five hours per night and was lowest in those who slept more than eight hours per night. Moreover, severe mental health problems may also be a result of a lack of sleep occurring in adolescents (Sarchiapone et al., 2014). A study by Sarchiapone et al. (2014) found that there was a negative correlation between mental health (emotional problems, hyperactivity, anxiety problems and suicidal ideations) and the average number of hours sleep adolescents were gaining per night. Similarly, a study by Zhang et al. (2017) reported that later bedtimes and shorter sleep duration in adolescents resulted in the likelihood of an increase in anxiety, behavioural disorders, suicidality and poor perceived mental health. Alternatively, Fuligni et al. (2018) found that adolescents who achieved 8.75-9 hours of sleep on a school night were at their peak mental health. Although a generalisation, research in this review has shown that adolescents may be at a higher risk of physical and mental health issues due to the disruption of sleep they experience, largely because of the busy lifestyles they have.

Electronic Device Usage

Over the last 10 years there has also been an increase in the use of electronic light-emitting devices amongst the adolescent population (Galland et al., 2020; Gamble et al., 2014; Twenge et al., 2017). In 2014 it was reported that over 70% of adolescents had two or more electronic devices in their room at night (Gamble et al., 2014), whilst in 2020 more than 84% of adolescents used at least one device on three or more nights per week (Galland et al., 2017). It has been reported that 35% of adolescents who use an electronic device for at least one hour per day, sleep less than 7 hours per night (Twenge et al., 2017). While it is known that increased device usage can be associated with shortened sleep duration (Mazzer et al., 2018), it is still unclear on the effect device usage has amongst adolescent athletes. A study by Figueiro and Overington (2015) found that a one and two hour exposure to light from self-luminous devices (computers, tablets, and cell phones) supresses melatonin in adolescents by 23% and 28% respectively. Similarly, a study by Chang et al. (2015) found that the use of electronic light-emitting devices suppressed evening levels of melatonin by 20% in adults. It is still unclear whether exposure to electronic light-emitting devices further supresses melatonin in adolescents, however, it has been reported that adolescents are more sensitive to light in the evening compared to other populations (Nagare et al., 2018) which could cause further disruption to sleep. Given the increase in electronic device usage observed in this population, it is important that research on electronic device usage is undertaken in the adolescent athlete population to understand the effects this may have on their sleep behaviour.

Table 3. Studies examining the importance of sleep in adolescents

Study	Subjects (*n*)	Topic	Population	Results
Beebe et al. (2013)	41	Obesity & poor diet choices	Typically developing adolescents (14-16 years)	Sleep restriction = ↑ sweet food consumption[#]
Brand et al. (2014)	92	MT	Adolescents (18.26 ± 4.17 years)	Low MT = ↓ SE, WASO & ↑ daytime sleepiness[#]
Cabré-Riera et al. (2019)	258	Device usage	Spanish adolescents (17-18 years)	↑ device usage = ↓ SE sleep quality & ↑ WASO[#]
Carrell et al. (2011)	6,156	AP	First year US Airforce Academy Students (ANP)	Earlier start times = ↓ AP[#]
Chen et al. (2006)	656	Health promoting behaviours, poor diet choices	Adolescents (13-18 years)	↓ sleep = ↓ health & ↑ poor diet choices[#]
de Sousa et al. (2007)	58	Sleep hygiene	Brazilian adolescent students (15.98 ± 0.93 years)	Sleep hygiene = ↓ sleep irregularity & SL[#]
Díaz-Morales and Escribano (2015)	796	Bedtime, social jet lag & AP	Adolescents (12-16 years)	Social jet lag negatively related to academic achievement & cognitive abilities[#]
Edwards (2012)	-	AP	Middle school students (ANP)	Later start time = ↑ AP[#]
Escribano et al. (2012)	1,133	AP	Spanish adolescents (12-16 years)	↑ sleep = ↑ AP[#]
Figueiro and Overington (2015)	20	Device usage/melatonin suppression	Adolescents (15-17 years)	↑ device usage = supressed melatonin levels[#]
Fredriksen et al. (2004)	2,259	Mental health	Students (11-14 years)	↓ sleep over time = ↑ depressive symptoms & ↓ self-esteem[#]
Fuligni et al. (2018)	421	Mental health	Mexican-American adolescents (15.03 ± 0.83 years)	↑ sleep = ↑ mental health[#]
Galland et al. (2020)	4,192	Device usage	New Zealand adolescents (13-17 years)	↑ device usage = ↓ sleep duration[#]
Gamble et al. (2014)	1,184	Device usage	Australian adolescents (11-17 years)	Device usage before bed = ↑ delayed SOT & WT
Hildenbrand et al. (2013)	14,782	Violence	Adolescents (ANP)	↓ sleep = ↑ violence-related behaviours
Mireku et al. (2019)	6,616	Device usage	UK adolescents (11-12 years)	Device usage = ↓ sleep duration

Ng et al. (2009)	59	AP	Hong Kong students (16-18 years)	↓ sleep = ↓ mathematics performance[#]
Palermo et al. (2007)	40	Pain	Adolescents (12-17 years)	Chronic pain = ↓ sleep quality & SE, ↑ insomnia & WASO
Park (2011)	73,836	Obesity	Korean adolescents (12-18 years)	BMI highest in those who slept less than 5h per night[#]
Peiró-Velert et al. (2014)	3,095	Device usage & AP	Spanish adolescents (12-18 years)	↑ sleep & ↓ device usage = ↑ AP[#]
Sarchiapone et al. (2014)	11,788	Mental health	European adolescents (14.9 ± 0.9 years)	↓ sleep = ↑ emotional problems, hyperactivity, anxiety & suicidal ideations[#]
Wahlstrom (2002)	12.000	AP	Secondary school students (ANP)	Later start time = ↑ AP
Wolfson et al. (2007)	205	AP	Middle school students (ANP)	↑ sleep = ↑ academic advantage
Yen et al. (2008)	8,004	Sleep disorders	Taiwanese adolescent students (ANP)	↓ sleep = ↑ insomnia

Notes: ↑ = increase and ↓ = decrease. [#]Statistically significant ($p<0.05$).
Abbreviations: MT, mental toughness; SE, sleep efficiency; WASO, wake after sleep onset; AP, academic performance; SL, sleep latency; SOT, sleep onset time; WT, wake time; h, hours; ANP, age not provided

Importance of Sleep for Adolescent Athletes

At present the majority of sleep research in the athletic field setting has focused on the elite or highly trained adult population, with few studies investigating the importance of sleep in the adolescent athlete population. The few studies that have explored sleep in adolescents have primarily focused on sleep deprivation and its relationship to injury occurrence (Copenhaver & Diamond, 2017; Luke et al., 2011; Milewski et al., 2014; von Rosen et al., 2017b). A study by Milewski et al. (2014) investigated the association of injury rates to sleep duration retrospectively in 112 adolescent athletes. Results showed that athletes who slept less than 8 hours per night on average were 1.7 times more likely to have had an injury compared to those who slept more than 8 hours per night. Similarly, von Rosen et al. (2017b) found that adolescents who on average had more than 8 hours sleep per night reduced the chance of obtaining a new injury by 61%.

Shortened sleep duration and inconsistent sleeping patterns have been found amongst adolescent swimmers and rowers (Gudmundsdottir, 2020; Steenekamp et al., 2020). A study involving 108 adolescent Icelandic swimmers found that total sleep time (TST) was significantly shorter on nights preceding early morning training (5:21 h:min) compared with later training or no training (6:37 h:min and 6:53 h:min respectively) (Gudmundsdottir, 2020). Research by Steenekamp et al. (2020) supports this, also finding that for nights where early morning training occurred, the next day sleep duration was significantly less (6:44 h:min) compared to no early morning training (8:45 h:min). Sleep onset time (SOT) was also significantly earlier for nights with morning training the preceding day during the week (10:13pm) compared with a night preceding a weekend morning off (11:31pm) (Steenekamp et al., 2020).

It has been recommended that adolescent athletes should not spend more hours per week than their age playing sport, to avoid early specialisation (Murray, 2017). However, despite this recommendation, sports such as gymnastics and swimming can be considered as early specialisation sports, with research showing 15 year old gymnasts averaged 14.7 hours per week (ranged 8.5 to 20 hours) , and 15 year old swimmers averaged over 13 hours (ranged 3.5 to 22.5 hours) (Maffulli et al., 1994). In comparison, 15 to 16 year old track and field athletes averaged less than the age recommended amount of sport of 7.3 hours per week (Huxley et al., 2014). However, due to the early specialisation in some sports and increased training loads, there can be negative effects such as fatigue, bad moods, soreness and most significantly the potential shortening of adolescents athletic careers (Murray, 2017; Watson & Brickson, 2018).

Table 4. Studies examining the importance of sleep in adolescent athletes

Study	**Subjects (*n*)**	**Topic**	**Population**	**Results**
Brown et al. (2020)	12	Training day sleep	Adolescent academy football players (14.18 ± 1.36 years)	Time attempted to fall asleep & time of sleep worse on days with evening training#
Gerber et al. (2018)	257	Athlete burnout	Swiss young elite athletes (16.8 ± 1.4 years)	↑ emotional/physical exhaustion = ↑ burnout symptoms at follow-up
Gomes et al. (2017)	309	Psychological symptoms	Adolescent athletes (10-19 years)	Poor sleep = ↑ stress/anxiety & depression#
Gudmundsdottir (2020)	108	Shortened sleep duration & sleep in adolescent swimmers	Icelandic adolescent swimmers (ANP)	TST ↓ when early morning training occurred#
Kölling et al. (2016)	55	Sleep/wake patterns during camp	Junior national rowers (17.7 ± 0.6 years)	↑ training volume & intensity = ↓ sleep#
Luke et al. (2011)	360	Injury	Adolescent athletes (6-18 years)	↓ sleep = ↑ fatigue related injuries#
Milewski et al. (2014)	112	Injury	Student athletes (12-18 years)	Less than 8h sleep = ↑ injury occurrence#
Sawczuk et al. (2018)	52	Training load	Youth athletes (16-18 years)	Daily wellbeing = no relationship with training load
Steenekamp et al. (2020)	32	Sleep in adolescent swimmers & rowers	Adolescent swimmers & rowers (13-18 years)	TST ↓ when early morning training occurred#
Suppiah et al. (2015)	11	Sleep & different intensities of sport	Singaporean male adolescent athletes (14.8 ± 0.9 years)	Higher-intensity sports = ↑ deep sleep & WT#
Suppiah et al. (2016)	29	Psychomotor performance	High-level student athletes (14.7 ± 1.3 years)	↓ sleep duration = ↓ psychomotor vigilance performance#
von Rosen et al. (2017a)	496	Injury	Elite adolescent athletes (15-19 years)	↑ training load & ↓ sleep = ↑ injury risk#
von Rosen et al. (2017b)	340	Injury	Elite adolescent athletes	Sleep longer than 8h = ↓ odds of injury#
von Rosen et al. (2019)	1016	Health	Elite & non-elite adolescent athletes (17.0 ± 1.0 years)	Elite athletes = ↓ stress & ↑ sleep compared to non-elite athletes#
Watson and Brickson (2019)	52	Specialised athletes	Youth female soccer players (13-18 years)	Specialised athletes had worse fatigue, mood, soreness & sleep quality#

Notes: ↑ = increase and ↓ = decrease. #Statistically significant (p<0.05).
Abbreviations: TST, total sleep time; WT, wake time; h, hours; ANP, age not provided

Training, Competition and Rest Day Requirements

Training Day

As previously mentioned, training loads in athletes are increasing and research is showing that this can have significant impacts on sleep (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018; Roberts et al., 2019; Sargent, Lastella, et al., 2014). A study by Sargent and colleagues (2014) discovered that for 70 nationally ranked athletes on nights prior to training days, athletes time spent in bed (8:18 h:min) and the amount of sleep they obtained (6:30 h:min) was significantly less than on rest days (8:42 h:min and 6:48 h:min respectively). It has also been found that when acute training loads were increased in 65 female soccer players, was shown to have negative effects on wellbeing (fatigue, mood, stress and soreness) due to a reduction in sleep duration (Watson & Brickson, 2018). Interestingly, when sleep duration increased but training loads stayed the same these factors were positively influenced (Watson & Brickson, 2018).

In regards to swimmers, it is widely known that they are required to get up early for training sessions (Gudmundsdottir, 2020; Sargent, Halson, et al., 2014; Steenekamp et al., 2020). A study by Sargent and colleagues (2014) assessed the sleep of seven world-class swimmers, finding that over a two week period 12 out of 14 days started with a training session at 6am and each swimmer only had two rest days. Subsequently, sleep duration was significantly less on the nights that preceded a training day compared to a rest day (5.4 hours vs. 7.1 hours respectively). Similarly, Forndran et al. (2012) measured the sleep of ten Olympic swimmers and found that on training sessions that started before 6am athletes time in bed (7.7 hours) and sleep duration (5.4 hours) were significantly less and wake time (5:18am) was significantly earlier compared to training sessions that started after 6am which were broken down into three categories of 6am to 9am (8.2 hours, 6.1 hours, and 6:06am respectively), 9am to 12pm (9.3 hours, 7.4 hours, and 7:06am respectively), >12pm (9 hours, 6.9 hours, and 7:06am respectively) and rest days (8.2 hours, 6.5 hours, and 7:30am respectively). It was also discovered that athletes training schedules were the main influence of their sleep/wake behaviours. Moreover, Gudmundsdottir (2020) found that adolescent athletes who had three or more early morning trainings a week had significantly less sleep than those who did not participate in early morning training. It has been reported that early morning training restricts the amount of sleep an athlete can obtain causing large amounts of sleep debt largely due to athletes spending less time in bed, allowing for less sleep duration which in turn causes poorer sleep efficiency (Sargent, Halson, et al., 2014). In order to alleviate sleep debt many athletes use napping strategies (Petit et al., 2014) which can result in improved performance and recovery (Davies et al., 2010; O'Donnell et al., 2018b). For the most effective nap duration it is recommended that naps should last less than 20 minutes to avoid waking up in slow-wave sleep, or for 90 minutes so a full sleep cycle (NREM and REM) can be completed (Davies et al., 2010; Petit et al., 2014). While previous research highlights the benefit of napping for athletes including improved athletic performance, it is unlikely that adolescent athletes are able to achieve naps due to daily school requirements (Copenhaver & Diamond, 2017). Therefore, many adolescent swimmers for example, may incur large amounts of sleep debt due to early morning trainings, high training loads and the inability to nap during the day.

Competition Day

Athletes experience extreme pressure during competitions, often resulting in poor sleep the night before and the night of big competitions (Biggins et al., 2020; Juliff et al., 2015; Juliff et al., 2018; O'Donnell et al., 2018c). A study by Biggins et al. (2020) discovered that 23% of athletes (65) were found to have either a moderate or severe clinically significant sleep problem during competition, whilst Juliff et al. (2015) found that 64% of athletes (283) indicated on at least one instance in the nights prior to competition they experienced worse sleep. The main sleep issue athletes reported having was difficulty falling asleep (82.1%), while the main reason for poor sleep was caused by thoughts about the competition and nervousness making up 83.5% and 43.8% respectively (Juliff et al., 2015). Similar findings by O'Donnell et al. (2018c) found that in ten elite netballers sleep duration from both perceived and objective measures was reduced by 1:42 h:min and 1:51 h:min respectively, on nights when a game occurred compared to the night before a game. The results observed were most likely observed due to the change in sleep onset time (11:57pm and 10:41pm respectively). Many athletes are required to travel for competitions and are often sleeping in different environments. Pitchford and colleagues (2017) assessed the sleep of 19 Australian rules football players across an eight day camp away from home. It was found that athletes sleep efficiency was considerably worse (84.7% vs. 78.7%) when away from their home sleeping environments (Pitchford et al., 2017). Athletes who have to travel overseas are also at risk of experiencing jet lag due to the rapid travel across multiple time zones and their circadian rhythms being out of synch with the local day/night cycle (Lee & Galvez, 2012). However, for adolescents it is not likely or less often that they experience the effects of jet lag and foreign sleeping environments.

For many athletes competition days are very demanding, especially for sports that require multiple events to be performed in one day, such as swimming for example. Most swim meets run for between two and eight days, consisting of two sessions per day (approximately two hours long each). At larger, national and international swim meets, competition days consist of a heat and a finals session where athletes are expected to race events in the morning and come back in the evening to race the same event again (Goodman, 2021). It is very common for heats sessions to be earlier in the morning, especially with the warm-up required, and for finals sessions to be late in the evening, often for TV viewing (Arshat, n.d.; Fullagar, Duffield, et al., 2015; Goodman, 2021). Adolescent athletes who compete at pinnacle competitions for the first time or who may not have experienced jet lag before, may be more at risk of experiencing impaired sleep due to the change of sleeping schedules and environments.

Rest Day

It is known that athletes experience a significant difference in sleep on training days compared to rest days (Forndran et al., 2012; Sargent, Halson, et al., 2014). It has also been shown that adolescent athletes experience similar sleeping patterns where sleep is significantly longer on rest days compared to days where early morning training occurs (Steenekamp et al., 2020). In regards to adolescents in particular, it has been shown that sleeping patterns vary greatly from weekend to weekday, due to school start times that require adolescents to wake up earlier, often causing a disruption to their sleep/wake cycle (Andrade & Menna-Barreto, 2002; Carskadon et al., 1998; Giannotti et al., 2002; Orzech, 2013; Wahlstrom, 2002; Yang et al., 2005). However, with no mandatory wake up times on weekends, adolescents get between one and two hours of additional sleep due to the extra time available (Andrade & Menna-Barreto, 2002; Yang et al., 2005). While it is recommended for sleep hygiene (Fullagar et al., 2016; O'Donnell & Driller, 2017) that similar sleep routines are maintained (maintain consistent sleep onset and wake times), many adolescents experience inconsistent sleep routines due to the varying sleep/wake times from weekdays to weekends, thus causing a potential impact on adolescents sleep indices (de Sousa et al., 2007; Malone, 2011).

Table 5. Studies examining training, competition and rest days of adolescent and elite athletes

Study	Subjects (*n*)	Type of Day	Fitness Level	Results
Biggins et al. (2020)	65	Competition	Elite international athletes	Sleep disturbance = ↓ health &↑ mood#
Brown et al. (2020)	12	Training	Adolescent football players	Time attempted to fall asleep & time of sleep worse on days with evening training#
Forndran et al. (2012)	10	Training	Olympic swimmers	Training <6am = ↓ TST, TTB & WT#
Gudmundsdottir (2020)	108	Training	Icelandic adolescent swimmers	Early morning training = ↓ TST#
Juliff et al. (2015)	283	Competition	Elite Australian athletes	↓ sleep prior to competitions#
Knufinke, Nieuwenhuys, Geurts, Møst, et al. (2018)	98	Training day load	Elite athletes	NS
O'Donnell et al. (2018c)	10	Competition	Elite female netballers	PSD, TST, TTB & SOT effected by competition#
Pitchford et al. (2017)	19	Training camp	Elite Australian rules football players	Sleep quality ↓ as TTB ↑ but TST did not#
Romyn et al. (2016)	8	Competition vs. training	State netball players	Competition = ↑ SE & earlier SOT & WT compared to training
Sanz-Milone et al. (2021)	8	Competition	Wheelchair rugby athletes	Competition = ↓ TST, SE & ↑ WASO
Sargent, Halson, et al. (2014)	70	Training/rest	Nationally ranked athletes	TST, TTB ↓ & SOT & WT earlier on training compared to rest days#
Sargent, Lastella, et al. (2014)	7	Training/rest	National swimmers	TST, TTB ↓ & SOT & WT earlier on training compared to rest days#
Sargent and Roach (2016)	22	Competition	Professional male Australian rules football players	Sleep after competition = ↓ TST, TTB & ↑ SOT
Skein et al. (2013)	11	Competition	Amateur rugby league players	↓ sleep = ↓ recovery after competition#
Steenekamp et al. (2020)	32	Training	Adolescent swimmers & rowers	Early morning training = ↓ TST & WT was earlier#
Watson and Brickson (2018)	65	Training	Adolescent female football players	↓ TST & ↑ training load = impairment of well-being#

Notes: ↑ = increase and ↓ = decrease. #Statistically significant (p<0.05).
Abbreviations: TST, total sleep time; TTB, total time in bed; WT, wake time; NS, non-significant; PSD, perceived sleep duration; SOT, sleep onset time; WASO, wake after sleep onset

Conclusion

The current review shows the complex relationship between sleep behaviours and adolescent athletes, highlighting the multiple factors that can impact adolescents' sleep. The current review has highlighted that the previous sleep research on athletes has mainly been completed in adult athlete populations and focused on the factors that impact sleep indices in adult athletes. Previous research illustrates that the biological delay in the circadian rhythm causes a delay to adolescents' sleep/wake schedules. Poor sleep behaviours in adolescents can result in severe mental health issues, obesity and an array of sleep disorders. Furthermore, both adult and adolescent athletes have reduced sleep duration due to higher volumes of training, and swimmers in particular are at higher risks of reduced sleep due to early morning training sessions. Early morning training sessions also result in a difference of sleep durations between weekdays and weekends in athletes to ensure they are ready for both training and competitions.

The current review has highlighted that at present, research into adolescent athletes' sleep is very limited. Given the fact that sleep provides a pivotal role in facilitating the recovery process through a number of both psychologically and physiologically functions, a greater understanding of the sleeping behaviours of adolescent athletes is needed. It is hypothesised that findings in the original study in Chapter Two, will show that adolescent athletes will have similar sleep behaviours and impairment to sleep indices as reported in elite adult athletes and that less sleep will occur on nights prior to early morning training sessions.

Chapter Two: Original Study

Sink or swim? Sleep in highly trained adolescent swimmers during the in-season phase of training

This chapter appears in the same format as required for submission to *The Journal of Sport and Exercise Science*

Abstract

Introduction: The training requirements in high performing adolescent athletes is increasing, however, it is largely unknown what effect this has upon their sleep. The aim of this study was to investigate the sleeping patterns of highly trained adolescent swimmers and compare their subjective (perceived) and objective (wrist actigraphy) measures of sleep.

Methods: 15 swimmers (mean age 16.4 ± 1.0 years) wore wrist actigraphs, whilst completing sleep diaries over a two-week ‘normal’ in-season training period. Types of nights were classified as early morning training (EARLY), day training (DAY), and no training (REST).

Results: Total sleep time (TST) was significantly shorter on nights preceding EARLY (6:55 ± 0:50 h:min) compared to nights preceding DAY (9:06 ± 1:01 h:min) and REST (9:43 ± 1:41 h:min). Participants overestimated subjective TST (7:42 ± 0:42 h:min) when compared to objective TST (6:48 ± 0:42 h:min), whilst sleep latency (SL) and wake episodes (WE) were also perceived to be significantly less than objectively-measured values.

Discussion: Early morning training decreased adolescents sleep by over two hours, whilst adolescents overestimated their sleep duration by approximately one hour per night. Sleep hygiene education may be required for adolescent athletes to emphasise the importance of sleep on recovery and performance.

Introduction

Poor sleep is a chronic issue in the general population and it has become common to see reports of adults sleeping less than seven hours per night (Lee & Sibley, 2019; Sheehan et al., 2018). In addition to the increasing issues with poor sleep in the general population, recent research has also revealed that short sleep duration may be an issue in elite athletes (Fullagar, Skorski, et al., 2015; Halson, 2008). Current research in elite athletes has shown that sleep disruption has been found to have a negative effect on athletic performance characteristics including speed (Skein et al., 2011), endurance (Oliver et al., 2009) attention (Simpson et al., 2017) and aerobic capacity (Teece et al., 2021). Sleep is vital to elite athletes' physical and cognitive recovery including but not limited to their daily physiological growth and repair, conservation of energy and reaction time (Leeder et al., 2012; Venter, 2012). It appears that adolescents may also be susceptible to poor sleep habits, with reports that 39% of adolescents in New Zealand obtain less than 7 hours sleep per night (Galland et al., 2020), less than the recommended 8-10 hours for optimal health and performance in adolescents (Paruthi et al., 2016). Adolescent athletes in particular, experience high levels of sleep disturbance due to increased academic and sporting training demands, often requiring early wake up times and late night training sessions to fit in with school schedules (Brown et al., 2020; Gudmundsdottir, 2020; Steenekamp et al., 2020). Adolescents experience a delayed circadian rhythm due to many varying factors including biological, psychological and socio-cultural influences (Carskadon, 2011). Sleep onset and offset is usually much later in adolescents, and while social influences have some effect upon delayed sleeping patterns, it is primarily a change in the biological timing mechanism that causes a delay in sleep onset (Carskadon et al., 1993). The change is mainly due to their pubertal development and the delay in the production of melatonin that they experience (Carskadon et al., 1993; Garcia et al., 2001). Compared to the general population, adolescents experience ~30 minutes longer circadian period, 25 hours for adolescents vs. 24.5 for the general population (Garcia et al., 2001).

Increased device usage before bedtime may also have some effect on the delayed sleep onset adolescents experience. A recent study by Galland et al. (2020) showed that more than 84% of adolescents used at least one device on three or more nights per week. Previous research has also shown that exposure to device usage before be supresses melatonin in adolescents (Figueiro & Overington, 2015). The hormone melatonin, contributes to the initiation of sleep in the circadian system through environmental cues (Escames et al., 2012). However, while it is known that shortened sleep duration can be associated with increased device usage, it is still unclear the effects device usage has on adolescents sleep indices (Mazzer et al., 2018). With the delayed sleep onset experienced by adolescents, sleep offset must also be later to cater for the delayed sleep/wake cycle, allowing adequate sleep quantity. However, due to growing demands, such as earlier school starts, extra-curricular activities, and part-time work, it often does not allow for the later sleep offset that adolescents require (Carskadon et al., 1998; Copenhaver & Diamond, 2017; Moore & Meltzer, 2008; Suppiah et al., 2015; Watson et al., 2017). Much of the research on adolescent sleeping behaviour has shown that earlier school start times can have a significant effect on academic performance (Carrell et al., 2011; Kelley & Lee, 2014; Wahlstrom, 2002; Watson et al., 2017). Previous research has also shown that sleep deprivation has been related to injury occurrence in adolescent athletes (Copenhaver & Diamond, 2017; Milewski et al., 2014; von Rosen et al., 2017b). A study by Milewski et al. (2014) in 112 adolescent athletes found that athletes who slept less than 8 hours per night on average were 1.7 times more likely to have had an injury compared to those who slept more than 8 hours per night which highlights the need for adolescent athletes to obtain the recommended 8-10 hours' sleep every night (Milewski et al., 2014; von Rosen et al., 2017b; Watson et al., 2017).

Furthermore, the research to date has shown that periods of sustained sleep loss could potentially compromise the recovery process, as less sleep restricts the opportunity for important physiological and cognitive benefits that occur during the sleep cycles (Skein et al., 2013). An important part of recovery for adolescent athletes is the production of growth hormone, as 95% of daily growth hormone is released during non-rapid eye-movement (NREM) sleep (Gunning, 2001), which is essential to body restoration and muscle growth and repair (Davenne, 2009; Halson, 2008; Shapiro et al., 1981). It is known that elite adult athletes experience higher levels of sleep disturbance due to a number of factors such as training schedules, scheduling of competitions, sleeping environments and sponsorship requirements, all of which impacts their sleep negatively (Gupta et al., 2017; Juliff et al., 2015; O'Donnell et al., 2018a). To our knowledge, very few studies have investigated the sleep of adolescent athletes and it would be valuable to assess if highly trained adolescent athletes experience disturbances to their sleep. Two previous studies by Steenekamp et al. (2020) and Gudmundsdottir (2020) have measured the sleep duration of adolescent swimmers using actigraphy, finding that total sleep duration prior to early morning training (6:44 h:min and

5:21 h:min respectively) was below the recommended 8-10 hours of sleep for adolescents (Gudmundsdottir, 2020; Steenekamp et al., 2020). Adolescents and elite athletes have shown to overestimate their sleep by 1:20 h:min and 19.8 minutes respectively. However, this is yet to be established in adolescent athletes. Although it is known that both elite swimmers (Sargent, Halson, et al., 2014) and adolescent swimmers (Steenekamp et al., 2020) experience similar disruption to their sleeping patterns due to the scheduling of early morning training sessions, it is still unknown how adolescent swimmers subjectively report on their sleep in this setting.

While there is an increase in sleep research occurring in the elite adult athlete population (Lastella et al., 2020), there is a paucity of research on the high performing adolescent (15-18 years) athlete. Given the different circadian rhythms to that of adults, combined with the training loads and extra-curricular activities that adolescent athletes experience, it is vital that we understand their sleeping patterns to allow for adequate recovery for health and performance in these young athletes. Therefore, the aim of the current study was to evaluate sleeping patterns in highly trained adolescent aged swimmers across a two-week training phase and compare their subjective sleep to objective sleep (actual sleep measured). A secondary aim of the study was to determine if there is a correlation between device usage prior to sleep onset and the effect on different sleep measures.

Methods

Participants

A total of 15 adolescent swimmers (between the ages of 15-18 years) volunteered to participate in the current study (mean ± SD; age 16.4 ± 1.0 years, 12 females/3 males). Participants were recruited through local and national swimming organisations in New Zealand. All participants who took part in the study attended high school and had all either represented their country or placed top three at a National event in the year prior to their recruitment. Ethics approval was obtained through Institutions Human Research Ethics Committee. All participants provided informed written consent before taking part in this study, and for participants under 16 years, consent was also provided by a parent/caregiver.

Design

In this cross-sectional study, participants completed four validated sleep questionnaires via an electronic survey link (Survey Monkey, CA, USA). Upon completion of the questionnaires, participants wore a wrist-actigraphy device for a two-week (14-day) period to monitor sleep. The sleep monitoring period was completed during a normal, in-season training phase, where participants on average had 10 training sessions per week, of which, seven were pool sessions and three were gym sessions. The sleep monitoring period was also completed during a regular school term. Each morning during the two-week sleep monitoring period, participants were asked to fill out a subjective sleep diary and at the conclusion of each day asked to fill out a daily training diary.

Classifications of Nights

Each night was coded based on the training schedule of the following day. Therefore, nights of sleep were placed into three categories dependent on the schedule for the preceding day; early morning training (EARLY) which consisted of any training commencing prior to 7am, daytime training (DAY) which consisted of training commencing any time after 7am, and no training (REST) which consisted of a full day rest with no training sessions.

Measures

<u>Sleep Questionnaires</u>

The sleep questionnaire contained personal characteristic questions, as well as four validated and common sleep questionnaires; the Pittsburgh Sleep Quality Index (PSQI), the Sleep Hygiene Index (SHI), the Epworth Sleepiness Scale (ESS), and the Athlete Sleep Behaviour Questionnaire (ASBQ). The PSQI, assesses sleep quality and disturbances over a one month period to give a global score relating to overall sleep quality (Buysse et al., 1989). Scores can range from 0-21 and a global score >5 is a result of poor sleep. The SHI, is a 13 question self-administered questionnaire that assesses sleep behaviour and habits thought to compromise sleep hygiene (Mastin et al., 2006). Scores range between 0-52 with higher scores reflecting poorer sleep hygiene practices. The ESS provides a measurement for general daytime sleepiness rated on a scale of 0-3 for eight everyday different activities (Johns, 1991). Scoring ranges between 0-24, with numbers greater than 16 indicating high levels of daytime sleepiness, numbers between 10-15 indicating abnormal daytime sleepiness, and numbers from

0-10 indicating normal daytime sleepiness. The ASBQ, is an 18 question questionnaire that focuses on the specific challenges to the sleeping behaviours of athletes (Driller et al., 2018). Athletes who score ≤36 are considered to have good sleep behaviour, whilst athletes who score ≥42 are considered to have poor sleep behaviour.

Sleep Monitoring

Participants were required to wear a wrist-actigraphy device (Fatigue Science, Readiband, Vancouver, Canada) over a two-week period to monitor and objectively quantify sleep patterns. The sleep indices obtained from the actigraph were: total sleep time (TST), total time in bed (TTB), sleep latency (SL), wake episodes per night (WE), wake after sleep onset (WASO), sleep efficiency (SE), sleep onset (SOT), and wake time (WT). The raw activity scores were translated to sleep-wake scores, based on computerized scoring algorithms (Sadeh, 2011). The Readiband is commonly used in the athletic setting as it is more practical and less intrusive compared to polysomnography (PSG) (Shearer et al., 2015). Participants were instructed to wear the actigraph device on the wrist they felt most comfortable (Driller et al., 2017), continuously for the two-week monitoring period, with the exception of time spent in pool training sessions and showering. Sleep indices were quantified via the Fatigue Science software at a sampling rate of 16 Hz. The Readiband devices used in the current study have shown high levels on intra-device reliability (Driller et al., 2016), and has been validated against the gold standard PSG (Dunican et al., 2017).

Sleep and Training Diaries

For the duration of the sleep monitoring period participants were also required to fill out a sleep and training diary each day. The sleep diary consisted of five subjective questions that asked participants to estimate how long they were on an electronic light-emitting device in the two hours prior to bedtime, how long it took them to fall asleep, how many times they woke during the night, how long they slept for, and to rate their quality of sleep on a scale of 1-5 (1 = very poor, 5 = very good). Similarly, the daily training diary asked participants to outline how many training sessions they had per day, as well as the time, type, and duration of each session.

Statistical Analysis

Simple group and descriptive statistics are reported as means ± standard deviations unless stated otherwise. Statistical analyses were performed with the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). A one-way analysis of variance was performed to determine if there was a significant difference for all sleep measures between the three types of nights; EARLY, DAY, and REST. Games-Howell post hoc *t* tests were performed to locate differences where main effects were evident (WE, TTB, & TST), with statistical significance set at $p \leq 0.05$. A Kruskal-Wallis test was conducted to determine if there were significant differences for SL, WASO, SE, SOT & WT. Pairwise comparisons were performed using Dunn's (1964) procedure. Magnitudes of the standardized effects were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, and 0.8 *small*, *moderate*, and *large*, respectively (Batterham & Hopkins, 2006). An effect size of < 0.2 was considered to be *trivial* and the effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects (Hopkins et al., 2009). A Pearson's product-moment correlation was run to assess the relationship between device usage and all sleep indices. The magnitude of correlation between device usage and the sleep indices was assessed using the following thresholds: .00–.19, *very weak*; .20–.39, *weak*; .40–.59, *moderate*; .60–.79, *strong*; and .80–1.0, *very strong* (Evans, 1996).

Results

The characteristics and measurements of the two-week monitoring period are presented in Table 2. Participants averaged 7.1 pool training sessions and 3.5 gym sessions per week. Electronic light-emitting devices were used on average for 63.7 ± 27.9 minutes in the two hours prior to bedtime (Table 6).

Table 6: Mean ± SD values for the measured sleep questionnaires, objective sleep variables and training load of the two-week monitoring period. Comparison of electronic device usage to sleep indices using the Pearson's moment correlation (r)

	All (n = 15)	**Correlations (r)**
Age (y)	16.4 ± 1.0	N/A
Sleep Questionnaires		
Pittsburgh Sleep Quality Index	5.2 ± 1.4 (poor)	N/A
Epworth Sleepiness Scale	8.5 ± 4.0 (normal)	N/A
Sleep Hygiene Index	18.1 ± 6.1 (moderate)	N/A
Athlete Sleep Behaviour Questionnaire	36.1 ± 5.3 (good)	N/A
Sleep Indices		
Total Time in Bed (h:min)	8:00 ± 0:30	0.14
Total Sleep Time (h:min)	6:40 ± 0:46	0.17
Sleep Efficiency (%)	84.3 ± 7.1	0.23
Sleep Latency (min)	27.3 ± 13.2	-0.12
Wake Episodes per Night (No.)	3.8 ± 1.7	-0.32
Wake After Sleep Onset (min)	36.7 ± 30.5	-0.18
Sleep Onset Time (time of day)	21:54 ± 0:34	0.06
Wake Time (time of day)	5:40 ± 0:30	0.33
Training Load		
Total Training Time per Week (h:min)	16:35 ± 3:30	N/A
Pool Training Sessions per Week (No.)	7.1 ± 1.5	N/A
Gym Training Sessions per Week (No.)	3.5 ± 1.5	N/A
Device Usage		
Time Spent on Device Before Bed (min)	63.7 ± 27.9	N/A

Note: evaluation from the questionnaires based on scoring of each specific questionnaire
Correlation (r): sleep indices compared to device usage

The data set was distributed across the three types of nights as EARLY (102), DAY (49), and REST (26). The values for the comparison of variables between EARLY, DAY and REST can be observed in Table 7 and 8. On nights where training occurred EARLY the next day, TTB averaged 6:55 ± 0:46 h:min. Games-Howell post-hoc analysis revealed substantial reductions in TST between EARLY and DAY (-1:47 ± 0:06 h:min, *d* = -1.68 ±0.54, p < 0.01, Table 8) and between EARLY and REST (-2:06 ± 0:13 h:min, *d* = -2.02 ±0.68, p < 0.01, Table 8). Substantial reductions were also observed in TTB between EARLY and DAY (-2:11 ± 0:11 h:min, *d* = -2.61 ±0.80, p < 0.01, Table 8) and between EARLY and REST (-2:48 ± 0:51 h:min, *d* = -2.73 ±1.17, p < 0.01, Table 8). Dunn's analysis revealed a significant difference for SOT between EARLY and REST (0:58 ± 0:12 h:min, *d* = 1.15 ±0.73, p < 0.05, Table 8) and DAY and REST (0:47 ± 0:12 h:min, *d* = 1.02 ±0.83, p < 0.05, Table 8). There were no significant differences observed in SE and SL for comparison between nights (Table 7).

Table 7: Mean ± SD values for the measured objective sleep variables and device usage on the night preceding an early morning training session (EARLY), a day training session (DAY) and a rest day (REST).

	EARLY	DAY	REST
Sleep Indices			
Total Time in Bed (h:min)	6:55 ± 0:50$^{\#,\wedge}$	9:06 ± 1:01	9:43 ± 1:41
Total Sleep Time (h:min)	5:53 ± 1:06$^{\#,\wedge}$	7:40 ± 1:12	7:59 ± 1:19
Sleep Efficiency (%)	85.2 ± 7.0	84.2 ± 9.8	82.9 ± 6.9
Sleep Latency (min)	26.5 ± 13.4	28.5 ± 18.4	24.5 ± 12.9
Wake Episodes per Night (No.)	3.0 ± 1.8$^{\wedge}$	4.3 ± 2.5	5.8 ± 2.0
Wake After Sleep Onset (min)	25.3 ± 22.6$^{\wedge}$	43.7 ± 42.3	61.9 ± 43.2
Sleep Onset Time (time of day)	21:38 ± 0:49$^{\wedge}$	21:49 ± 0:49$^{\wedge}$	22:36 ± 1:01
Wake Time (time of day)	4:20 ± 0:27$^{\#,\wedge}$	6:40 ± 0:41$^{\wedge}$	8:01 ± 1:16
Device Usage (min)	59.7 ± 27.7	65.1 ± 30.1	62.8 ± 40.4

$^{\#}$significantly different to DAY ($p < 0.05$).
$^{\wedge}$significantly different to REST ($p < 0.05$).

Table 8. Mean ± SD data for differences between nights for objective sleep indices and device usage, including effect sizes (d) and 90% confidence limits (90% CL) for comparison between conditions.

Sleep Indices	EARLY – DAY (effect size)	EARLY – REST (effect size)	DAY – REST (effect size)
Total Time in Bed (h:min)	-2:11 ± 0:11[#] -2.61 ±0.80 *Very Large*	-2:48 ± 0:51[#] -2.73 ±1.17 *Very Large*	-0:37 ± 0:40 0.09 ±0.73 *Unclear*
Total Sleep Time (h:min)	-1:47 ± 0:06[#] -1.68 ±0.54 *Large*	-2:06 ± 0:13[#] -2.02 ±0.68 *Very Large*	-0:19 ± 0:07 0.29 ±0.41 *Unclear*
Sleep Efficiency (%)	1.0 ± 2.8 -0.09 ±0.46 *Unclear*	2.3 ± 0.1 -0.16 ±0.53 *Unclear*	1.3 ± 2.9 -0.05 ±0.56 *Unclear*
Sleep Latency (min)	-2.0 ± 5.0 0.12 ±0.69 *Unclear*	2.0 ± 0.5 -0.22 ±0.44 *Unclear*	4.0 ± 5.5 -0.25 ±0.60 *Unclear*
Wake Episodes per Night (No.)	-1.3 ± 0.7 1.06 ±0.61 *Moderate*	-2.8 ± 0.2[#] 1.37 ±0.59 *Large*	1.5 ± 0.5 0.20 ±0.55 *Unclear*
Wake After Sleep Onset (min)	-41.4 ± 19.7 1.11 ±0.74 *Moderate*	-36.6 ± 20.6[#] 1.22 ±0.56 *Large*	18.2 ± 0.9 0.06 ±0.56 *Unclear*
Sleep Onset Time (h:min)	0:11 ± 0:00 0.13 ±0.58 *Unclear*	0:58 ± 0:12[#] 1.15 ±0.73 *Large*	0:47 ± 0:12[#] 1.02 ±0.83 *Moderate*
Wake Time (h:min)	2:20 ± 0:14[#] 4.43 ±0.63 *Very Large*	3:41 ± 0:49[#] 7.78 ±1.57 *Very Large*	1:21 ± 0:35[#] 2.21 ±1.02 *Very Large*
Device Usage (min)	-5.4 ± 2.4 0.36 ±0.36 *Small*	-3.1 ± 12.7 0.04 ±0.51 *Unclear*	2.3 ± 10.3 -0.29 ±0.59 *Unclear*

[#]significant difference between nights ($p < 0.05$).

A Pearson's product-moment correlation was run to assess the relationship between device usage and sleep indices (TTB, TST, SE, SL, WE, WASO, SOT and WT). There was no statistically significant correlation observed between device usage and sleep indices ($p > 0.05$).

There were significant differences observed for all three sleep indices (SL, WE & TST) when comparing the participants objective sleep data to their subjective sleep diary data from the two-week monitoring period (Table 9). Participants significantly underestimated their subjective SL compared to actual SL (17.5 ± 5.6 minutes and 27.3 ± 13.2 minutes, respectively, d = 0.97 ±0.55, $p < 0.05$, Table 9) and WE (0.8 ± 0.6 and 3.7 ± 1.8, respectively, d = 1.75 ±0.63, $p < 0.05$, Table 9). Whereas participants significantly overestimated their subjective

TST compared to objective TST (7:42 ± 0:42 h:min and 6:48 ± 0:42 h:min, respectively, d = -1.00 ±0.68, $p < 0.05$, Table 9).

Table 9. Mean ± SD data for differences between subjective and objective sleep for objective sleep indices, including effect sizes (d) for comparison between conditions.

Sleep indices	Subjective sleep	Objective sleep	Subjective Sleep v Objective Sleep Difference (raw)	Subjective Sleep v Objective Sleep (effect size ±90% CL)
Sleep Latency (min)	17.5 ± 5.6	27.3 ± 13.2	9.8 ± 7.6$^{\#}$	0.97 ±0.55 *Moderate*
Wake Episodes per night (No.)	0.8 ± 0.6	3.7 ± 1.8	2.9 ± 1.2$^{\#}$	1.75 ±0.63 *Large*
Total Sleep Time (h:min)	7:42 ± 0:54	6:48 ± 0:42	-0:54 ± -0:10$^{\#}$	-1.00 ±0.68 *Moderate*

$^{\#}$significant difference between subjective and objective measures of sleep ($p < 0.05$)

Discussion

The primary aim of this study was to investigate the sleeping patterns of highly trained adolescent swimmers over a two-week period. Adolescent swimmers in this study averaged 6:40 h:min of total sleep duration over the two-week monitoring period, which falls below the recommended sleep duration of 8-10 hours sleep for adolescents (Paruthi et al., 2016). Furthermore, differences in sleep indices were observed between the three types of nights (EARLY, DAY, and REST), with TST significantly reduced on the night preceding EARLY training compared to both DAY training and REST by 1:47 h:min and 2:06 h:min, respectively. When comparing to objective measures, adolescent swimmers in this study objectively overestimated their TST by approximately one hour per night, whilst also substantially underestimating SL and WE when compared to their objective sleep measures determined by actigraphy.

As reported by Steenekamp and colleagues (2020), sleep duration was significantly reduced on nights preceding early morning training (6:44 h:min) compared to nights with no early morning training session (8:45 h:min) in 32 adolescent swimming and rowing athletes (Steenekamp et al. (2020). A further study by Gudmundsdottir (2020) reported sleep duration was significantly shorter on nights preceding early morning training (5:21 h:min) compared with later morning training (6:37 h:min) and no morning training (6:53 h:min) the preceding day in 108 Icelandic adolescent swimmers (Gudmundsdottir, 2020). The results of the current study are consistent with Steenekamp et al. (2020) and Gudmundsdottir (2020) findings, with TST significantly reduced on the night prior to EARLY training sessions (5:53 h:min) compared to DAY training sessions (7:40 h:min) and REST (7:59 h:min). It appears that the athletes in the current study adjusted their bedtimes to offset the earlier wake times due to the early morning training, as SOT was significantly earlier on nights preceding early morning and day training (EARLY and DAY) compared with rest days (REST).

To our knowledge, the current study is the first to examine the difference between subjective and objective sleep measures in adolescent athletes. In elite athletes, the use of subjective self-perceived sleep measures has been shown to be in agreement with objective actigraphy-derived sleep measures (Caia et al., 2018). However, the current study indicates that adolescent swimmers significantly overestimate TST and significantly underestimate SL and WE, suggesting that subjective sleep measures are not in agreement with objective sleep measures in adolescent athletes. These findings are similar to previous research in adolescents in the general population who also significantly underestimate sleep when compared to objective sleep measures (Short et al., 2012; Short et al., 2013). Moreover, to our knowledge this is also the first study to examine perceived versus actual WE. It is interesting that adolescent athletes significantly underestimated their WE and therefore warrants the need for further research in this area. Despite subjective sleep measures providing a non-invasive and easily accessible way of measuring sleep in adolescents (Saw et al., 2016), the current study suggests that objective sleep measures should be used where possible for the most accurate data. Educating adolescent athletes on the importance of sleep is essential so they can counteract the underestimates on their sleep, as observed in the current study, and can consciously put more focus on their sleep.

Research from the current study suggests that adolescent athletes whose sleep is disrupted by early morning training amass sleep debt throughout the week resulting in them trying to ‘catch up’ on rest days. These sleeping patterns lead to disruption in the circadian timekeeping system (Díaz-Morales & Escribano, 2015). Similarly, Steenekamp and colleagues (2020) research found that adolescent athletes extended their sleep on weekends without training compared to weekdays with early morning training. It is still unknown whether disruption to sleeping patterns for adolescent athletes from early morning training further impairs the effects (negative metabolic and psychological health outcomes) of a disrupted circadian timekeeping system (Díaz-Morales & Escribano, 2015; Malone et al., 2016). However, it is known that adolescent athletes who obtain less than eight hours sleep per night are at a higher risk of acquiring new injuries (Milewski et al., 2014; von Rosen et al., 2017b). Therefore, adolescent athletes from the current study may be at risk of acquiring new injuries, as they did not reach the recommended sleep duration (average 6:44 h:min per night), largely due to the high training load and early morning training sessions they experience (Milewski et al., 2014; von Rosen et al., 2017b). Early specialisation is also and issue amongst many sports, such as swimming, where is has been recommended that adolescent athletes should not spend more hours per week than their age playing sport to avoid this (Maffulli et al., 1994; Murray, 2017). Within the current study, the training load of an average 16:35 h:min per week matched the particpants average (16.4 years), which is an area of potential concern for early specialisation. Therefore, the implementation of sleep hygiene education and strategies (Fullagar et al., 2016; O'Donnell & Driller, 2017) may be beneficial for adolescent athletes in order to understand the importance of sleep and tools to improve their sleep.

Scores from the PSQI suggest that adolescent athletes were poor sleepers (5.2), whilst the SHI suggests that adolescent athletes were moderate sleepers (18.1). These results contrast what Setyowati et al. (2020) found in 101 Indonesian adolescent school students. The students from Setyowati and colleagues (2020) research scored on average 32 for the SHI, which would place them one category worse (fair) compared to the adolescents in the current study, this could be due to the predominately male population group in this study compared to the predominantly female population group in the current study. Male and female adolescents experience differences in their sex hormones, largely due to the female menstrual cycle and therefore this could be reasoning why differences were found between the two studies (Alonso et al., 2021). A further reasoning for the difference in SHI observed between the two studies could be the differing school times, with a 7am start and 1pm finish in Indonesia compared to approximately 8:40am and 3:20pm in New Zealand. Results from the ASBQ also showed that adolescent athletes have better sleep behaviours (36.1) than individual and team sport elite athletes, as reported previously (44.3 and 42.6 respectively) (Driller et al., 2021). Adolescent athletes may report having better sleep behaviours than elite athletes on the ASBQ due to the relevance of certain questions. For example, questions relating to alcohol, travel, foreign sleeping environments, sleeping pills and use of stimulants scored extremely low in adolescent athletes, which may offer a reason why adolescent athletes scored lower than elite athletes on the ASBQ. It could be suggested that a modified version of the ASBQ be created for adolescent athletes that is more relatable to this population

Another factor adolescent athletes' experience is the effect of their academic requirements. Furthermore, it is thought that academic outcomes may also be negatively impacted due to disrupted sleep. When adolescents obtain more sleep and have a later school start time, academic performance is improved (Carrell et al., 2011; Kelley & Lee, 2014; Wahlstrom, 2002; Wolfson et al., 2007). Adolescents who receive over an hour more sleep on school nights are far more academically advantaged to their peers and have significantly less daytime sleepiness (Wahlstrom, 2002; Wolfson et al., 2007). If it were possible, scheduling of training would also consider academic requirements for the benefit of the athlete, but this is difficult to achieve due to the high volume of training that these athletes are required to do. Therefore, the schedules of adolescent athletes should be further considered for both athletic and academic performance benefits and outcomes. Interestingly, athletes from the current study ranked in the 'normal' range for daytime sleepiness in the ESS questionnaire which is surprising given the early morning training session prior to school. However, there was a relatively large range (1-17) which indicates that differences exist within the individual athletes in the sample group and that some athletes did suffer from excessive daytime sleepiness.

Electronic light-emitting devices were used by adolescent athletes in this study on average for ~1h per night in the two hours prior to bedtime. It is known that increased device usage can be associated with shortened sleep duration (11-24 minutes) (Galland et al., 2020; Mazzer et al., 2018; Mireku et al., 2019; Twenge et al., 2017). Mazzer and colleagues (2018) found that over one year, increased device usage was associated with less sleep in the future and a shortened sleep duration was also related to using a device more often after one year. Interestingly, no correlations were found for device usage and sleep indices (TTB, TST, SE, SL, WE, WASO, SOT and WT) in the current study. Perhaps differences would have been found if some of the participants abstained from any device usage in the lead-up to bedtime, however, this was not the case, as all athletes used their devices for at least 30 minutes in the two hours prior to bed. Despite the results in the current study, research that has focused specifically on adolescents has found that a one and two hour exposure to light from self-luminous devices (computers, tablets, and cell phones) supresses melatonin in adolescents by 23% and 28% respectively (Figueiro & Overington, 2015). Much like adolescents', adults who use electronic light-emitting devices before bed, had suppressed evening levels of melatonin by 20% (Chang et al., 2015). Previous research however, has focused on the effect electronic light-emitting devices have had on adolescents in the general population, however it is still unclear the effect of device usage on adolescent athletes (Galland et al., 2020; Gamble et al., 2014; Twenge et al., 2017).

One of the limitations of the current study was the recruitment of participants from a number of different training programs around the country, which meant the schedule and intensity of training sessions varied across the cohort. As this was a field-based study, there were multiple variables (diet, caffeine intake, environment, and scheduling) that were unable to be controlled for, which could have had an impact on the overall results of the study. Female menstruation cycles were not controlled in this study, which could have had some impact on the female athletes results. Although the current study had a relatively small sample size (n=15), the ability to recruit highly trained adolescent swimmers in New Zealand is somewhat limited. Indeed, the overall population to draw from that fits the inclusion criteria is small (n=~40), therefore, we believe that our sample is representative of this cohort.

Conclusion

In summary, the results of the current study showed that across a two-week monitoring period, early morning training resulted in a reduced sleep duration and time in bed in adolescent swimmers in the night preceding. Additionally, adolescent athletes significantly overestimate their sleep duration and underestimate their time to fall asleep. It was also found that electronic device usage before bedtime showed no correlations to sleep indices. The findings of the current study show the importance of coaches, parents and school administrators needing to be aware of the sleeping habits of adolescent athletes and the subsequent impact that early morning training sessions have on their sleep. Where possible, adjusting schedules so adolescent athletes can better balance their sleep around training and school requirements has the potential to benefit their sleep, reduce injury risk and improve academic performance. Further research is required to investigate interventions that may enhance the sleep/wake behaviour of adolescent athletes to support adolescent athletes in sport.

Chapter Three: Summary, Practical Applications, Limitations and Future Research

Summary

The first chapter of this thesis comprised of a literature review, which examined the sleep of adolescent athletes and the various factors that influence their sleep. Sleep is considered to be vital to the physiological and cognitive function in humans and is also crucial for recovery in athletes (Halson, 2014b). Adolescents experience a delay in their circadian rhythm due to a change in their biologic timing mechanism (Carskadon et al., 1993). Whilst it is recommended that adolescents obtain 8-10 hours sleep per night (Paruthi et al., 2016), key findings of this literature review indicate that adolescent athletes experience sleep durations significantly below the recommendation, and swimmers in particular are at a higher risk of poor sleep due to the requirements of the early morning training sessions observed in this sport (Gudmundsdottir, 2020; Steenekamp et al., 2020). Despite recommendations suggesting that adolescent athletes should not spend more hours per week than their age playing sport (Murray, 2017), swimming is still considered to be an early specialisation sport with many adolescent swimmers averaging training hours over their age each week (Maffulli et al., 1994). Furthermore, adolescent swimmers experience differences in their sleep between weekdays and weekends, where sleep durations on weekends are significantly longer than on weekdays (Steenekamp et al., 2020). Moreover, research has also shown sleep has substantial impacts on adolescents' academic performance. Earlier school start times disadvantage adolescents academic performance significantly, whilst simultaneously increasing daytime sleepiness and causing more trouble to stay awake in classes (Carrell et al., 2011; Edwards, 2012; Wahlstrom, 2002; Wolfson et al., 2007). Finally, measuring sleep in adolescents from the general population has also shown that adolescents significantly overestimate their total sleep duration compared to their actual sleep duration (Short et al., 2012; Short et al., 2013). Using PSG in adolescents is not favoured due to the large costs and many laboratories are not willing to test young people (Meltzer et al., 2012). However, it has also been shown to be impractical in athletes as well due to the laboratory setting and unusual sleep environments (O'Donnell et al., 2018a). Therefore, wrist actigraphy, sleep diaries, and questionnaires are the preferred option as they are accessible and easy to administer in both adolescents and athletes (Sadeh, 2011; Short et al., 2012)

Sleep in highly trained adolescent athletes is still a relatively small research field. Therefore, the aim of the original study in chapter two was to evaluate the sleeping patterns of highly trained adolescent swimmers across a two-week 'normal' in-season training phase and compare their subjective sleep to their objective sleep. The main findings from this study showed that early morning training sessions (EARLY) significantly reduced total sleep time and total time in bed in adolescent swimmers compared to day training (DAY) and rest days (REST). Athletes in this study also significantly adjusted their bedtime to be earlier on nights preceding early morning training compared to rest days to account for the early wake up time. Further findings showed that adolescent swimmers subjectively overestimated their sleep duration to be significantly longer compared to their objective sleep duration, while significantly underestimating their time to fall asleep and wake episodes per night compared to their objective SL and WE. While electronic devices were used by all participants before bedtime, no correlations were found when compared to different sleep indices. Whilst the sleeping patterns of adolescent swimmers in this study show similar findings to previous research, to our knowledge it is the first study to investigate adolescent athletes subjective sleep versus objective sleep indices. The small number of previous studies that have investigated sleep in adolescent athletes, alongside the findings from the current study in chapter two warrants the need for further research in these areas. Not only would this provide those working with adolescent athletes a greater understanding of how adolescents sleep, it may also lead to the longevity of high performing adolescents in sport.

Practical Applications

The findings of the current study show the importance of coaches, parents and school administrators needing to be aware of the sleeping habits of adolescent athletes and the subsequent impact that early morning training sessions have on their sleep. Where possible, adjusting adolescent athletes training schedules to better balance their sleep around training and school requirements has the potential to benefit not only their sleep, but also reduce injury risk and improve academic performance. In addition, educating coaches on the role of sleep for adolescent athletes may help in coaches providing later start times of morning training, which in turn may influence adolescent swimmers' success in the sport. Furthermore, educating adolescents on the importance of sleep and providing sleep hygiene practices could be advantageous to improving their sleep indices. Further research is required to investigate interventions that may enhance the sleep/wake behaviour of adolescent athletes to support the longevity of adolescent athletes in sport.

Limitations

- A primary limitation of this study was the small sample size, which was largely due to the overall population that fits the inclusion criteria is small (n=~40). The ability to recruit highly trained adolescent swimmers in New Zealand was somewhat limited, however, the small sample size is representative of this cohort.
- Due to the small population that fitted the inclusion criteria, it meant that participants came from a number of different training programs across the country. Therefore, the schedule and intensity of training sessions may have varied across the cohort.
- As this was a field-based study, there were variables that were unable to be controlled for, such as diet, caffeine intake, environments and scheduling could have had an impact on the sleep disturbances that adolescents experienced in this study.
- A further limitation of the current study was finding a two-week period that was representative of a 'normal' training phase that occurred during a normal school term and did not involve competitions. Accordingly, the data collection period occurred across several months and was completed in consultation with coaches and athletes to ensure the two-week monitoring period was reflective of a 'normal' training phase during a typical school period.
- The Readiband device used for measuring objective sleep has limitations with the accuracy of measuring sleep latency and sleep efficiency. It has been recommended to interpret these indices with caution.
- Female menstruation cycles were not controlled in this study, which could have had some impact on the female athletes results and therefore, results were not interpreted with this in mind.
- Finally, as this study focused specifically on highly trained adolescent swimmers, there were no adolescent athletes from other sports to compare sleep measures to. Our results are therefore not reflective of a variety of highly trained adolescent athletes.

Future Research

From the outcomes and results presented within this thesis, the following key areas for future research are suggested.

- Future research should endeavour to collect data from highly trained adolescent athletes across a variety of sporting codes to gain a better overall picture of sleep behaviours in a wide range of highly trained adolescent athletes.
- Furthermore, investigating the sleep of adolescent athletes that have predominantly evening based training sessions would be of interest, and would expand the knowledge on the effects training time has on highly trained adolescent athletes sleep.
- Future research investigating sleep hygiene in the highly trained adolescent athlete population would be beneficial to see if education and implementation of sleep hygiene strategies improves sleep amongst this population.
- Research looking at both physical and cognitive performance markers across a season would also be beneficial to investigate the effect that poor sleep has on performance over a period of time.
- Future research investigating the effects of competition on highly trained adolescent athletes' sleep would be worthwhile to further enhance our knowledge on variables that may affect adolescent athletes sleep. It would also allow for comparisons to be made to elite athletes and the effect competition has on their sleep indices.
- Despite screen time showing no correlations in this study, extended device usage before bedtime is known to be an issue in this population so further research would be valuable to assess the specific impacts device usage has on the adolescent athlete population.
- Assessing the impacts of the menstrual cycle in adolescent female athletes would be beneficial as it may give some insight into how adolescent females sleep is affected by their menstrual cycle.

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Appendices

Appendix 1: Participant Information Sheet

Participant Information Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Project Title: Sleeping Patterns in Highly Trained High School Aged Swimmers

Purpose
The purpose of this project is to provide better understanding of sleeping patterns in highly trained high school aged swimmers.

What is this research project about?
This research project is investigating the sleeping patterns of highly trained high school aged swimmers through the use of sleep questionnaires and measuring sleep through actigraphy devices (sleep watches). Sleep watches provide a variety of measures that can be analyzed to determine sleeping patterns and quality of sleep.
This is a baseline study that could be used for further research in this field. Future studies could help to determine if sleep does in fact have an effect on swimming performance in highly trained high school swimmers.

What will you have to do and how long will it take?
To participate in this study, you will be required to fill out 4 sleep questionnaires. The sleep questionnaires should only take approximately 10-15 min to fill out. After the initial filling out of questionnaires you will be required to wear a sleep watch on your wrist for three weeks (it can be taken off for your training and showering) to give us accurate data of sleeping patterns and activities. Whilst wearing the sleep watch you will also be required to fill out a sleep diary each morning which should take no longer than 5 minutes to complete.

Potential risks/discomforts and their minimization
There are no foreseeable risks that could cause harm to the participants in this study.
There is potential for the sleep watch to cause discomfort for a couple of days if you are not used to wearing a watch, but this discomfort should ease after a couple of days.

Minors under 16
Consent for a minor under 16 will need to be provided by a legal guardian and the minor. 16- and 17-year old participants can consent as an adult.

Potential benefits
If you participate in this study, you will receive an individualized sleep report from the data we collect. This sleep report can be used to help improve your sleep for better sleeping patterns which could have a positive effect on your athletic performance.

What will happen to the information collected?
The information collected in this study will be used to write research reports, for a post-graduate thesis, and potentially used in a poster or to give presentations. All data used in reports etc. will be confidential and no one will be identified without consent. In publications and research all participants will be anonymous. We will ensure anonymity by assigning a code (letter or number) to each participant and referring to this code throughout.
Only the primary investigator and supervisors of the project will have direct access to the information. All personal information will be destroyed at the conclusion of the project, but all raw data is required to be kept for 5 years as per the University of Waikato's policy. This data will be kept in secure storage which it will then be destroyed after 5 years.

Participation and withdrawal
Participation in the project must be consensual and you will have three weeks after the data collection period to withdraw from the study.

Declaration to participants
If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw from the study at any point in time throughout the study.
- Ask any further questions about the study that occurs to you during your participation, at any time.
- Be given access to a summary of findings from the study when it is concluded.

Who's responsible?

- Claudia Ashby: Primary investigator (crga1@students.waikato.ac.nz)
- Shannon O'Donnell: Primary Supervisor (shannon.odonnell@waikato.ac.nz)
- Matthew Driller: Secondary Supervisor (matthew.driller@gmail.com)
- University of Waikato

Appendix 2: Participant Consent Form

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Consent form

Project Title: Sleep Patterns in Highly Trained High School Aged Swimmers

Researchers: Claudia Ashby, Shannon O'Donnell, Matthew Driller

I _______________ agree to participate as a volunteer in a scientific investigation as an approved part of a research program at the University of Waikato under the supervision of Shannon O'Donnell and Matt Driller.

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

- I have been given an opportunity to ask whatever questions I may have had and all questions have been answered to my satisfaction.
- I understand that the data collected in this research project may be reported in scientific publications, presentations, teaching, and student theses.
- I understand that I am free to withdraw from the project and ask for my data to be destroyed up to three weeks after the data collection period, without disadvantage to myself.
- I understand that my data will be anonymized through a coding system, to protect my identity in the research reporting.
- I am participating in this project of my own volition and I have not been coerced in any way to participate.

Signature of Proxy (if under 16): ___________________________________

Signature of Participant: ____

Date: ____/____/____

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

Signature of Researcher: _____________________________________
Date: ___/____/___

Contact Details for Researchers:

Claudia Ashby: crga1@students.waikato.ac.nz

Shannon O'Donnell: shannon.odonnell@waikato.ac.nz

Matthew Driller: matthew.driller@gmail.com

Appendix 3: Ethics Approval

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road
Hamilton, New Zealand

Human Research Ethics Committee
Roger Moltzen
Telephone: +6402165811 9
Email:humanethics@waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2 July 2020

Claudia Ashby
Te Huataki Waiora School of Health
DHECS
By email: clodashby@hotmail.com

Dear Claudia

HREC(Health)2020#45 : Sleep Patterns in Highly Trained High School Aged Swimmers

Thank you for your comprehensive responses to the Committee's feedback.

We are now pleased to provide formal approval for your project.

Please contact the committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

____

Emeritus Professor Roger Moltzen MNZM
Chairperson
University of Waikato Human Research Ethics Committee

Appendix 4: Questionnaires

Pittsburgh Sleep Quality Index

INSTRUCTIONS: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, when have you usually gone to bed at night?
   USUAL BEDTIME ____________________

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?
   NUMBER OF MINUTES ____________________

3. During the past month, when have you usually gotten up in the morning?
   USUAL GETTING UP TIME ____________________

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed)
   HOURS OF SLEEP PER NIGHT ____________________

INSTRUCTIONS: For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you…

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
…cannot go to sleep within 30 minutes				
…wake up in the middle of the night or early in the morning				
…have to get up to use the bathroom				
…cannot breathe comfortably				
…cough or snore loudly				
…feel too cold				
…feel too hot				
…have bad dreams				
…have pain				

Other reason(s), please describe
____
____

6. During the past month how would you rate your sleep quality overall?

Very good	Fairly good	Fairly bad	Very bad

7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?

Not during the past month	Less than once a week	Once or twice a week	Three or more times a week

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month	Less than once a week	Once or twice a week	Three or more times a week

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

Not a problem at all	Only a very slight problem	Somewhat of a problem	A very big problem

10. Do you have a roommate (e.g. share a room with a sibling)?

No roommate	Roommate in other room	Have a roommate but don't share a bed	Have a roommate and share a bed

If you have a roommate, ask him/her how often in the past month you have had…

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
…loud snoring				
…loud pauses between breaths while asleep				
…legs twitching or jerking while you sleep				
…episodes of disorientation or confusion during sleep				
…other restlessness while you sleep Please describe below				

Sleep Hygiene Index

No.	Question	Always	Frequently	Sometimes	Rarely	Never
1	I take daytime naps lasting more than two hours					
2	I go to bed at different times from day to day					
3	I get out of bed at different times from day to day					
4	I exercise to the point of sweating within 1h of going to bed					
5	I stay in bed longer than I should two or three times a week					
6	I use caffeine within 4h of going to bed or after going to bed					
7	I do something that may wake me up before bedtime (e.g. video games, use internet, or clean)					
8	I go to bed feeling stressed, angry, upset or nervous					
9	I use my beds for things other than sleeping (e.g. watch TV, read, eat, study)					
10	I sleep on an uncomfortable bed (e.g. poor mattress or pillow, too much/not enough blankets)					
11	I sleep in an uncomfortable bedroom (e.g. too bright, stuffy, hot, cold, noisy)					
12	I do important work before bedtime (e.g. schedule, study)					
13	I think, plan or worry when I am in bed					

Epworth Sleepiness Scale

How likely are you to dose off or fall asleep in the following situations, in contrast to just feeling tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently, try to work out how they would have effect you.
Use the following scale to choose the most appropriate number for each situation:
0 = would never doze **1 = slight chance of dozing** **2 = moderate chance of dozing** **3 = high chance of dozing**

Situation	Chance of dozing (0-3)
Sitting and reading	
Sitting, inactive in a public place (e.g. theatre or meeting)	
As a passenger in a car for an hour without a break	
Lying down to rest in the afternoon when circumstances permit	
Sitting and talking to someone	
Sitting quietly after lunch	
In a car while stopped for a few minutes in traffic	

Athlete Sleep Behavior Questionnaire (ASBQ)

	In recent times (over the last month)........					
	Question	**Never**	**Rarely**	**Sometimes**	**Frequently**	**Always**
1	I take afternoon naps lasting 2 or more hours					
2	I use stimulants when I train/compete (e.g. caffeine)					
3	I exercise (train or compete) late at night (after 7pm)					
4	I go to bed at different times each night (more than ± 1hour variation)					
5	I go to bed thirsty					
6	I go to bed with sore muscles					
7	I use light-emitting technology in the hour leading up to bedtime (e.g. laptop, phone, television, video games)					
8	I think, plan and worry about my sporting performance when I am in bed					
9	I think, plan and worry about issues not related to my sport when I am in bed					
10	I use sleeping pills/tablets to help me sleep					
11	I wake up to go to the bathroom more than once per night					
12	I wake myself and/or my roommate with my snoring					
13	I wake myself and/or my roommate with my muscle twitching					
14	I get up at different times each morning (more than ± 1hour variation)					
15	At home, I sleep in less than ideal environment (e.g. too light, too noisy, uncomfortable bed/pillow, too hot/cold)					
16	I sleep in foreign environments (e.g. hotel rooms)					
17	Travel gets in the way of building a consistent sleep/wake routine					

Appendix 5: Daily Sleep Diary

Daily Sleep Diary

Please complete the diary each morning ("Day 1" will be your first morning). Don't worry too much about giving exact answers, an estimate will do.

Your Name____________________________ The date of Day 1________________

		Day1	Day2	Day3	Day4	Day5	Day6	Day7
	Enter the weekday (Mon, Tues etc)							
1	How long were you on a device (e.g. laptop, TV, phone) in the 2 hours prior to your bedtime?							
2	After settling down, how long did it take you to fall asleep?							
3	After falling asleep how many times did you wake up during the night in total?							
4	How long did you sleep for last night? (Hours and minutes)							
5	How would you rate the quality of your sleep last night? (1 = very poor, 2 = poor, 3 = average, 4 = good, and 5 = very good)							

Appendix 6: Daily Exercise Diary

Daily Exercise Diary

Please complete the diary each morning ("Day 1" will be your first morning). Don't worry too much about giving exact answers, an estimate will do.

Your Name___________________________ The date of Day 1_______________

	Time of Session			Type of Session			Duration of Session		
Write in day (Mon, Tue etc.)	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3
Day 1									
Day 2									
Day 3									
Day 4									
Day 5									
Day 6									
Day 7									
Day 8									
Day 9									
Day 10									
Day 11									
Day 12									
Day 13									
Day 14									