AN INVESTIGATION INTO THE SLEEPING PATTERNS OF YOUTH SOCCER PLAYERS DURING THE COMPETITIVE SEASON

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ABSTRACT

Sleep is a recurring state that is considered a critical process in the optimal attainment of daily functions and recovery in athletes. However individuals from elite sports, such as soccer, may be exposed to a number of situations that may impact sleep within the competitive season (such as inconsistent schedules and travel), which may result in sub-optimal sleeping patterns. However, research documenting the sleep of soccer players is at present limited. Therefore it would seem important to investigate how soccer players sleep to further the understanding of how sleep may be impacted. On this basis, the aim of the current thesis was to examine the typical sleeping patterns of youth soccer players and the factors effecting sleep. This was completed through a series of investigations conducted during the competitive youth soccer season.

The aim of the first study (Chapter 3) was to validate a commercially available wireless sleep-monitoring device (WS). This was done in an attempt to provide a viable methodology to measure sleep within the habitual environment of soccer players. Nine randomly selected male participants were monitored over 3 nights and comparisons were made between the WS and other established field measures of sleep (Wristwatch actigraphy, sleep diary and Firstbeat bodyguard heart rate system). The relationships between the WS and the other sleep devices, indicated strong to very strong correlations ($r > 0.6$) and no significant differences between a range of outputs; total sleep time (Actigraphy assumed sleep time [0.97] & Sleep Diary [0.87] $p > 0.05$), sleep onset latency (Actigraphy [0.69] $p > 0.05$) and number of awakenings (Sleep Diary [0.69], $p > 0.05$). There were also low bias and narrow limits of agreement (LOA) within the comparison of mean differences with the WS for assumed sleep time (2 ± 17 min 95% LOA: -30 to 34 min [Actigraphy]), sleep onset latency (7 ± 17 min, 95% LOA -28 to 40 min [Actigraphy]), and number of awakenings (0.05 ± 1, 95% LOA -3 to 3 [Sleep Diary]). These results suggested that the WS is a viable device for the detection of these selected sleep variables.

Chapter 4 looked to provide a comparison of sleep measures between a sample of youth soccer players (N=8) and non-athletes (N=8). Both groups were monitored over a period of 6 days within the habitual setting using the WS. The findings showed the

soccer player group attained greater amounts of sleep quantity in comparison to the non-athlete group (504 ± 22 vs. 433 ± 46 min [+71 min] total sleep time, ES: 2.0, Large, $p < 0.01$). This may have been as a result of a later time of final awakening (08:54 ± 00:14 vs. 07:34 ± 00:46 [+77 min], ES: 1.7, Large, $p < 0.01$). Such an observation suggested that the soccer players were afforded greater time in bed as a result of the imposed soccer schedule. The soccer players also displayed a statistically greater time spent in wake (13(13) vs. 3(5) min [+10 min], PS: 0.86 ES: 1.5, Large, $p < 0.05$) on average each night. This data suggested that the sleep of the youth soccer players might be less efficient (as a consequence of greater levels of disturbance), despite desirable quantities of sleep being attained than non-athlete controls.

Chapter 5 provided a daily comparison of sleep measures conducted over a 14-day assessment period. It is apparent that youth soccer players attained more sleep quantity in the nights preceding the match day (M-2: 488 ± 53 min [ES: 0.91, Moderate; $p = 0.06$] & M-1: 486 ± 64 min [ES: 0.84, Moderate; $p = 0.02$] respectively) in comparison to the night of the day after the match day (M+1: 422 ± 61 min). Such a finding suggested that youth soccer players adopt behaviours that reduce their sleep quantity on the designated recovery day (M+1) by >60 min, which may impact the recovery processes associated to this day. Relationships between sleep parameters and training and match load indicated a 100 au rise in RPE_{LOAD} (RPE * Duration) increased the time spent in wake (42 s [90% CI: 0 to 84 s]; ES: 0.36, Small; $p = 0.098$). It was also observed that an increase of 1000 m total distance increased the time spent in wake (40 s [90% CI: 5 to 75 s]; ES: 0.33, small; $p = 0.06$) A 100 m rise in high-speed running distance increased the number of awakenings observed (0.14 [90% CI: 0.03 to 0.25]; ES: 0.28, $p = 0.04$) and the time spent in wake on average each night (1.5 min [90% CI: 0.78 to 2.3 min]; ES: 0.57, Small; $p = 0.04$). A similar outcome was observed in Chapter 6 were a 100 m rise in average high-speed running distance across three different 14-day training periods during the youth soccer season showed a 5 min increase in the time spent in wake on average (ES: 0.88, moderate; $p = 0.04$). Such outcomes provided a potential link between increases in training intensity (i.e. high-speed running distance) and sleep disturbances within youth soccer players. Increases in high-speed running distance also related to an increase of 24 min (90% CI: 12 to 36 min) on average for total sleep time (ES: 1.3, large; $p < 0.01$). Similarly increased high intensity heart rate (>85% max HR) was shown to effect total sleep time +20 min (90% CI: 6 to 32 min; ES: 0.87, moderate; p = 0.035). This may suggest that increases in intensity also may impact the amount of sleep quantity within youth soccer players. At present the mechanism for this response largely remains unknown.

Within Chapter 7, a practical sleep hygiene strategy (10 min showering at ~40 °C, 20 min before time of lights out) was investigated. A group of ten youth soccer players were evaluated under normal sleeping conditions (control) and a shower intervention period, each consisting of three days within a randomized cross over trial design. Sleep information was collected using the WS. In addition to skin temperature, which was evaluated using iButton skin thermistors. The iButtons were used to establish both distal and proximal skin temperatures. This data was also used to create the distal to proximal gradient (average of distal measures – average of proximal measures = DPG). The data demonstrated that the shower intervention elevated distal skin temperature by (+1.1 °C [95% CI: 0.1 to 2.1 °C]; ES: 0.44, Small; $p = 0.04$) on average during a 10-minute period prior to lights out in comparison to the control condition. This elevation was also present during the first 30 minutes following lights out (1.0 °C [95% CI: 0.4 to 1.6 °C]; ES: 0.65, Moderate; $p < 0.01$), which was also accompanied by an increased DPG between conditions (0.7 °C [95% CI: 0.3 to 1.2 °C]; ES: 0.45, Small; $p < 0.01$). Additionally it was observed that on average the sleep onset latency of the youth soccer players was lower in the shower intervention condition (-7min [95% CI: -13 to -2 min]; ES -0.55, Moderate; $p = 0.007$). However no other sleep variable was affected as a result of the intervention. These findings demonstrate that a warm shower performed before lights out may offer a practical strategy to alter the thermoregulatory properties of distal skin temperature, which may advance sleep onset latency within youth soccer players.

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CONTENTS

LIST OF ABBREVIATIONS

Aβ - β-amyloid

ACT – Wristwatch Actigraphy

AST – Assumed Sleep Time

AU – Arbitrary Units

BA – Bland Altman

CI – Confidence Interval

CNS – Central Nervous System

CON – Control

CRP – C-Reactive Protein

DPG – Distal to Proximal Gradient

DUR - Duration

EEG – Electroencephalography

EMG – Electromyography

EOG – Electrooculography

ES – Effect Size

FBG – Firstbeat Body Guard

GH – Growth Hormone

GPS – Global Positioning System

HR – Heart Rate

HR_{HI} – Time spent above 85% Maximum Heart Rate

HSD – High-Speed Running Distance

IL-1 – Interleukin 1

IL-6 – Interleukin 6

IQR – Interquartile Range

LoA – Limits of Agreement

M – Match Day

M-1 – Day before the Match Day

M-2 – Two days before the Match Day

M-3 – Three days before the Match Day

M-4 – Four days before the Match Day

M+1 – Day after the Match Day

NA – Not Applicable

NREM – Non Rapid Eye Movement

N$_{WAKE}$ – Number of Awakenings

OFF – Designated day off within soccer schedule

POAH – Preoptic area of the anterior hypothalamus

P1 – Period 1

P2 – Period 2

P3 – Period 3

PS – Probability of Superiority

PSG – Polysomnography

REM – Rapid Eye Movement

RPE – Rate of Perceived Exertion

RPE$_{LOAD}$ – Duration multiplied by session Rate of Perceived Exertion

SCN – Suprachiasmatic Nucleus

SI – Shower Intervention

SD – Sleep Diary

Sd – Standard Deviation

SOC – Soccer Players

SOL – Sleep Onset Latency

SQ – Perceived Sleep Quality

TD – Total Distance

TNFα - Tumer Necrosis Factor α

TOFA – Time of Final Awakening

TOLO – Time of Lights Out

Trp - Tryptophan

TST – Total Sleep Time

VO2$_{MAX}$ – Maximal Oxygen Uptake

WASO – Wake after Sleep Onset

WS – Zeo Wireless Bedside Sleep Monitor

WSNs – Warm Sensitive Neurons

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CHAPTER 1

GENERAL INTRODUCTION

1.1 BACKGROUND

Elite soccer performance is often regarded as being complex in nature (Morgans, *et al*, 2014). Such complexity may derive from the diverse performance demands and the intermittent physiological profile associated with the sport, were each player is required to complete varied aspects of movements and intensities (e.g. walking to maximal sprinting) (Drust, *et al*, 2007). These include numerous changes of direction (every 4-6 seconds) (Stolen, *et al*, 2005; Dellal, *et al*, 2011) and the requirement to repeat high-intensity bouts of exercise on average every 70-90 seconds (Stolen, *et al*, 2005). Soccer players are also required to carry out a high number of technical actions for successful performance (e.g. passing, shooting, tackling, heading etc...) and to maintain psychological focus around the tactical constraints of the match (Morgans, *et al*, 2014). Such a profile results in a contribution from multiple energy systems during match play as well as high psychological and cognitive demands (Bangsbo, 1994).

To facilitate the demands of soccer match-play a multidimensional ergonomic approach is often taken towards soccer training, with physical components (i.e. aerobic, anaerobic, strength and power activities) of training integrated alongside the technical and tactical aspects (Stolen, *et al,* 2005; Morgans, *et al*, 2014). Typically such a training schedule takes place alongside the requirement to complete a minimum of one competitive match per week (Morgans, *et al*, 2014). Such intensive competition schedules may restrict the available windows of trainability (Morgans, *et al*, 2014), thereby complicating the training process. These requirements also necessitate an emphasis on recovery in an attempt to maintain optimal performance.

Sleep is often described as the most efficacious recovery strategy available to athletes (Halson, 2008) and is thought to play an important role in supporting optimal athletic performance on a daily basis (Davenne, 2009; Venter, 2012). Inadequate sleep (e.g. sleep restriction & sleep deprivation) may negatively affect factors relating to optimal exercise performance (Reilly & Piercy, 1994; Reilly & Edwards, 2007; Orzel-Gryglewska, 2010). Such factors may also be related to physiological functions implicated in the recovery process, such as a reduction in growth hormone, increased cortisol and impaired glucose metabolism (Spiegal, *et* al, 1999; Kato, *et al*, 2002;

Padilha, *et al*, 2011; Peeri, *et al*, 2012). Shorter sleep durations have also been suggested to increase the risk of infection (<7hrs; Prather, *et al*, 2015) and injury (<8hrs Milewski, *et al*, 2014), which may render an athlete unavailable for competition selection. Alternatively extending sleep above habitual baseline has been suggested to have positive effects on exercise performance outcomes, such as faster sprint times and increased accuracy in technical sporting tasks (e.g. shooting accuracy), as well as improved alertness, mood and a reduced perception of fatigue (Dement, 2005; Mah, *et al*, 2011). These effects may be due to the physiological and psychological restorative qualities of deep (NREM stages 3 & 4) and rapid eye movement (REM) sleep (Samuels, 2008; Davenne, 2009). Therefore it has been suggested that athletes should look to extend their sleep above habitual baseline (up to 10 hrs) over a period of weeks to improve athletic performance (Mah, *et al*, 2011). This may compensate for accumulated sleep debt, which may enhance the regenerative processes associated with sleep (Samuels, 2008: Davenne, 2009). In turn this may positively influence subsequent sporting performance.

Research detailing the sleep within elite athletic populations is still within its infancy, though the research that is available provides some evidence for the existence of sleep related problems in elite sports athletes, which may lead to sub-optimal sleeping patterns (Taylor, *et al*, 1997; Samuels, 2008; Davenne, 2009; Venter, 2010; Leeder, *et al,* 2012; Venter, 2012; Lastella, *et al*, 2015; Nedelec, *et al,* 2015a; Shearer, *et al*, 2015; Fullagar, *et al*, 2016a). However it has also been suggested that regular participation in the sport of soccer is beneficial to the process of sleep (Brand, *et al,* 2009; Brand, *et al*, 2010). Though at present the relationship between soccer and sleep still remains unclear (Nedelec, *et al*, 2015a). This may partly be due to the limited data that exists that documents the sleep of soccer players during the competitive season using objective sleep measures (Robey, *et al,* 2014; Nedelec, *et al*, 2015a; Fullagar, *et al*, 2016a). Given the lack of information detailing the sleep of soccer players, it seems important to objectively quantify sleep within the sport of soccer to examine the potential factors influencing the process of sleep. This would provide a better understanding of the typical sleeping habits of youth soccer players. Such information could also provide detail of the potential situations that may impact sleep during the soccer season. Additionally this may also highlight the need for sleep hygiene strategies to be developed, in an attempt to improve sleep in soccer players. To present date no study has looked to investigate the habitual sleeping pattern within full-time youth soccer players during the competitive season in any detail. As a consequence the following aims for this thesis are:

1.2 AIMS AND OBJECTIVES

The primary aim of the present thesis is to investigate the habitual sleeping pattern of youth soccer players during the competitive youth soccer season to examine the relationship with training and matches. This will be investigated through the completion of the following objectives:

1. Evaluate of the validity of a commercially available wireless sleep-monitoring device to monitor sleep in field conditions.

2. To quantify and evaluate the typical sleeping pattern of youth soccer players during the competitive season and compare them to a non-athlete control group.

3. To examine the relationship between sleep, training and match load.

4. Develop and incorporate a practical sleep hygiene strategy that may impact the sleeping patterns of youth soccer players.

CHAPTER 2

LITERATURE REVIEW

2.1 SLEEP

Sleep is a behavioural state that habitually alternates with waking (Stickgold & Walker, 2009). During sleep changes in human physiology, reduced movement and diminished consciousness occur (Stickgold & Walker, 2009). Sleep is typically defined as two different types; Non Rapid Eye Movement-sleep (NREM; which is subsequently split into four stages; light [stages 1&2] and deep sleep [stages 3&4]) and Rapid Eye Movement-sleep (REM) (Stickgold & Walker, 2009). The profile of NREM sleep within the sleep cycle is seen as gradual, were a progressive increase in high amplitude, and decrease in frequency of electroencephalographic (EEG) waves occur throughout the four stages into the deepest categorised sleep (Stickgold & Walker, 2009). Additionally during NREM the brain reduces its activity, neuronal activities become synchronized and heart rate and respiration rate decline (Davenne, 2009; Stickgold & Walker, 2009; Venter, 2012). The stage of REM sleep typically occurs after 30 – 40 minutes of a sleep cycle and transitions from NREM sleep (Stickgold & Walker, 2009; Venter, 2012). REM is described as paradoxical due to the contrast in EEG activity in comparison to NREM sleep (Stickgold & Walker, 2009). During the stage of REM sleep low amplitude, high frequency EEG waves are produced; in which the brain is considered most active and greater resembles that of the waking state, despite a consequent reduction in muscular tone ("REM atonia") (Stickgold & Walker, 2009). Additionally rises in heart rate, body temperature and respiration can also be observed during periods of REM sleep (Davenne, 2009; Venter, 2012).

In adults NREM and REM sleep stages generally reoccur within roughly 90-minute cycles (Stickgold & Walker, 2009; Venter, 2012). As sleep increases throughout the night the duration of REM sleep increases within each respective cycle were as NREM stages 3&4 are concomitantly reduced until the point of final awakening (Stickgold & Walker, 2009; Venter, 2012). It is suggested that the stages of sleep serve critical processes that contribute to both cognitive and physiological function (Samuels, 2008; Davenne, 2009). Sleep is therefore seen as a basic essential need that is required to perform everyday tasks optimally, though the exact reason for why humans sleep is still largely unknown (Ferrara & Degennaro, 2001). Sleep must, however, serve as a vital function given that it is a recurring state in all humans that has survived so many years of evolution.

2.1.1 CONTROL OF SLEEP

The tendency to sleep within humans is typically described by a two-process model containing both a homeostatic (hourglass, referred as process S) and circadian component (clock, referred as process C) (Romeijn, *et al*, 2012; Borbely, *et al*, 2016). This two-process model is thought to continuously interact throughout the 24 h day, influencing patterns of both wakefulness and sleep (Borbely, *et al*, 2016). The homeostatic factor of the hourglass refers to the time passed since the last sleep episode, whereby the accumulation of neuromodulators (i.e. nitric oxide and adenosine levels in areas such as the basal forebrain and cortex) during wakefulness acts to "fill" the hourglass (thus increasing the homeostatic pressure to sleep) (Porkka-Heiskanen, *et al*, 1997; Brown, *et al*, 2012; Romeijn, *et al*, 2012). These neuromodulators have been suggested to inhibit wake-promoting processes, such as the cholinergic system, orexin neurons and GABAergic outputs, which in turn may activate sleep-activiating neurons in the ventrolateral preioptic area of the hypothalamus and promote sleep (Rainnie, *et al*, 1994; Morairity, *et al*, 2004; Liu & Gao, 2007, Brown, *et al*, 2012). Sleep is subsequently thought to "flip" the hourglass, which is marked by reduced concentrations of adenosine (thereby dissipating the pressure and restarting the process) (Porkka-Heiskanen, *et al,* 1997; Romeijn, *et al*, 2012).

The need for sleep is also influenced by the time of day (i.e. the circadian clock) (Borbely, *et al*, 2016). The circadian (circa: about, dies: days) component of sleep is linked primarily to the derived rhythms of the suprachiasmatic nucleus (SCN) (the central clock of the brain) that arise at a particular time of day. The SCN promotes both sleep and wake as a master output at specific portions of the day (Romeijn, *et al*, 2012). One of the principle zeitgeibers (time givers) contributing to the processes of the SCN is the change in environmental light and darkness to which individuals are exposed to within a daily cycle (Reilly, *et al*, 1997; Davenne, 2009). As a consequence of the hours of darkness, increased levels of melatonin are observed, which also induces distal vasodilation and in turn increases sleep propensity (Krauchi, *et al*, 1997; Stickgold & Walker, 2009). Other mediated processes such as changes in posture, the regulation of temperature, endocrine and metabolic function, physical exercise and patterns of feeding are also thought to contribute to the synchronicity of the daily circadian cycle and thus influence the sleep-wake cycle (Van Someran, 2000; Laposky, *et* al, 2008; Davenne, 2009; Stickgold & Walker, 2009).

An individual's sleep needs seem to vary (Ferrara & Degennaro, 2001). Therefore it is suggested that sleep has a large inter-individual variability (Ferrara & Degennaro, 2001). Such differences may derive through the genetic and physiological differences of the individual's biological clock and how such processes are entrained (Facer-Childs & Brandstaetter, 2015). One example of this is the differences in chronotype seen between individuals that result in a distinct circadian phase and a disparity within the morning-eveningness dimension (Samuels, 2008; Facer-Childs & Brandstaetter, 2015). A morning type, also referred to as "lark", displays an advance rhythm, which is categorised by an earlier time of bed and awakening (Facer-Childs & Brandstaetter, 2015). Alternatively an evening type individual, A.K.A "night owl", displays tendencies of delayed rhythmicity (later bed and times of final awakening) in comparison to intermediate and morning types (Facer-Childs & Brandstaetter, 2015). Further differences could also occur as a result of gender, age, social factors and behaviours of the individual. Combined this range of factors may contribute to important processes in the structure of the mechanism of the sleep-wake cycle (Ferrara & Degennaro, 2001).

2.1.2 FUNCTIONAL ROLES OF SLEEP

There is a growing body of evidence into the study of sleep that confirms the link between critical sleep factors and physiological, metabolic and cognitive functions (Samuels, 2008). Frank (2006) summarised specific theories (somatic, neural and cognitive) behind the potential role of sleep. These included the recovery of all the major physiological systems that are important for the completion of an exercise challenge (e.g. the muscular system, the central nervous system [CNS], the neuroendocrine system, immune system and the brain) and cognitive development. This may suggests sleep also plays an important role in processes such as learning and memory function (Frank, 2006; Van Cauter, *et al*, 2008). A combination of the specific stages of sleep (Non Rapid Eye Movement-sleep [NREM], which is subsequently split into four stages [light, stages 1&2 and deep sleep, stages 3&4] and Rapid Eye

Movement-sleep [REM]) is thought to have distinct influences to these functional processes (Frank, 2006).

The NREM stage of sleep is one suggested factor that is linked to the physiological restoration of sleep (Davenne, 2009). During NREM the brain reduces its activity, neuronal activities become synchronized and heart rate and respiration rate decline (Davenne, 2009). An increased release of hormones from the endocrine system is also seen, with more than 95% of daily hormonal secretion observed during NREM sleep (Gunning, 2001). The restorative effects of NREM sleep have been primarily associated with the pulse activity of growth hormone (GH) secretion (Van Cauter, *et al,* 1997; Davenne, 2009; Stickgold & Walker, 2009). Increases in growth hormone are deemed important for recovery as it can stimulate growth, cell reproduction and the protein synthesis needed for the restoration of muscle tissue and energy metabolism. A loss in deep sleep (NREM stages 3 and 4) may however attenuate the amount of growth hormone that is secreted during the night (Kato, *et al*, 2002). This may potentially impact the athlete's post exercise recovery processes (Samuels, 2008).

In addition to the impact of sleep on the recovery of the essential supporting physiological systems, is the belief that sleep also plays a restorative function to the brain and central nervous system (CNS). This neuro-metabolic theory of sleep is thought to be associated with the "metabolic cost" during the waking state. Sleep provides a mechanism were the "debt" for the activity that is completed during wake can be "paid" during sleep (Frank, 2006). This may be linked to the accumulation of a number of neuro-metabolic substances. During waking hours a number of neuro-metabolic by-products are thought to accumulate within the interstitial space surrounding cells of the brain (such as β-amyloid [Aβ]) (Xie, *et al*, 2013). Such waste products are thought to be adverse to the CNS and therefore may impair important functions relating to athletic performance (e.g. cognitive function). Sleep increases the volume of the interstitial space, as a consequence of a clearance of these neurotoxic compounds (Xie, *et al*, 2013). This would suggest that sleep has an important role contributing to neuro-metabolic homeostasis (Xie, *et al*, 2013). Therefore sleep is likely to provide athletes with restorative properties that may allow daily optimal functioning of the brain and the central nervous system.

Other established evidence linking sleep and the function of the brain is related to specific aspects of cognitive function. It is thought that sleep has a pronounced effect on both the process of learning and memory consolidation (Diekelmann & Born, 2010). Walker and Stickgold (2005) suggested that it is practice, with sleep, that makes perfect. This referred to the delayed improvements in learning, without subsequent further practice (Walker & Stickgold, 2005). Such observations suggest that the process of learning is associated with the neuronal process of sleep (Walker & Stickgold, 2005). Both NREM and REM stages of sleep are considered to be important factors within this process (Stickgold & Walker, 2009; Diekelmann & Born, 2010). During NREM stage 2 and deep sleep (stages 3 & 4) neuronal activity is synchronized, whereby newly encoded memories are organised and consolidated with long term memory structures (Diekelmann & Born, 2010). REM sleep is categorised by a subsequent de-synchronisation of neural activity were the brain resembles a more waking state, which is suggested to be critical for forming brain connections (Diekelmann & Born, 2010). This process is also suggested to strengthen the representation of the newly formed memories (Diekelmann & Born, 2010). Therefore the cognitive benefits of sleep could prove essential to the acquisition, storage and transfer of specific skills and actions that are required within sport, which are arguably essential to athletic development and performance.

2.1.3 MONITORING OF SLEEP

The current understanding of the functions and mechanisms of sleep have primarily resulted from methodologies available to effectively monitor the process. A scoring criterion developed by Rechtschaffen & Kales (1968) utilising electroencephalography (EEG, measuring electrical activity of the brain; 'brain waves'), electrooculography (EOG, the resting potential of the retina) and electromyography (EMG, the electrical activity of skeletal muscles) (collectively termed Polysomnography), has become the main method to describe sleep architecture (differentiating the stages of sleep and wake). Polysomnography (PSG) is therefore considered the gold standard methodology for sleep assessment, as this can provide a breakdown of specific sleep phases, latencies and number of awakenings (Flemons & Littner, 2003). The practicality of using PSG to effectively monitor habitual sleep is however somewhat more difficult. For example PSG typically requires a laboratory setting and the use of manual interpretation of the data from sleep experts (Shambroom, *et al*, 2012). Such a monitoring approach would therefore prove impractical within an athletic setting, given that it is time consuming, costly and largely invasive to the athlete. This may consequently be one reason as to why sleep monitoring within athletes is difficult during training and competition (Driver & Taylor, 2000). There are now alternative methods that allow for the automatic monitoring of sleep patterns and in some cases sleep staging, which can be more easily integrated into an individual's habitual sleeping environment (Martin & Hakim, 2011; Shambroom, *et al*, 2012). Such methods therefore offer a more practical means of collecting sleep data for the athlete without the need of visits to a sleep laboratory (Shambroom, *et al*, 2012). Such methodologies may prove useful for the monitoring of sleep over multiple nights in an athletic setting as the individuals daily routine will not be disturbed.

Wristwatch actigraphy is one such example of an alternative means to monitoring sleep quantity (total sleep time) and quality (sleep efficiency) (Martin & Hakim, 2011). Such technology categorises the activity profile of the individual during sleep, derived from the movement of the non-dominant wrist, through an accelerometer embedded within a small lightweight wristwatch. The accelerometer detects the frequency and intensity of movement and uses this information to determine periods of activity (wakefulness) and inactivity (sleep) using automated scoring algorithms (Pollack, *et al*, 2001). Such methods are considered a cost effective and time efficient means to evaluate the habitual sleep of individuals within their home environment (Sadeh, 2011). A number of validation studies comparing the detection of sleep between actigraphy and PSG have suggested positive overall agreement between the approaches, though actigraphy is somewhat limited in the detection of specific sleep parameters (Martin & Hakim, 2011; Sadeh, 2011). As movement is the primary indicator for "wake" within the analysis of an actigraphy profile, an individual who was to lay motionless during sleep onset would increase their quantified periods of sleep (Martin & Hakim, 2011). It is therefore likely that an overestimation of total sleep time may occur by using actigraphy devices, as a consequence of a sub-optimal detection of sleep onset (Pollack, 2001; Martin & Hakim, 2011). The wake time after sleep onset may also be overestimated, as this also is related to the movement detected during the night (Tonetti, *et al,* 2008).

It has been suggested that wristwatch actigraphy should be used in conjunction with other established methods to provide greater accuracy of information in the quantification of specific sleep parameters (Martin & Hakim, 2011). The provision of subjective information on issues such as sleeps timings (i.e. time of lights out, initiation of sleep onset, recollection of awakenings and time of final awakening) may provide the practitioner with additional sleep information that enables a more accurate interpretation of the data provided by wristwatch actigraphy to be made (Sadeh, 2011; Carney, *et al*, 2012). The application of subjective approaches such as sleep diaries will require a detailed recollection of sleep (Carney, *et al*, 2012). This may lead to bias within the data due to a reliance on the individual's ability to recall specific detail during sleep events (Arora, *et al*, 2013).

Wireless signalling systems have been evaluated as a novel way to provide a solution to accurately evaluate sleep away from the laboratory environment (Shambroom, *et al*, 2012; Tonetti, *et al*, 2013). Devices such as the Zeo Wireless Bedside monitor (Zeo, Inc; Newton, MA, USA) are commercially available equipment that uses these approaches. This device utilises a dry fabric silver-coated headband, which acts to detect EEG activity of the forehead, using a singular bipolar channel located approximately at Fp1 – Fp2 (Shambroom, *et al*, 2012). The subsequent signal that is derived is then digitally converted using a 12-bit analog converter (which filters and amplifies the signal) before it is transmitted to a local base station (bedside unit) for data storage (Shambroom, *et al*, 2012). This base station then utilises a microprocessor, to evaluate the collected sleep information and to analyse it real-time to calculate the specific stage of the sleep signal (Shambroom, *et al*, 2012).

Previously the Zeo wireless system has been compared to PSG in an attempt to provide validation to the system (Shambroom, *et al,* 2012; Tonetti, *et al*, 2013). A summary of the results detailing the comparison of specific sleep variables within these studies can be seen in Table 2.1. Within the study of Tonetti & Colleagues (2013), there were significant mean differences between the WS and PSG for both total sleep time and wake after sleep onset. Though these results were statistically significant it remains questionable whether such values are clinically significant given that such mean differences are also typical within comparisons of actigraphy (considered the field gold standard) and PSG (Tonetti, *et al*, 2008; Elbaz, *et al*, 2013).

Table 2.1. Studies comparing the Zeo Wireless System (WS) to Polysomnography (PSG)

Reference	Sleep Variable	Reported Results
Shambroom, *et al*, 2012. N = 29 (Rated against two PSG scorers)	Total Sleep Time (min)	Mean Diff: +10.8 & +17.7 min (NS); ICC (0.92 & 0.95)
	Sleep Onset Latency (min)	Mean Diff: +1.9 & +4.9 min (NS); ICC (0.42 & 0.50)
	Number of Awakenings (#)	Mean Diff: -1.04 & +0.84 # (NS); ICC (0.60 & 0.69)
	Wake After Sleep Onset (min)	Mean Diff: +5.9 & +15.8 min (NS); ICC (0.85 & 0.90)
Tonetti, *et al*, 2013. N = 11 (Compared to a consensus score of two PSG scorers)	Total Sleep Time (min)	Mean Diff: +23.29 min ↑
	Sleep Onset Latency (min)	Mean Diff: -6.82 min (NS)
	Number of Awakenings (#)	Mean Diff: -0.64 # (NS)
	Wake After Sleep Onset (min)	Mean Diff: -17.46 min ↓

ICC (intraclass correlation coeffecient) – ranging from -1 to 1, 1 representing a perfect correlation, 0 representing complete lack of correlation; NS = Non significant difference ($p > 0.05$); ↑ significant overestimation of the WS ($p < 0.05$); ↓ significant underestimation of the WS ($p < 0.05$).

Consequently it has been suggested that the wireless system has a positive overall agreement (90 - 97% epoch to epoch comparative agreement) when compared with PSG for the detection of sleep and wake (Shambroom, *et al*, 2012; Tonetti, *et al*, 2013). It should also be noted that such levels of agreement are higher than those associated with the comparison of actigraphy and PSG (86.3% & 85.7%, shown within the same study) (Shamboom, *et al,* 2012). Combined these results led to the suggestion that the wireless system is a viable method for detecting sleep in comparison to other validated field measures (e.g. wristwatch actigraphy) (Shambroom, *et al*, 2012). This is likely due to the use of EEG signalling as the main derived detection strategy for the quantification of sleep. Therefore such home-based wireless signalling devices may have promise in the detection of sleep within athletic population.

2.2 SOCCER

Soccer is a sport categorized by intermittent bouts of physical exercise, with the ability to repeat high-intensity exercise considered crucial for successful physical performance outcomes (Reilly, *et al*, 2008). Typically outfield players will cover distances of 8 – 14 km during match play depending on factors such as playing position and formation (Reilly, 2003; Dellal, *et al*, 2011; Barnes, *et al*, 2014). This distance is often covered in a range of intensities from low intensity activities (e.g. walking) to high intensity movements (e.g. maximal sprinting) (Drust, *et al*, 2007; Di Salvo, *et al*, 2009). In addition to the changes in exercise intensity the game includes multiple high-speed changes in direction (Dellal, *et al,* 2011), accelerations/decelerations, as well as multiple technical actions (e.g. jumping, tackling, heading, kicking) (Bangsbo, 1994, Bangsbo, *et al,* 2006; Barnes, *et al*, 2014). These specific match actions, lead to a requirement for soccer players to be able to generate high muscle forces for 90 min or in some cases longer (e.g. extra time) (Bangsbo, 1994).

As a result of the requirements of soccer, the preparation strategies needed for soccer players are multidimensional (Morgans, *et al*, 2014). This means that multiple physical components must be integrated within the programming for technical and tactical training sessions for effective development of athletic performance within the sport (Morgans, *et al*, 2014). Such considerations make training programmes within soccer both physically demanding and potentially time consuming. Such demands will also necessitate the use of recovery strategies to balance the training process (Meeusen, *et al*, 2012). Without adequate recovery, physiological homeostasis may not be achieved, maladaptation may ensue and decrements to performance may be observed (Meeusen, *et al*, 2012). Given that sleep has multiple restorative qualities that occur on a daily basis, it may be suggested that sleep is a primary contributor to the recovery processes of any athlete (Davenne, 2009).

2.2.1 SLEEP WITHIN SOCCER

The available evidence within athletic populations would suggest that the sleep quantity and quality of athletes is sub-optimal in comparison to aged matched non-athlete counterparts (Leeder, *et al*, 2012). Leeder & Colleagues (2012) observed comparable sleep times between an athlete (Olympic level athletes) and an aged matched non-athlete group (6:55 ± 0:43 vs. 7:11 ± 0:25) using wristwatch actigraphy. This was despite the athletes spending a greater duration within bed in comparison to the non-athlete group (8:36 ± 0:53 vs. 8:07 ± 0:20), which reflected reduced sleep efficiency within the athlete group (80.6 ± 6.4 % vs. 88.7 ± 3.5 %; i.e. longer sleep onsets, more frequent awakenings and longer time spent in wake) (Leeder, et al., 2012). Similar sleeping patterns have also been reported within team sports athletes, such as Australian Rules football, Rugby Union and soccer (average total sleep time 7 ± 1.2 h and sleep efficiency 86.4 ± 4.8 %) (Lastella, *et al*, 2014) and elite youth soccer players, prior to a pre-season camp at altitude (total sleep time: 7 ± 0.5 h; sleep efficiency: 80 ± 3 %) (Roach, *et al,* 2013) and during the competitive season (total sleep time: 7.12 ± 0.39 h and 7.42 ± 1.01 h; sleep efficiency: 89.4 ± 5.4 % and 88.9 ± 8.1 %) (Robey, *et al*, 2014). This may indicate that sub-optimal sleeping patterns are also apparent in team sports athletes such as soccer players.

It has, however, been suggested that soccer produces positive benefits for the processes of sleep (Brand, *et al*, 2009). Brand, et al (2009) showed that adolescent male soccer players (aged 15 ± 1 yrs) demonstrated a higher sleep quality, shortened sleep onset, lower number of awakenings and a greater sleep quantity during the subjective recall of sleep, in comparison to non-athlete age matched controls. Such sleep times recorded by Brand, et al (2009) (8.60 ± 1.02 h) is higher than those subsequently reported in other youth soccer populations (6-7.5 h) (Roach, *et al*, 2013; Robey, *et al*, 2014). However these differences may be a result of the use of subjective sleep measurement, which may overestimate sleep information in comparison to objective measurements such as actigraphy (Teng, *et al*, 2011). Further work by Brand, et al (2010) also suggested that adolescent soccer players have higher sleep efficiency, lowered sleep onset latency and an attainment of a higher amount of deep sleep, during laboratory based PSG evaluations of sleep, in relation to non-athlete controls. However despite the suggested increased sleep quality, provided through the objective measurement of sleep staging, the average sleep quantity recorded for the soccer players was 7 ± 0.5 h (Brand, *et al*, 2010). Collectively these results would suggest that soccer players typically sleep less than 8 h a night. Thereby suggesting that some soccer players display sub-optimal sleeping patterns despite these other perceived positive outcomes.

Given that such sleep times may fall below the criteria range (7-9 h) recommended for healthy sleepers to maintain optimal daily functions (Ferrara & Degennaro, 2001; Van Dongen, *et al*, 2003), such sleep durations are likely inefficient for athletes, such as soccer players (Davenne, 2009; Leeder, et al., 2012). A lack of evidence that details the exact sleep needs of soccer players or the factors that typically influence the sleep-wake cycle during the soccer season prevents clear evaluations to be made of the specific consequences of such findings. It would therefore seem relevant to identify the factors that influence sleep in soccer players and to attempt to further the understanding of the functions of sleep for this population.

2.3 POTENTIAL FACTORS INFLUENCING SLEEP IN SOCCER PLAYERS

During the soccer season, it is theorised that soccer players may be exposed to a number of stressors that may interfere with the typical processes that are involved in the control of sleep (Nedelec, *et al*, 2015a). Sleep may be influenced by externally derived factors such as the variability in match schedules and the requirement for regular travel, factors which may alter circadian processes linked to sleep-wake cycle (Roach, *et al,* 2013; Nedelec, *et al*, 2015a; Fullagar, *et al*, 2016). The processes of sleep may also be altered by the factors relating to participation in the sporting activity (e.g. the physiological load imposed on the player) (Leeder, *et al*, 2012). Such factors may impact the homeostatic control of sleep. The modern day soccer player is also likely to face more mental, emotional and social demands (Nedelec, *et al*, 2015a). Individuals with a greater number of life stressors are also likely to display greater disruptions to sleep (Mezick, *et al*, 2009). Such issues may also be prevalent in soccer players especially those at the elite level. Combined these myriad of factors may lead to altered behaviour, irregular sleep routines, a desynchronisation of entrained circadian rhythms and altered homeostatic control linked to the sleep-wake cycle. Subsequently this may alter the quantity and quality of the sleep of soccer players, which may impact the recovery process and athletic performance within the sport (Davenne, 2009; Nedelec, *et al*, 2015).

2.3.1 VARIABILITY IN SCHEDULES

It is well documented that peaks in athletic performance follow circadian rhythms during the day, consequently offering a time period in which optimal athletic performance may be achieved (Drust, *et al*, 2005; Reilly, 2009). Such performance outcomes (e.g. aerobic endurance capacity) are suggested to be different between those individuals displaying morning vs. evening circadian phenotypes (Facer-Childs & Brandstaetter, 2015). These differences are thought to relate to the entrained sleep-wake cycle (Facer-Childs & Brandstaetter, 2015). This is further evidenced when circadian derived processes are disrupted (e.g. as a result of disturbed sleep) there can be adverse effects to performance outcomes (Davenne, 2009; Reilly, 2009), which may relate to a desynchronization of the entrained phase of the sleep-wake cycle (Facer-Childs & Brandstaetter, 2015). As a soccer player relies upon performing optimally during training and competition, it may be suggested that there is an increased importance of maintaining entrained circadian rhythms through maintaining a regular sleep-wake schedule (Reilly, 2009). This may be achieved through maintaining regular sleep times, increasing internal factors (e.g. establishing a bedtime routine, waking up naturally) and reducing external factors that can disturb sleep (e.g. comfortable dark environment, noise free) (Davenne, 2009). However for the soccer player this may be difficult, as the scheduled activities of the sport may be subject to change (Morgans, *et al*, 2014). This may contribute to irregularity within the schedule of sleep within soccer players, which may result in periods of sleep loss (Nedelec, *et al*, 2015a; Fullagar, *et al*, 2016).

One such example would be exposure to evening fixtures (19:45 - 22:00 h kick off times). This is a typical feature for teams participating within both league and domestic/european cup competitions, where evening fixtures are commonly scheduled Consequently participation in evening fixtures is likely to negatively impact sleep (Nedelec, *et al*, 2015; Fullagar, *et al,* 2016). A reduction in sleep quantity (>3hr difference) has previously been observed following evening matches in comparison to afternoon matches and training days within elite soccer players (Fullagar, *et al,* 2016). Such observations have also been reported within other team sports such as rugby union (Eagles, *et al*, 2014; Shearer, *et al*, 2015). It is likely that evening matches expose the soccer player to situations (e.g. bright lights from floodlights, increased arousal and ergogenic aids like caffeine) that may alter the circadian derived processes that are linked to sleep propensity (Nedelec, *et al*, 2015; Fullagar, *et al*, 2016; Shearer, *et al*, 2015). As a consequence players may find it difficult to initiate sleep, thus adopting a later time of lights out and consequently reducing habitual total sleep time. Such a situation may elevate the perception of fatigue and soreness, which may suggest implications to the recovery process following competition (Shearer, *et al*, 2015; Fullagar, *et al*, 2016)

A reduction in sleep quantity may also be further magnified by the inclusion of scheduled activities (such as morning training sessions), which may result in an enforced early morning awakening for the soccer player (Sargent, *et al*, 2014). This has previously been documented within other sports were athletes arise early to facilitate the completion of their training requirements (Sargent, *et al*, 2012; Sargent, *et al*, 2014). This may result in a mismatch between the preferred circadian derived processes associated with the sleep-wake cycle of the individual and the schedule demands of the sport (Samuels, 2008; Sargent, *et al*, 2012). Individuals may shorten their sleep for up to several hours, as a result of the requirement to arise earlier. (Samuels, 2008; Sargent, *et al*, 2012). Such a scenario may have greater consequences for those individuals that display evening type (night owls) tendencies, as these individuals will prefer a later morning awakening (Samuels, 2008). This could lead to severely pronounced restrictions in sleep quantity in certain individuals that may subsequently affect the level of sleep quality attained (Davenne, 2009). In turn this may elevate the perception of fatigue, decrease mood and alter motivation of the athlete prior to exercise, which may impair the athletes ability to perform optimally during training and competition (Reilly & Peircy, 1987; Sargent, *et al*, 2014).

Restrictions in sleep quantity that result from changes in the typical sleeping pattern of individuals may also directly impact exercise performance. Souissi & Colleagues (2008) demonstrated that exercise performance (i.e. peak power within the 30 s Wingate test) was reduced during the evening following a night of partially restricted sleep (sleep being allowed between 22:30 – 03:00, with an enforced 4h earlier awakening). Such declines in anaerobic performance have also been demonstrated within soccer players (Abedelmalek, *et al*, 2013a) and Judo athletes (HajSalem, *et al*, 2013; Souissi, *et al*, 2013) following similar periods of sleep restriction. Maximal strength and sub-maximal strength within typical compound lifts (i.e. back squat & deadlifts, which require a number of large muscle groups) have also been shown to be impaired following consecutive periods of sleep restriction (~3 h per night for 3 nights) (Reilly & Piercy, 1994). It has also been documented that impairments to peak voluntary force and action can occur following longer periods (30 h) of sleep deprivation (Skein, *et al*, 2011). Within the same study decrements to intermittent sprint performance were also noted (Skein, *et al*, 2011). Similar periods of sleep deprivation have also been suggested to limit self-pacing during 30 min treadmill exercise (Oliver, *et al*, 2009) and decrease the time to exhaustion in an incremental cycling exercise test (Azboy, *et al*, 2009). Such literature suggests that sleep loss may impair exercise capacities important to athletic performance.

Other literature offers contrasting results showing no effects of sleep loss (restriction/deprivation) on exercise performance markers (Table 2.2.). It has been suggested that aerobic capacity (Mougin, *et al*, 1991 Mejri *et al*, 2014), anaerobic performance (Mougin, *et al*, 1996, Souissi, *et al*, 2003; Vardar, *et al*, 2007) and the development of muscular force (Blumert, *et al*, 2007; HajSalem, *et al*, 2013) remain unaffected during observed sleep loss. An overview of the current literature showing the contrasting findings regarding the impact of sleep loss on exercise performance is shown in Table 2.2. It should also be noted that such outcome discrepancies might be attributed to the differences in experimental designs (i.e. participants, timing of exercise protocols and sleep intervention used) between studies. The transferability of the current literature documenting sleep loss to elite athletes is also debatable; as such periods of sleep loss (e.g. 4.5 hrs a night or full nights of restricted sleep) may not be fully representative of situations that result in sleep loss within athletic populations. Therefore periods of sleep loss applicable to athletes should also be investigated.

Table 2.2 Overview of studies detailing the effects of sleep loss (i.e. periods of sleep restriction and deprivation) on exercise performance outcomes

Reference	Participants (Sample Size)	Exercise Protocol	Period of Sleep Loss	Result
		Aerobic Exercise		
Azboy, & Kaygisiz (2009)	Volleyball Players	Incremental cycling to exhaustion	25-30 h Sleep Deprivation	↓ Time to exhaustion
	Runners		25-30 h Sleep Deprivation	Non Significant
Hill, et al, (1994)	Students (N = 14)	Incremental cycling to exhaustion	25-30 h Sleep Deprivation	Non Significant
Goodman, et al, (1989)	Young Females	Incremental cycling to exhaustion	60 h Sleep Deprivation	Non Significant
Mougin, et al, (1991)	Cyclists (N = 7)	Incremental cycling to exhaustion	3 h Sleep Restriction	Non Significant
Oliver, et al, (2009)	Male Recreationally Active (N = 11)	30 min self paced treadmill run	30 h Sleep Deprivation	↓ Distance Covered [m]
Martin & Chen (1984)	Graduate Students (N = 8)	Walking treadmill to exhaustion	50h Sleep Deprivation	↓ Time to exhaustion
Reilly & Deykin (1983)	Trained Participants (N = 8)	Incremental Treadmill Test	2.5 h sleep 3 nights Sleep Restriction	Non Significant

Continuation of Table 2.2

Reference	Participants	Exercise Protocol	Period of Sleep Loss	Result
		Anaerobic Exercise		
Souissi, et al (2008)	Male Students (N=11)	30 s Wingate Test	~4 h Beginning of night ~4 h End of night	Non Significant [e m] Non Significant [m] ↓ Mean Power [e] ↓ Peak Power [e]
Souissi, et al (2013)	Judo Athletes (N=11)	30 s Wingate Test	Sleep Restriction ~4 h SR beginning of the night ~4 h SR end of night Sleep Restriction	Non Significant [e m] Non Significant [m] ↓ Mean Power [e] ↓ Peak Power [e]
HajSalem, et al (2013)	Judo Athletes (N=12)	30 s Wingate Test	Sleep Restriction	↓ Mean Power ↓ Peak Power
Abdelmalek, et al (2013a)	Soccer Players (N = 12)	30 s Wingate Test	4.5 h Sleep Sleep Restriction	↓ Mean Power [e m] ↓ Peak Power [e]
Mougin, et al (1996)	Male Highly Trained (N=8)	30 s Wingate Test	~4 h Sleep Sleep Restriction	Non Significant [m]
Vardar, et al (2007)	Male Students (N=13)	30 s Wingate Test	~4 h SR at beginning of the night Sleep Restriction	Non Significant
Souissi, et al (2003)	Male Students (N=13)	30 s Wingate Test	30h Sleep Deprivation 24h Sleep Deprivation 36 h Sleep Deprivation	Non Significant Non Significant [e m] ↓ Mean Power [e] ↓ Peak Power [e]

Continuation of Table 2.2

Reference	Participants	Exercise Protocol	Period of Sleep Loss	Result
		Intermittent Exercise		
Mejri et al, (2016)	Male Taekwondo Athletes (N = 10)	Yoyo Intermittent Recovery Test I	4 h Sleep Restriction beginning & end of night	↓ Distance Covered [e]
Mejri, et al, (2014)	Male Taekwondo Athletes (N = 10)	Yoyo Intermittent Recovery Test I	4 h Sleep Restriction beginning & end of night	Non Significant [m]
Skein, et al, 2011	Male Team Sport Athletes (N=10)	15 m sprints with ~50 s self paced exercise for 50 min (1 min rest every 10 min)	30 h Sleep Deprivation	↓ 15 m sprint time
		Muscle Force		
Reilly & Deykin (1984)	Trained Participants (N = 8)	Isometric Grip Strength	2.5 h sleep 3 nights Sleep Restriction	Non Significant
Goh, et al (2001)	Military Service (N=7)	Isometric Grip Strength	24 h Sleep Deprivation	Non-Significant
Meney, et al (1998)	Healthy Males (N=14)	Grip, back strength, leg Strength	24 h Sleep Deprivation	Non Significant ↓ Back Strength
Skein, et al, 2011	Male Team Sport Athletes (N=10)	Maximal Isometric Voluntary Contraction 15 reps right knee	30 h Sleep Deprivation	↓ MVC ↓ Peak Voluntary Force

Continuation of Table 2.2				
Reference	**Participants**	**Exercise Protocol**	**Period of Sleep Loss**	**Result**
Bulbulian, et al (1996)	Male US Marine Corps (N=24)	Max knee flexion and extension contraction at isokinetic speeds (1.57,2.62 & 3.66 rad·s^{-1}) followed by 45 consecutive contractions at 3.14 rad·s^{-1}	30 h Sleep Deprivation	↓ Knee extension peak torque ↓ Knee flexion peak torque
Blumert,et al, (2007)	Male Collegiate Weightlifters (N=9)	Snatch, Clean and Jerk and Front Squat (1 RM)	24 h Sleep Deprivation	Non Significant
Reilly & Piercy (1987)	Male Participants (N=8)	Weight Lifting at maximal and submaximal loads	3 h Sleep 3 Nights Sleep Restriction	↓ Bench Press (Both) ↓ Deadlift (Both) ↓Leg Press (Both) ↓ Bicep Curl (Submax)

[m] observed on morning exercise performance
[e] observed on evening exercise performance
↓ significant decline in reported outcome ($p < 0.05$)

The scheduled activities in the elite sport might not always impose restrictions to sleep. Robey, *&* Colleagues (2014) observed that soccer players adopted a later time of lights out when training was imposed in the evening, however, the following morning the players displayed a later time of final awakening. This was a consequence of the scheduled recovery day, which allowed sleep quantity to be maintained (Robey, *et al*, 2014). Therefore careful scheduling of activities could allow athletes to maintain sleep quantities and avoid sleep loss following situations that may impose sleep restrictions. However, athletic populations may be afforded with longer times in bed as a result of the schedule of the sport, yet still display a lower sleep efficiency in comparison to non-athletes (Leeder, *et al*, 2012; Lastella, *et al*, 2014). Such disruption to sleep, leading to a lowered sleep efficiency, may mean that other factors, such as the training induced stress within the elite sport, may also be an important contributor to the processes of sleep in athletic populations (Leeder, *et al*, 2012).

2.3.2 PHYSIOLOGICAL DEMANDS OF TRAINING AND COMPETITION

It is traditionally perceived that exercise is beneficial to the process of sleep (Chennaoui, *et al*, 2014). Exposure to exercise has been suggested to increase sleep propensity, deep sleep, sleep quantities and reduces sleep disturbances, though such conclusions are drawn from non-athlete populations and so may not be applicable to athletes (Chennaoui, *et al*, 2014). In elite swimmers an increase in training load volume was related to increased movement during sleep (indicating increased sleep disturbance) (Taylor *et al*, 1997). Increased intensities of training load over a three-week training phase have also been demonstrated to reduce both sleep quantity and quality in male road cyclists (Teng, *et al*, 2011). Such observations of a diminished sleep quantity and quality are also consistent with those shown within elite triathletes who undertook a 3-week period of intensified training, in which functional overreaching was observed in 7 of the selected subjects (Hausswirth, *et al*, 2014). Killer & Colleagues (2015) has also observed other similar findings 2015. Such literature would suggest that an increased intensity of exercise might negatively impact sleep in athlete populations. As the athletes within the studies of both Hausswirth & Colleagues (2014) and Killer & Colleagues (2015) were observed to display a state of functional overreaching, which may have been the reason for the elevated sleep disturbance. Therefore it may be suggested that the misbalance of recovery and accumulation of fatigue in relation to the training load are important considerations that impact sleep.

Intense physical exercise loads produce a significant increase in pro-inflammatory cytokines during the recovery period (Santos, *et al*, 2007). Circulating cytokines including interleukin 1 (IL-1), interleukin 6 (IL-6) and tumer necrosis factor α (TNFα) are suggested to be modulators of sleep (Santos, *et al*, 2007). Consequently disturbances to sleep have also been linked to increased cytokine responses, namely increased production of IL-6 (Santos, *et al*, 2007; Main *et al*, 2010; Irwin, *et al*, 2015). Such responses may relate to periods of overload training (increases in volume and intensity), were the concentration of these cytokines is further expressed (Santos, *et al*, 2007; Main, *et al*, 2010). Given that overload training can lead to overreaching in athletes, it is likely that the increased elevation of cytokines may be responsible for the increased level of sleep disturbance in overreached athletes (Santos, *et al*, 2007; Main, *et al*, 2010; Meeusen, *et al*, 2012). Therefore the physiologically derived processes in response to the training load that a soccer player is exposed to may also have important implications for sleep and result in periods of sleep loss.

The loss of sleep may also be responsible for the alteration of the typical secretion of pro-inflammatory cytokines as well as a number of other hormones such as, GH, prolactin, cortisol, testosterone and natural killer cells (Lange, *et al*, 2010; Orzel-Gryglewska, 2010; Cote, *et al*, 2012; Abedelmalek, *et al*, 2013a). Sleep loss may also impair glycogen resynthesis following intermittent exercise, which may influence the availability of energy for subsequent exercise performance (Skein, *et al*, 2011). Individuals who display sub-optimal sleep times are likely to be more susceptible to infection, indicating decreased immune function (Prather, *et al*, 2015). Millewski & Colleagues, (2014) also documented those who sleep <8 h a night are also more likely to sustain an injury than those regularly achieving more sleep (>8 h). Therefore the loss of sleep may have direct consequences on the physiological status of the athlete through inadequate recovery, which may contribute to the maladaptive symptoms of overreaching such as a reduction in exercise performance or injury (Meeusen, *et al*, 2013).

Alternatively, there has been previous suggestion that the physiological load imposed on the soccer player is an important factor that positively impacts sleep quantity and quality (Brand, *et al*, 2009; Brand, *et al*, 2010). Only one study has attempted to investigate the effects of exercise load on sleep in youth soccer players (Robey, *et* al, 2014). No differences were observed for the measures of sleep quantity and quality using wristwatch actigraphy between evening high-intensity training days in comparison to days of rest (before and after the training exposure over a 6-week period) in elite youth soccer (Robey, *et al*, 2014). Therefore the training load seemed to neither impair nor improve sleep in relation to days when no training was carried out. This data may not however, be representative of situations (e.g. matches, accumulated training days) during the soccer season were the imposed physical load on the athlete might be intensified. Therefore this warrants further investigation.

2.3.3 PSYCHOLOGICAL DEMANDS OF TRAINING AND COMPETITION

In addition to the physiological factors that may impact sleep in soccer players, there may also be psychological factors that influence the sleep process. It has been reported that one of the main reasons for poor sleep within team sports players is related to nervousness, anxiety and/or stress associated with the demands of competition (Julliff, *et al*, 2014). Such psychological stressors may result in longer sleep onsets and a more varied duration and greater fragmentation of sleep (Mezick, *et al*, 2009). In turn individuals who experience sleep loss are more susceptible to altered mood, increased stress, lowered self confidence, increased anxiety and in cases depression (Venter, 2012). These emotional changes following sleep loss may result in higher perceived fatigue the following morning (Sargent, *et al*, 2014), increased sleepiness (Julliff, *et al*, 2014) and increased exertion during exercise the next day (Reilly & Piercy, 1994). This may in turn impact the motivational level of the player to sustain exercise at a given intensity, which may limit performance outcomes within soccer (Reilly & Piercy, 1994). However detriments in performance are not always perceived within athlete populations. Julliff et al (2014) reported 46.6% of 283 Australian elite athletes (individual and team sports athletes) had no perceived influence of sleep loss on subsequent competitive performance. Were as 14% reported worsened performance as a result of sleep loss before competition (Julliff, *et al*, 2014). Individuals experiencing sleep loss will miss out on important periods of restorative sleep (i.e. deep and REM sleep) during the night, which may have impairments for memory function and the acquisition of newly learnt skills and tactics (Walker & Stickgold, 2005; Davenne, 2009). This may reduce the desired development of the skills worked on in training, which in turn may impact the ability to optimally perform during soccer matches, contrary to perceptual beliefs of the athlete.

Cognitive function may decline more rapidly than physical capabilities if sleep is affected (Reilly & Edwards, 2007; Davenne, 2009). As a result, sleep loss may lead to more errors during the subsequent performance of tasks that require intricate technical skills (Reilly & Edwards, 2007). Jarraya, *et al*, (2013) studied the effects of partial sleep deprivation on twelve male handball goalkeepers. The study compared a nights habitual sleep to both a partially sleep deprived night (were sleep was restricted at the beginning [03:00 – 07:00am] or the end of a night [22:00 – 03:00am]), with each night being evaluated against a reaction time test and attention tests the following day. The results indicated a significant negative effect of partial sleep deprivation on reaction time and attention capacities. This may have particular transferability to goalkeepers within soccer, who rely on quick anticipation and positioning to deny the opposition scoring a goal. The dribbling capacities of soccer players have also been assessed following 36 h of sleep deprivation (Hefzollesan, *et al*, 2013). The group consequently showed significant performance decrements in the time taken to execute the dribbling task in comparison to baseline data generated following a sufficient sleep (Hefzollesan, *et al*, 2013). Typically to compensate for the increased amount of errors during performance, sleep deprived individuals often take more time when they perform a particular action (Orzel-Gryglewska, 2010). This can often prove critical in the outcome of performance within elite competition, were the fast and effective execution of tasks may be the difference between the success and failure of a particular desired performance outcome (e.g. scoring/denying a goal).

2.4 SLEEP EXTENSION

Evidence may suggest that extending sleep above the habitual baseline may be of some benefit to the athlete (Kamdar, *et al*, 2004; Davenne, 2009; Mah, *et al*, 2011). Within the study by Kamdar, *et al* (2004) the participants were allowed to sleep as much as possible, being encouraged to extend sleep above their typical baseline (431 ± 53 min). The results showed significant improvements in multiple sleep latency test scores, reaction times and mood scales following the sleep extension period within both early phase (1-7 days of sleep extension >500 min) and late phase (>8 days sleep extension) periods of sleep extension (Kamdar, *et al*, 2004). Extended sleep (over a period of 5-7 weeks) has also been shown to increase exercise performance (i.e. faster sprint times), improve shooting accuracy, within collegiate basketball players (Mah, *et al*, 2011). This period of sleep extension was also associated with psychological benefits, such as increased alertness, positive mood changes and a reduced perception of fatigue and tiredness when compared to baseline values of habitual sleep during the competitive season (Mah, *et al,* 2011). Similar findings by the same group were also displayed in collegiate football players, who displayed increased performance in NFL combine drills (20m shuttle and 40 yard dash time) and reduced perception of fatgue and increased vigor (Mah, *et al*, 2010). It is likely that such periods of extension allow the synchronisation of the sleep-wake cycle within an athletes preferred rhythm and thus dissipate the effects of sleep debt and deprivation, which may have accumulated as a result of poor sleep hygiene (Samuals, 2008; Mah, *et al*, 2011). Therefore actively increasing sleep quantity may have a positive impact on performance, particularly in those athletes that display sub-optimal sleeping patterns and apparent sleep debt. This may be achieved by promoting strategies that encourage the athlete to sleep as much as possible, by focussing on improving habitual sleep habits.

2.5 SLEEP HYGIENE

Recognising the perceived benefits of extending sleep on athletic performance, increased focus has been placed on the implementation of sleep hygiene strategies in an attempt to enhance sleep quantity and quality within athletes (as reviewed elsewhere by Halson, 2014; Nedelec, *et al*, 2015b). Such approaches typically adopt strategies that look to invoke sleep-promoting behaviours and control factors that promote wakefulness based on scientific rationale (e.g. environmental conditions such as exposure to light, harsh temperatures and noise or the avoidance of stimulants such as caffeine) (Cole, 2005). This has led to the development of practical strategies and recommendations that the athlete can simply incorporate into their habitual routine.

2.5.1 LIGHT EXPOSURE

Exposure to bright light (2500 lux) 2 h prior to bedtime has been suggested to supress the typical secretion of melatonin, increase body temperature, delay sleep onset and alter sleep architecture (e.g. reduced REM sleep) in comparison to dim light exposure (Bunnel, *et al*, 1992). Similar results have also been reported as a consequence of using electronic reading devices before bedtime, showing decreased subjective sleepiness, supressed melatonin secretion and altered delta and theta EEG activity, thus altering sleep propensity (Chang, *et al*, 2012). Soccer players may be subjected to bright light exposure before bedtime during situations such as evening matches (e.g. floodlight exposure and media requirements) (Nedelec, *et al* 2015a; Fullagar, *et al*, 2016a; Fullagar, *et al*, 2016b) and as a consequence of typical pre-bed behaviours (e.g. use of electronic devices) (Fullagar, *et al*, 2016b). Such factors may negatively impact sleep in soccer players, therefore strategies addressing such factors may positively influence sleep.

Fullagar & Colleagues (2016b) looked to investigate the effectiveness of a sleep hygiene strategy following an evening night match within amateur soccer players. The strategy consisted of an altered environment (i.e. dimmed lighting and 17 °C room temperature), the provision of eye masks and earplugs (optional) and the restriction of electronic devices (15-30 min before lights out at 00:00). This was compared to the soccer player's normal activities, in which they could freely use electronic devices until 02:00, which was selected based anecdotal reports of typical bedtimes following night matches in soccer players (Fullagar, *et al*, 2016b). Though the sleep hygiene strategy showed improvements in total sleep time, the authors showed that this did not improve performance (i.e. countermovement jump height, force production, yoyo intermittent recovery test score) and recovery (i.e. subjective wellness information, creatine kinase) following the night fixture, in comparison to the control (Fullagar, *et al*, 2016b). Though this infers increased sleep had no beneficial effects following night matches, there still needs to be more evidence that looks to investigate these effects in more detail.

It is plausible that a combination of strategies may offer an effective means to improve the sleep of athletes. Duffield, et al (2014) investigated the use of a sleep hygiene strategy (i.e. avoidance of electronic devices 30 min before bedtime, low light exposure of 3-8 lux, adopting a cool bedroom environment [19 ± 2 °C] and sleeping with a self selected eye mask) in combination with typical recovery strategies employed in team sports (i.e. 15 min cold water immersion, followed by use of compression garments immediately post exercise). It was suggested that this strategy improved total sleep time in comparison to a control condition (no imposed recovery strategies and exposure to 60±12 lux pre-bed lighting) within professional tennis players (Duffield, *et al*, 2014). The resultant extended sleep time was also associated with reduced perceived fatigue and muscle soreness the following morning (Duffield, *et al*, 2014). Therefore the athlete may facilitate improvements to the recovery process through the use of combining recovery modalities and sleep hygiene strategies that look to control environmental conditions and manipulate behaviours before bedtime. However more studies are required looking at the use combinative strategies that attempt to promote sleep during different situations during the competitive season (e.g. night fixtures).

2.5.2 STRATEGIES MANIPULATING THERMOREGULATION

The circadian cycle in human thermoregulation is thought to be a contributing factor to the sleep-wake process (Murphy & Campbell, 1997; Krauchi, 2007; Krauchi & Doboer, 2011). Within humans, sleep propensity (the need to sleep) is suggested to rise in relation to the regulated maximal decline in core body temperature (CBT), which is typically observed in the evening, with the inverse relationship being apparent within the morning (i.e. increased CBT relating to increased wakefulness) (Murphy & Campbell, 1997; Krauchi, 2007). Sleep propensity is also suggested to be associated with increased distal skin temperatures (vasodilation) and reduced proximal skin temperatures (Krauchi, 2007'; Krauchi & Doboer, 2011). Therefore the circadian derived thermophysiological processes associated to heat loss seem to be important factors that influence the initiation and maintenance of sleep (Krauchi & Doboer, 2011).

Sleep hygiene research has focused on the direct effectiveness of typically employed recovery strategies in sport, such as cold-water immersion (CWI), on sleep. Given that such a strategy may promote changes in the thermoregulatory system (i.e. rapid conductive heat loss and lowered core body temperature for up to 90 mins) (Gregson, *et al*, 2011). Therefore such a strategy may also facilitate favourable sleep behaviours (Murphy & Campbell, 1997; Krauchi, 2007). Al Haddad & Colleagues (2012) demonstrated positive effects on subjective sleep quality within highly trained swimmers following exposure of CWI (15 °C for 5 min) for 5 days in comparison to control conditions. However other evidence indicates that CWI (seated at 14 °C for 15 min) following evening exercise has no effects on objective markers of sleep quantity and quality in comparison to control conditions (exercise only or rest) in trained cyclists and triathletes (using polysomnography) (Robey, *et al*, 2013) and elite youth soccer players (using actigraphy) (Robey, *et al,* 2014). However, this may be partly due to the timing of the strategy in the early evening. For example, within the study of Robey & Colleagues (2013) differences within core temperature were observable up to 2.5 h post CWI, though these values became the same at lights out within each condition. This may suggest that the effects of CWI on temperature had dissipated at this point. Therefore it could be plausible that the use of a CWI strategy closer to lights out may benefit sleep. Though this response presently remains unknown.

The facilitation of sleep has also been linked to increases in the temperature of distal regions of the body, through vasodilation of the periphery, thereby inducing rapid heat loss (Krauchi, *et al,* 1999; Krauchi, 2007). Therefore research has also focussed on strategies such as targeted skin warming (whole body heating or distal skin heating such as the feet) in an attempt to cause subtle elevations to skin temperature, which in turn facilitate the process of heat loss (Krauchi, *et al*, 1999; Sung & Tochihara, 2000; Raymann, *et al*, 2005; Raymann, *et al,* 2007; Raymann, *et al*, 2008). Sung & Tochihara (2000), demonstrated that the use of both a warm bath (submersion to shoulders at 40 °C for 20 min) and a warm footbath (submersion to knee level at 42 °C for 30 min), performed separately 50 min before lights out, caused elevations to skin temperature (~3-4 °C) at lights out in comparison to the control condition (no heating).

Subsequently the elevations in skin temperature were also linked to a reduction in sleep onset latency (Sung & Tochihara, 2000). Similarly, Raymann, et al (2008) has demonstrated the effectiveness of both a hot footbath (42 °C for 30 min) 50 min prior to lights out and the use of neutral temperature bed socks in the elderly to accelerate sleep onset latency. Additionally the authors also demonstrated significant effects on sleep onset latency using both neutral and warm bed socks (~43 °C) worn for 30 min at lights out in young healthy participants (Raymann, *et al,* 2008). Such strategies may therefore offer a promising means of improving sleep onset latency in soccer players, who display difficulties when initiating sleep. Though at present no data has looked at this relationship within athlete populations and therefore requires future work.

2.5 NUTRITIONAL STRATEGIES

The timing of nutritional intake has been suggested to be amongst several external cues that synchronise the circadian component of the sleep wake cycle (Edwards, *et al*, 2009; Crispim, *et al*, 2011; Peuhkuri, *et al*, 2012). Food intake can also influence sleep, by increasing levels of the amino acid tryptophan (Minet-Ringuet, *et al*, 2004; Peuhkuri, *et al*, 2012). Tryptophan (Trp) is the precursor for both brain derived serotonin and melatonin, which are important neuro-regulators of sleep (Hajak, *et al*, 1991; Peuhkuri, *et al*, 2012). Given that tryptophan is primarily influenced by dietary intake, it could be suggested that the manipulation of macronutrient intake in an attempt to promote tryptophan may positively influence the process of sleep.

Minet-Ringuet & Colleagues (2004) demonstrated that the use of a milk protein enriched with alpha lactalbumin (α-lactalbumin; a source of tryptophan) had significant restorative effects on sleep within rats following caloric restriction in comparison to a whole milk protein. The authors also demonstrated that the α-lactalbumin condition had greater increases in tryptophan in relation to other large neutral amino acids (LNAA's) (increasing the Trp:LNAA ratio). This may suggest an increase in the transport of tryptophan across the blood brain barrier and therefore increased serotonin and melatonin concentrations (considered a sleep promoting condition) (Minet-Ringuet, *et al*, 2004). Such observations of increased Trp:LNAA ratio were also made within healthy human participant within the study of Markus & Colleagues (2005), through administration of a 20g tryptophan rich α-lactalbumin protein milkshake (4.8g/100g tryptophan) in comparison to a 20g placebo milkshake (1.4g/100g tryptophan) in the evening. However the tryptophan rich α-lactalbumin demonstrated no influences on evening sleepiness (Markus, *et al*, 2005). Though the author's did observe significant improvements in sleepiness, alertness and reaction times the following morning (Markus, *et al*, 2005), which may enhance cognitive functions related to sports performance in soccer players. Additionally in the absence of objective measures of sleep, it cannot be suggested that α-lactalbumin condition had no influences (Markus, *et al*, 2005), as other observations have demonstrated a positive influence on objective sleep markers within insomnia patients (Hudson, *et al*, 2011). The administration of protein enriched with α-lactalbumin before bedtime may therefore be of benefit to soccer players displaying sleep difficulties.

The type of food administered may also vary the influence on sleep. For example, a diet high in protein may benefit sleep, by reducing the number of awakenings (Lindseth, *et al*, 2011). However as LNAA's are more abundant than tryptophan in typical protein food sources, this may lower the concentration of plasma tryptophan and limit transport across the blood brain barrier (Silber & Schmitt, 2010). Therefore a high protein diet in the absence of tryptophan rich protein (e.g. α-lactalbumin) may have implications to sleep onset (Silber & Schmitt, 2010). The administration of carbohydrates may, however, offset some of the observed decreases in tryptophan (Fernstrom & Wurtman, 1971; Wurtman, *et al,* 2003; Lindseth, *et al*, 2011; Peuhkuri, *et al*, 2012). Ingestion of carbohydrates promotes an increased secretion of insulin, which stimulates the uptake of LNAA's within the skeletal muscle, with the exception of tryptophan (Fernstrom & Wurtman, 1971; Peuhkuri, *et al*, 2012). Therefore insulin dependent decreases of plasma LNAA concentrations, would suggest favourable conditions for tryptophan uptake across the brain blood barrier and in turn promote sleep onset (Fernstrom & Wurtman, 1971; Silber & Schmitt, 2010; Peuhkuri, *et al*, 2012). This can be demonstrated in the study of Afaghi & Colleagues (2007), who showed the ingestion of a high-glycemic index (GI) carbohydrate meal (which would have pronounced effects on plasma glucose and insulin) resulted in significant decreases in sleep onset latency when compared to a low GI meal. Additionally within this study the timing of carbohydrate was also important, as administration of the same high GI meal was more effective 4h than 1h before lights out (Afaghi, *et al*, 2007). This may relate to the time course of insulin secretion which may peak >2h following ingestion (Wurtman, *et al*, 2003). Additionally there has also been suggestion that high GI carbohydrate in combination with milk, provided 1h before lights out, may increase the frequency of awakenings during sleep (Jalilolghadr, *et al*, 2011). This may suggest that it is important to consider the type and timing of macronutrient consumption, as this may have a varied effects on sleep propensity and architecture.

Soccer players may also utilise other nutrient strategies as a sleep aid, such as tart cherry juice. Tart cherries, particularly the Montmorency (*Prunus cerasus*), are shown to contain a high abundance of melatonin (3.46 ± 1.10 ng/g), amongst other phytochemicals (Burkhardt, *et al*, 2001). The circadian timing of melatonin secretion has been related to increased sleep propensity and the onset of sleep (Krauchi, *et al*, 1997; Stickgold & Walker, 2009). Therefore dietary strategies that increase exogenous levels of melatonin may influence sleep. Howatson & colleagues (2012) demonstrated that dosing of Montmorency tart cheery juice (30 mL equivalent to 90-100 cherries), twice daily (within the morning 30 min following awakening and 30 min before the evening meal), for seven days, significantly increased melatonin concentrations and improved sleep quantity and efficiency in comparison to a placebo, within 20 healthy participants (10 male and 10 female). Further additive benefits of tart cherry juice have also been suggested, as it may influence the process of recovery following exercise (Connolly, *et al*, 2006; Howatson, *et al*, 2010; Bell, *et al*, 2016). Connolly & Colleagues (2006), demonstrated that the use of cherry juice (12 oz equivalent to 50-60 cherries), provided in the morning and evening for 3 days before and 4 days after muscle damaging exercise, reduced the perception of pain and strength loss in comparison to a placebo beverage. Similarly within marathon runners, supplementation of Montmorency cherry juice (8 oz equivalent to 50-60 cherries, in the morning and evening 4 days before and 2 days following a marathon) reduced markers of inflammation (i.e. IL-6 & CRP) and improved isometric strength (knee extenstion) in comparison to a control condition (Howatson, *et al*, 2010). Following the same supplementation protocol, Bell & Colleagues (2016) also displayed significant reductions in IL-6, performance improvements in isometric strength, countermovement jump and change of direction, following an intermittent exercise protocol in semiprofessional soccer players. The authors also reported significant improvements in muscle soreness after 48 h as a result of the cherry juice supplementation (Bell, *et al*, 2016). Such a strategy may therefore be beneficial to the soccer player as it may serve dual functions, influencing both sleep and the recovery process.

2.6 SUMMARY

At present it is thought that sleep serves important physiological and psychological functions that contribute to both the recovery process and in the attainment of optimal performance in athletes such as soccer players (Samuels, 2008; Davenne, 2009; Venter, 2012; Mah, *et al*, 2011; Nedelec, *et al*, 2015). This suggestion may be a consequence of sports, such as soccer, relying on the interaction of multiple physiological processes and cognitive technical actions for successful performance outcomes, which may be impaired by periods of sleep loss or poor sleeping habits (Reilly & Edwards, 2007; Davenne, 2009). Alternatively such functions may be enhanced during periods of sleep extension, which may dissipate the effects of sleep debt and induce performance benefits (Kamdar, *et al*, 2004; Mah, *et al*, 2011). However at present there is a lack of scientific data that looks to quantify the quantity and quality of sleep of soccer players during the competitive season using objective measures (Roach, *et al*, 2013; Robey, *et al*, 2014; Fullagar, *et al*, 2016a). Therefore the factors influencing the mechanism of sleep within soccer players are still poorly understood (Nedelec, *et al*, 2015a). It would seem necessary to quantify the typical sleep habits of soccer players using viable measures within the applied setting, to further the understanding of how sleep is displayed in such soccer playing populations. An understanding of the impact of participation in soccer on sleep may be derived through comparisons with non-athlete populations. Additionally profiling soccer players within their habitual environment may also allow practitioners to identify factors that impact sleep during the course of the soccer season. This would then allow the specific development and orientation of sleep hygiene strategies to improve sleep within soccer players when necessary.

CHAPTER 3

AN EVALUATION OF THE VALIDITY OF A COMMERCIALLY AVAILABLE SLEEP MONITORING SYSTEM

3.1 INTRODUCTION

Interest in research regarding sleep has increased recently partly as a consequence of evidence that it can play a major role in the performance and recovery of athletes (Davenne, 2009; Venter, 2012). The ability to monitor sleep within elite athletes during the competitive period is, however, difficult (Driver & Taylor, 2000) as current methods are hard to apply without affecting the athlete's daily routine. As a consequence little normative sleep data within athletic populations exists (Leeder, *et al*, 2012). The gold standard methodology for sleep assessment is often considered to be Polysomnography (PSG) (Flemons & Littner, 2003). Using this approach a detailed breakdown of sleep can be provided that illustrates specific sleep stages, sleep latencies and sleep arousals. However, the use of this approach with the majority of athletes is deemed impractical, as it requires attendance at a laboratory where trained technicians instrument EEG, ECG and EOG monitoring on the athletes in order to accurately quantify sleep during the night.

In attempt to provide more non-invasive measures of sleep, alternative systems of monitoring have been developed. These approaches essentially provide the ability to monitor sleep using equipment and procedures that are easy to integrate into an athlete's habitual routine (Leeder, *et al*, 2012; Shambroom, *et al*, 2012, Tonetti, *et al*, 2013). One such system is wristwatch actigraphy, which is often seen as the most convenient means to assess sleep (i.e. sleep quantity and efficiency) when multiple nights of sleep assessment are desired (Sadeh, 2011). Data from actigraphy is, however, limited due to its sole dependence on movement as the detection strategy for periods of wakefulness. This limitation can potentially result in an overestimation of sleep duration (Pollack, *et al*, 2001), as actigraphy seems unable to detect wakefulness from sleep during specific periods of sleep (Tonetti, et al, 2008). Actigraphy can also overestimate the number of awakenings during the night (as a consequence of the effect of moving while asleep); this would subsequently lead to a reduction in the observed total sleep duration (Elbaz, *et al*, 2013). Therefore it is suggested that actigraphy should be used in conjunction with other more subjective sleep assessment tools, such as sleep diaries in order to improve the accuracy of quantifying important sleep parameters (Carney, *et* al, 2012). These approaches do, however, require the subjective recall of sleep (Carney, *et al*, 2012). This may potentially bias the data and lead to inaccurate estimates of sleep (Arora, *et al*, 2013).

Recent developments within the field of sleep monitoring have produced a commercially ready wireless headband sleep monitoring system (Shambroom, *et al*, 2012). Such a system allows the quantification of sleeping pattern through the detection of EEG, EOG (eye movements) and activity of the frontalis muscle (Shambroom, *et al*, 2012). Such signals are also used in the determination of the primary indicators of sleep staging within PSG (Kushida, *et al*, 2001). This wireless system has been suggested to have strong positive agreement in the assessment of sleep (i.e. sleep onset, total sleep time, awakenings and specific sleep stages) with the established method of PSG when used within the laboratory setting (Shambroom, *et al*, 2012; Tonetti, *et al*, 2013). This suggests that the wireless system may potentially be able to accurately collect sleep information within the participant's habitual sleeping environment and hence provide a practical solution to the accurate assessment of an athletes sleep. The aim of the current study was therefore to examine the validity of a commercially available wireless device's ability to measure important sleep parameters within the habitual environment. In order to address this aim the data from the wireless device was compared to other established methodologies that are currently available to use with athletic populations in their everyday sleeping environments. This data will provide new insights into the suitability of the commercially available wireless device as a sleep-monitoring tool in athletes.

3.2 METHODS

3.2.1 RESEARCH APPROACH

To evaluate the validity of a commercially available wireless headband sleep monitoring system the study attempted to compare the data generated for the Zeo Sleep Manager – Bedside Sleep Management Wireless System (WS) (Zeo Inc, Newton: Mass) during normal sleep with that obtained using a number of other established sleep monitoring methods: Wristwatch Actigraphy (ACT), a consensus sleep diary (SD) and the Firstbeat body guard (FBG). Data was collected over a three-day period from nine healthy randomly selected participants.

3.2.2 PARTICIPANTS

The participants were a group of nine randomly selected males (Age 24 ± 4 years). The participants were physically active (~3-5 physical activity sessions per week) and healthy at the time of the study. Anthropometric characteristics (mean ± *sd*) were; Height 1.75 ± 0.03 m; Weight 73 ± 5 kg. Prior consent was obtained for each participant before any measurements were obtained. Ethical approval was granted through the Liverpool John Moores University Institutional Ethics Committee. Additionally all participants were made aware of the research design of the study and what was expected of them through a participant information sheet prior to any data collection. Participants agreed to refrain from alcohol, caffeine and other stimulating substances (i.e. tobacco & sleeping tablets) on the day(s) of which sleep measurements were collected.

3.2.3 EXPERIMENTAL DESIGN

Prior to any data collection, each participant was provided with each sleep measurement tool to be used during the study. This equipment included the Zeo Sleep Manager – Bedside Sleep Management Wireless System (Zeo Inc, Newton: Mass), a Motionwatch 8 - Wristwatch Actigraph (CamNtech Ltd., Cambridge: UK), a First Beat Body Guard (Firstbeat Technologies Ltd, OY: Finland) and a sleep diary (Carney, *et al*, 2012). Pre-assessment training was provided for each experimental methodology that was included in the investigation. This was done in an attempt to show the participant how each piece of equipment was used to collect sleep data. This approach helped minimise errors in data collection during the study period. The participants were made aware that each method should be worn/attached at the start of the intended bedtime upon lights out and removed upon final waking. Once the participant had arisen, they were required to fill out the sleep diary in full. The first night recordings were used for re-familiarisation for each participant to the experimental methodologies. This enabled participants to become comfortable with each measurement tool during their sleep. The subsequent two nights sleep was used for data collection, as per procedures previously documented for a method comparison of this type (Tonetti, *et al*, 2008). Identical data collection procedures were implemented on each specific night's sleep.

3.2.4 EXPERIMENTAL PROCEDURES

Prior to the commencement of the data collection, the participants reported to the laboratory to collect all the relevant equipment. Each set of equipment was configured to ensure the correct time and date was used during the data collection period. All previous data was erased from the memory. The participants were instructed on the use of each specific methodology to monitor their sleep. The WS used proprietary dry silver-coated sensors situated in a headband to collect electrophysiological signals (consisting of contributions from EEG, eye movement and the frontalis muscle) from the forehead. The signals were captured at 128 samples per second and filtered within a second-order band pass frequency of 2-47 Hz. From this a microprocessor located in the base station of the WS categorised the sleep staging in real time from the output signal using an in-built artificial neural network. The neural network uses time and frequency features from the derived signal, with sleep staging being assigned to each 2-s interval of recording. This data is then averaged and reported every 30s to establish an estimate sleep during the night (Shambroom, *et al*, 2012). An example of the WS is shown in Figure 3.1. Instructions were also provided to each participant on how to undock the WS headband and how to accurately position the sensor on the head (see Figure 1, C.). Participants were also given a specific demonstration on the important software procedures, such as how to await confirmation from the onscreen indicator (Figure 3.1, D.) showing that data collection had been initiated.

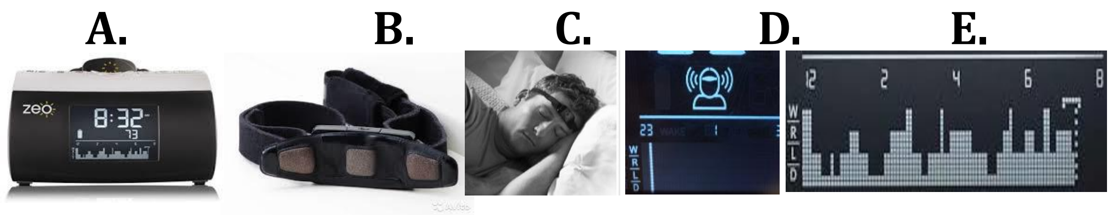


Figure 3.1. Displayed is a figurative overview of the commercial wireless Zeo Bedside Sleep Monitor (Zeo, Inc). **A**. Shows an example of the wireless bedside monitor that contains the microprocessor, allowing detection of the 2.4 GHz transmitted signal of the headband. **B.** Provides the design of the wireless headband and placement of proprietary dry silver-coated sensors used to detect, convert (using a 12-bit analog to digital converter) and process (using a unit that amplifies and filters) the electrophysiological signalling during the night. **C.** Is an example showing the correct placement of the headband during the assessment of sleep. **D**. Shows when the wireless signal is detected enabling data collection to be commenced. **E.** Is an example output of the sleep pattern detected during the night reported by the wireless device.

The participants were also instructed with regards to the correct placement of the actigraph on the non-dominant wrist. The epoch length of the actigraph was set to 60s with the onset of data collection commencing at 8pm on the evening of the first night of data collection. The sampling period for this device was continual until the cessation of data collection following the third night of sleep. Further relevant instructions were also given for the Firstbeat Bodyguard. This information detailed how the device was connected, using electrodes placed at two designated sites on the torso. Site one was located directly below the right clavicle with site two located on the rib cage directly below the left pectoral. This electrode placement allowed for an accurate recording of the heart rate (at a sampling frequency of 1000 Hz) during sleep. Once connected the Firstbeat Bodyguard switched on allowing data collection to start. Each participant was finally instructed to connect all relevant equipment when sleep onset was planned each night for the duration of the study.

Upon final awakening in the morning the participants were required to dock the WS headband within the designated base station. This allowed for the automatic download and analysis of the data. The software within the WS enabled the calculation of, total sleep time (TST), sleep onset latency (SOL) and number of times woken during the night (N_{wake}) (See Table 2.1 for all definitions). The wristwatch actigraph data was also stored automatically and subsequently analysed using the Motionware 1.0.12 software (CamNtech LTD, Cambridge: UK) at the end of the data collection period. Key variables from this measurement approach included: total sleep time, sleep onset latency, and the number of awakenings to provide comparative sleep measures to the WS. Due to the detection of movement being the primary mechanism in which wake is detected by the ACT, it is often common that such devices exceedingly overestimate the number of awakenings within the night, consequently underestimating total sleep time (Elbaz, *et al*, 2013). Therefore an additional variable (assumed sleep time [AST]) from the actigraph was also included within the current analysis. The assumed sleep time output negates the subtraction of awakening(s) during the night (Definition also shown in Table 3.1). As a consequence this may lead to a better estimate of total sleep time by the device for the comparison within the current study.

Table 3.1 Definitions of sleep variables from each respective sleep-monitoring device (WS, ACT, SD, FBG).

Total Sleep Time (TST) (min)	The total time asleep between sleep onset and awakening, minus the factor of wake after sleep onset (WASO)
Sleep Onset Latency (SOL) (min)	The difference between planned initiation of sleep onset and actual sleep onset
Number of Awakenings (N_{wake}) (#number)	Number of times the participant awoke during the sleep period (excluding final awakening)
Assumed Sleep Time (AST) (min)	Total duration of assumed sleep time using the wristwatch actigraph – no subtraction of time in wake after sleep onset

The participants were also instructed to carefully remove the Firstbeat Bodyguard following waking. All data was automatically stored within the Firstbeat Bodyguard device for subsequent analysis. The respective night's data was then downloaded and analysed using Firstbeat Sports analysis software (version 4.2.0.2, Firstbeat Technologies Ltd, OY: Finland). This equipment provided an indication of total sleep time from the night's sleep, through inferences on the change in resting heart rate following lights out and final awakening. Finally within 15 minutes of waking the participants were also required to fill out their sleep diary. This timing is suggested to reduce error in self-recall of sleep time (Arora, *et al,* 2013). All questions were answered as accurately as possible (See appendix 1 for specific questions). The questionnaire required each participant to provide information on the time to bed, estimated time to sleep onset (SOL), the number of awakenings before final awakening and the time of waking was recorded as well as the time of rising. This allowed for subsequent analysis to calculate TST, SOL and N_{Wake} from the sleep diary to be used in the comparative analysis with the WS device. Additionally the data within the sleep diary also provided a means to accurately determine the bedtime and time of final awakening for the Actigraphy measures.

3.2.5 STATISTICAL ANALYSIS

The data were analysed using the statistical package R version 3.1.0 Software (The R Foundation for Statistical Computing, 2014.). In total 22 data samples were collected meeting the comparison criteria from a total of 9 participants within the current study. All data are reported as mean ± standard deviation, unless otherwise indicated. A paired samples *t*-test was calculated to compare the means of each devices related sample to the WS to establish any systematic bias between the outputs of the respective sleep monitoring methodologies. Additionally established statistical approaches were taken to assess the relationship and agreement between the WS and the other recognized sleep-monitoring devices. Pearson's correlation coefficient and 95% confidence intervals were calculated to establish the strength of relationship between the WS and the other sleep monitoring systems (i.e ACT, SD & FBG). The adapted Cohens scale for coefficient values was used to assess the scale of magnitude for linear trends associated to each variable; 0-0.1 = trivial, 0.1–0.3 = weak/minor, 0.3-0.5 = moderate, 0.5-0.7 = strong, 0.7-0.9 very strong, 0.9-1 = nearly, practically or almost: perfect linearity (Cohen, 1988; Hopkins, 2002). In addition Bland Altman (BA) plots with limits of agreement (LoA) (Bland & Altman, 1986) were also created using XLSTAT (Statistical package for Microsoft Excel, Addinsoft, NY, USA) to establish the relative agreement between WS & ACT, WS & SD and WS & FBG. This allowed the differences to be plotted against the mean between the WS and respective sleep monitoring devices, and thus to assess the variability of the differences across mean values and identify possible trends of differences with respect to the mean.

3.3 RESULTS

A summary of mean values of sleep variables as assessed with the WS and reference methods can be seen in Table 3.2.

Table 3.2. Sleep data for the WS, ACT, SD and FBG (mean ± *sd*). NB values are left blank for devices did not provide an indication of that specific sleep variable.

Device	TST (min)	SOL (min)	N_{WAKE}
WS	418 ± 61	22 ± 24	2 ± 2
ACT	361 ± 66 *	17 ± 21	26 ± 11*
(Assumed Sleep Time)	(415 ± 68)		
SD	435 ± 64	12 ± 10*	2 ± 2
FBG	461 ± 57 *		

*** *p* < 0.05 vs. WS**

The following data was deemed to be statistically different; total sleep time between the WS and FBG ($p = 0.03$), total sleep time between the WS and ACT ($p < 0.01$), number of awakenings between the WS and ACTIGRAPH ($p < 0.01$) and sleep onset latency between WS and SD ($p = 0.02$). The significant differences between these values indicate a potential systematic bias between devices. All other values were statistically non-significant between the respective devices ($p > 0.05$).

3.3.1 PEARSONS CORRELATION COEFFECIENTS

The Pearson's Correlation Coefficients for the comparisons between the sleep monitoring approaches can be seen in Table 3.3. The results show a very strong positive relationship between WS and all respective sleep monitoring devices; actigraph (r = 0.87, very strong, 95 % CI 0.68 to 0.95), SD (r = 0.87, very strong, 95 % CI 0.71 to 0.95) and Firstbeat Bodyguard (r = 0.77, very strong, 95 % CI 0.43 to 0.92) for the estimation of total sleep time. Additionally there was an almost perfect correlation between the total sleep time of the WS and the assumed sleep time output of the actigraph (0.97, almost perfect, 95 % CI 0.92 to 0.99). For the comparison of sleep onset latency, there were also strong positive relationships between WS and actigraphy (r = 0.69, Strong, 95 % CI = 0.35 to 0.87) as well as WS and SD (r = 0.65, Strong, 95% CI 0.31 to 0.84). Lastly there was a strong positive relationship for the number of awakenings recorded by both

WS and sleep diary (r = 0.69, Strong, 95 % CI 0.38 to 0.86). In contrast there was a non-significant negative relationship observed between the WS & actigraphy (r = -0.22, Weak, 95 % CI -0.61 to 0.26) for the estimation of number of awakenings.

Table 3.3. Pearson's Correlation Coefficients (*r*) in comparison to the WS.

Device	TST	SOL	N_{WAKE}
ACT	0.87***	0.69***	-0.22
(ACT: AST)	0.97***		
SD	0.87***	0.65***	0.69***
FBG	0.77***		

***p <0.01**

3.3.2 BLAND ALTMAN STATISTICS

An overview of the mean differences and 95% CI calculated from the Bland Altman statistics between the WS and actigraphy, WS and sleep diary, WS and Firstbeat Bodyguard is shown in Table 3.4 and 3.5. The Bland Altman statistics are also visually displayed in Figures 3.2, 3.3, 3.4 and 3.5 respectively. For the measure of total sleep time between WS and actigraphy, the bias indicates a large overestimation by the WS of approximately 59 min (95% LoA -5 to 123 min), with the distribution of all but one value being above zero (as shown in Figure 3.2.A). The evaluation of assumed sleep time of the actigraph indicated only a small overestimation of total sleep time (2 min) and reasonably narrow 95% LoA (-30min to 34min) when compared to total sleep time of the WS. In comparison, the WS underestimates total sleep time when compared to both sleep diary and Firstbeat Bodyguard methodologies, with the mean difference of -10 min (95% LoA, -75min to 55 min), and -26 min (95% LoA -106 min to 55 min) respectively.

The WS also slightly overestimated sleep onset in comparison to actigraphy (+7 min) with the observed differences ranging within the 95% agreement range of -28 to 40 min. Similarly the comparison of the WS & sleep diary for the measure of sleep onset had a mean difference of +9min (95% LoA -24min to 42min). In the comparison of number of awakenings, a proportional bias (negative linear regression of differences on averages) was observed together with a trend to heteroscedasticity (a decrease of the difference value and a decrease of difference variability was observed with increasing average values Figure 3.5.G). Therefore, an adjusted "V-Shaped" 95% LoA were used, calculated according to Ludbrook (2010) (Figure 3.5.G). Overall, there was an underestimation in the number of awakenings recorded using the WS in comparison to actigraphy (-26 difference for the overall average value of 14, 95% LoA -31 to -20). In contrast the closest observable agreement was between the WS & sleep diary for the measure of number of awakenings. In this comparison the bias was almost represented as zero and sufficiently narrow limits of agreement is present, 0.05 (95% LoA -3 to 3) (Figure 3.5.H).

Table 3.4. Bland Altman statistics showing comparison of the ZEO wireless sleep manager (WS) and Wristwatch Actigraph (ACT) devices.

	WS – ACT			
	TST (min)	**AST (min)**	**SOL (min)**	**N_{WAKE} (#)**
Mean Differences (Bias)	59	2	7	-25
Standard Deviation	33	17	17	12
95 % LoA Upper Limit	123	34	40	2
95 % LoA Lower Limit	-5	-30	-28	-51

Table 3.5. Bland Altman statistics showing comparison of the wireless ZEO wireless bedside sleep manager (WS), consensus sleep diary (SD) and first beat bodyguard (FBG) device.

		WS - SD		WS - FBG
	TST (min)	**SOL (min)**	**N_{WAKE} (#)**	**TST (min)**
Mean Differences (Bias)	-10	9	0.05	-26
Standard Deviation	33	17	1	41
95 % LoA Upper Limit	55	42	3	55
95 % LoA Lower Limit	-75	-24	-3	-106

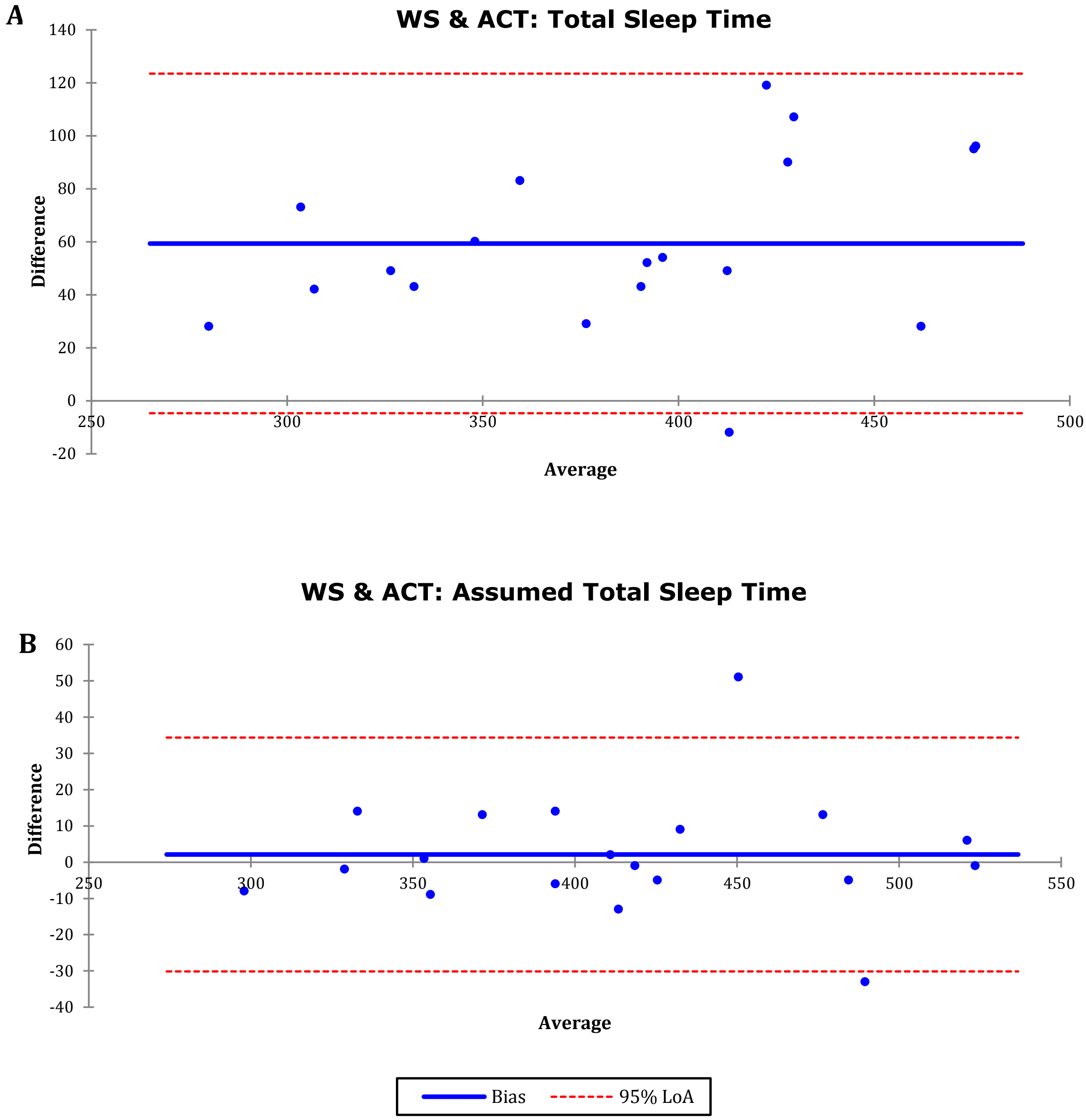
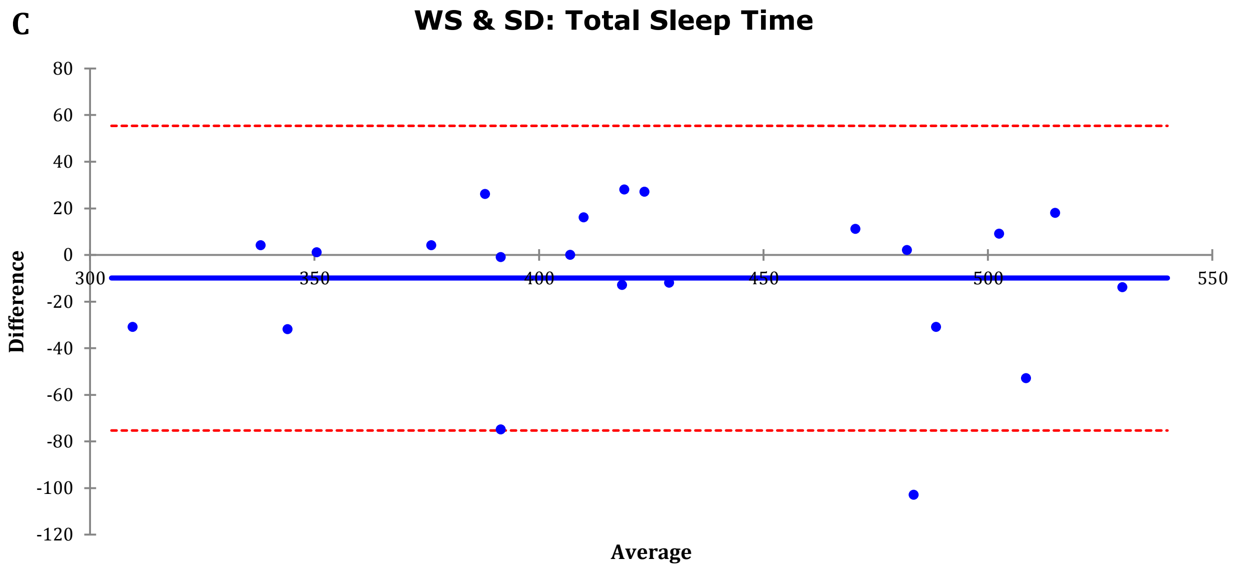


Figure 3.2. Bland Altman plots showing limits of agreement (LoA) between WS and respective sleep measurement devices (ACT) for the comparison of total sleep time and assumed sleep time. **A.** Comparison of mean difference TST (min) and average measurement of TST (min) between the WS & ACT indicates 59 ± 33 min of difference between devices. **B.** Comparison of assumed sleep time (AST) between WS & ACT shows 2 ± 17 min of differences. The solid blue line represents the mean of differences between the devices (Bias). Values above zero signify an overestimation of the specific parameter presented, values below zero represent an underestimation of the WS in relation to the specific sleep device in the comparison. The red dotted line shows the 95% limits of agreement between the devices.

C



D

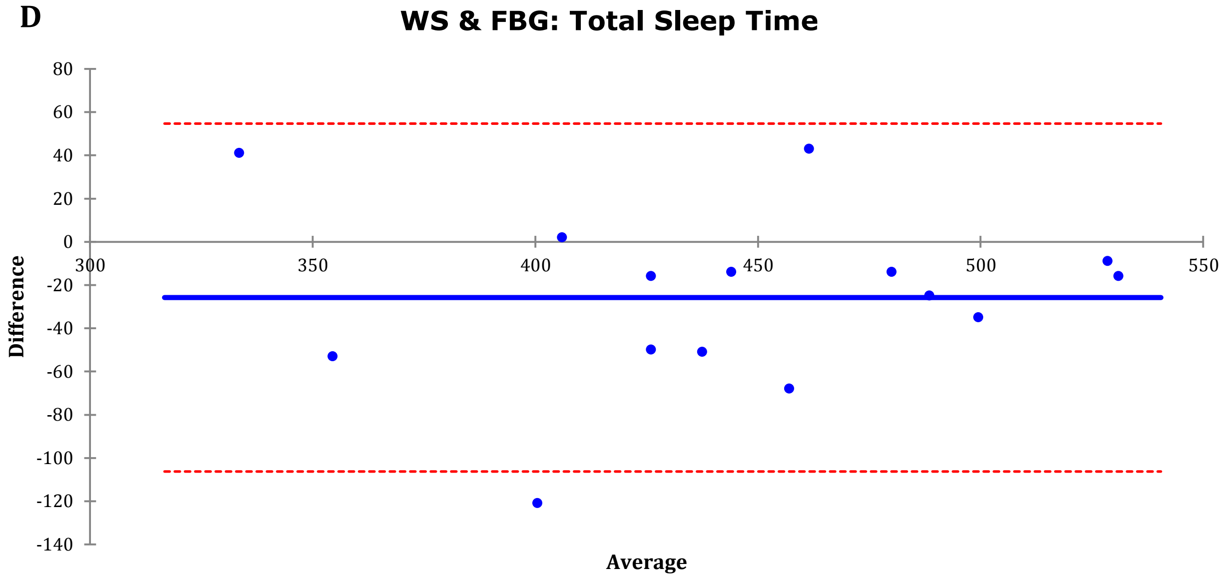
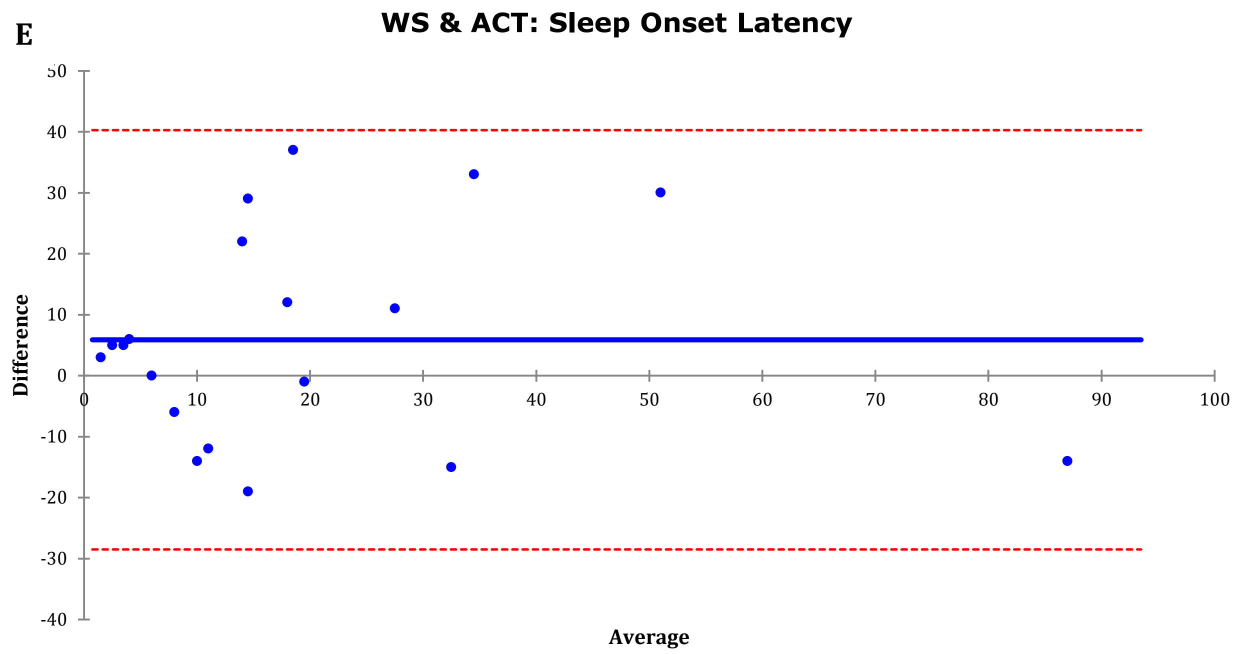


Figure 3.3. Bland Altman plots showing limits of agreement (LoA) between WS and respective sleep measurement devices (SD & FBG) for the comparison of TST.**C.** Comparison of TST between WS & SD indicating a mean difference of -11 ± 33 min. **D.** Comparison of TST between WS & FBG indicating a subsequent bias of -26 ± 41 min.

E



F

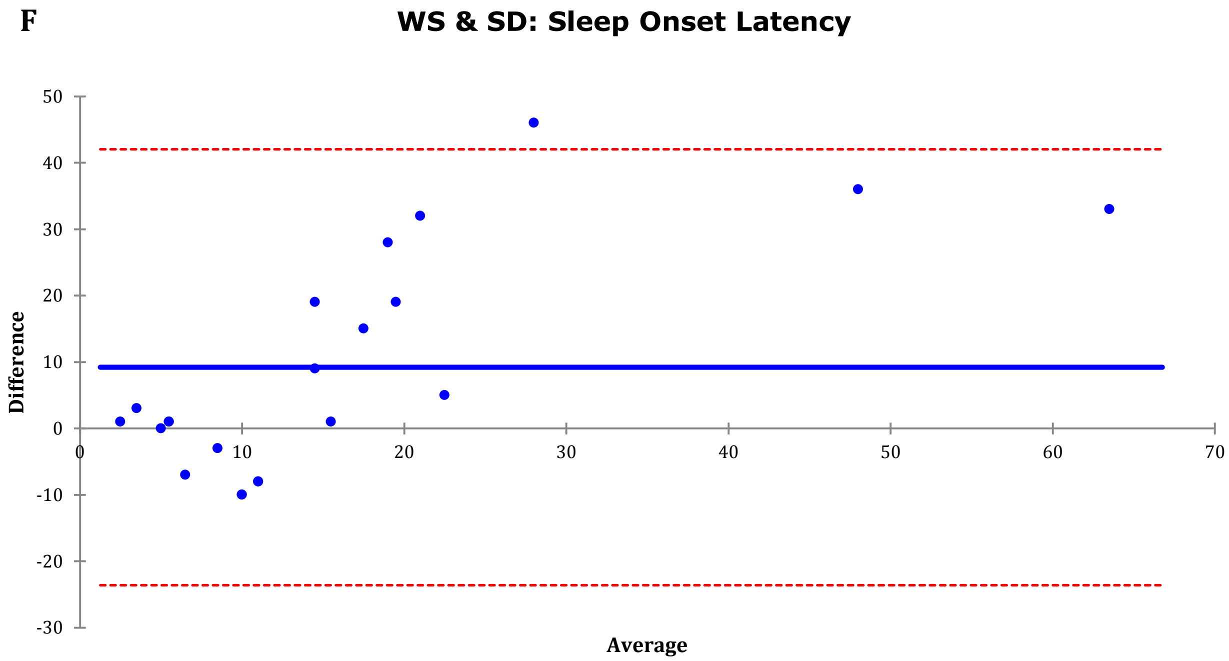
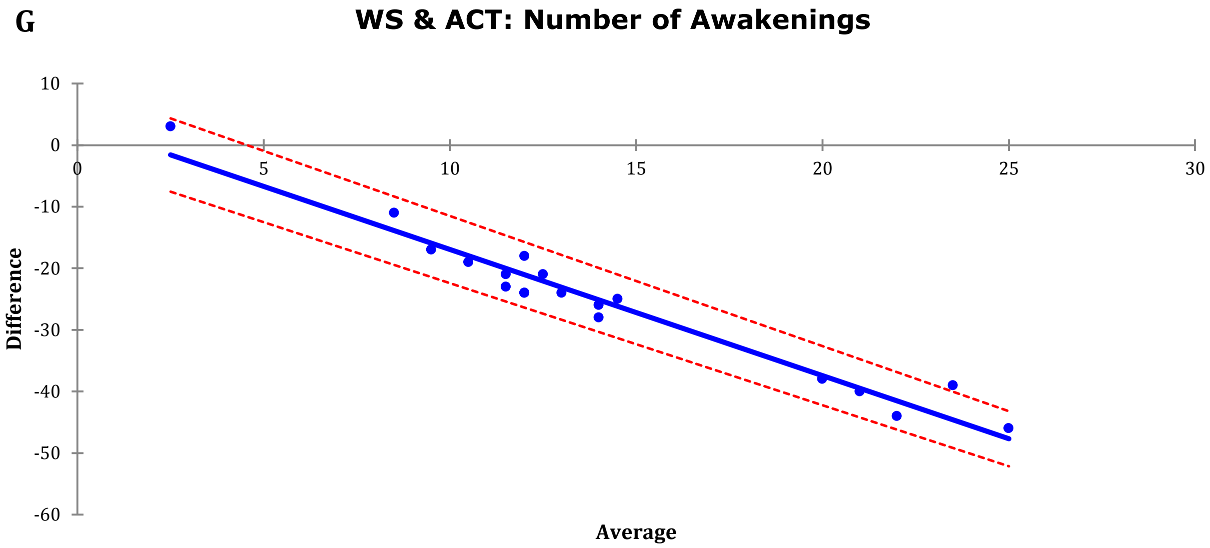


Figure 3.4. Bland Altman plots showing comparison of SOL (min) between WS & ACT and WS & SD. **E.** Compares the WS & ACT for SOL, showing 7 ± 17 min of differences. **F.** Shows the comparison of SOL between WS & SD, representing 9 ± 17 min of mean differences.

G



H

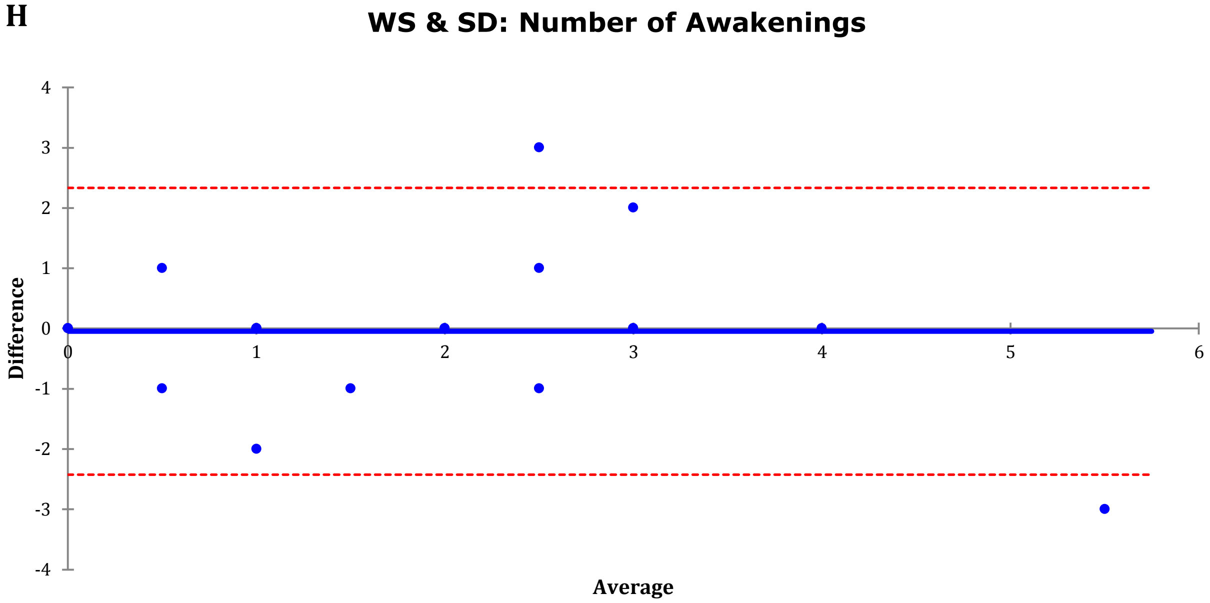


Figure 3.5. Bland Altman plots showing comparison of number of awakenings during the night between WS & ACT and WS & SD. **G.** Shows the comparison between the WS & ACT, representing a negative bias of differences -26 ± 12 . **H.** Shows the comparison between WS & SD for N_{wake}, indicating an almost perfect agreement and low bias (-0.05 ± 1).

3.4 DISCUSSION

The current study aimed to determine the validity of a commercially available wireless sleep monitoring device (WS) in relation to other established field measures of sleep. The comparative relationships between the WS and the other sleep devices, for the selected measures of sleep, indicated strong to very strong correlations between a range of outputs; total sleep time [ACT, SD & FBG], sleep onset latency [ACT & SD] and number of awakenings [SD] and low bias and narrow limits of agreement (indicating good agreement) within the comparison of mean values for assumed sleep time [ACT], sleep onset latency [ACT], and number of awakenings [SD]. However despite the strength of these observed relationships there were significant differences between the mean outputs of the WS and Firstbeat Bodyguard as well as WS and actigraphy for the quantification of total sleep time. Additionally there was also a significant difference between WS and sleep diary for the calculation of sleep onset latency. Finally there was a complete lack of association between the measure of number of awakenings between the WS and actigraphy. These differences indicate a potential systematic bias between the methods for each of the respective sleep measures. Although systematic bias may be apparent for some of the comparisons between the devices within some of the selected sleep variables, such biases may be as a result of the limitations of the established sleep methodologies and not the WS per se. It would therefore seem that the WS is a viable method to be used within research that involves the evaluation of sleep in real world athlete monitoring investigations.

When comparing the relationship for total sleep time between the WS and actigraphy a statistical significant difference between the data produced by the devices was shown. When the Bland and Altman plots are analysed for this data, there was a +59 min bias regarding the difference in mean recordings of total sleep time. The 95% limits of the agreement range from the current study was -5 to 123 min with only one data point being below zero. This suggests a large overestimation of total sleep time recorded by the WS in comparison to the actigraph and some systematic bias. Previous research into the agreement between the WS and actigraphy has shown a small underestimation of total sleep time (mean bias = -12 min) (Tonetti, *et* al, 2012). This data is a stark contrast with the observations for the agreement of total sleep time from the data collected here using ACT. One explanation for the observed differences in the agreement for total sleep time between these two studies could be attributed to the use of different actigraphy (Basic Mini-motionlogger actigraph [Ambulatory Monitoring, Inc., Ardsley, NY, USA] vs. Motionwatch 8 Wristwatch Actigraph [CamNtech Ltd., Cambridge, UK]) as differences are common in the algorithms used to quantify sleep and wake between different actigraphy devices (Sadeh, 2011). It could therefore be suggested that the differences between the current data and the data presented by Tonetti & Colleagues (2012) for total sleep time, may be explained through the specific equipment used to provide the comparative measure (Actigraphy).

Actigraphy uses movement as a surrogate for wakefulness in the assessment of sleep (Sadeh, 2011; Elbaz, *et al*, 2013). Therefore the actigraph device used in the current study is limited in its ability to record and measure sleep and wake due to its sole reliance on the frequency and intensity of wrist movement (Pollack, *et* al, 2001; Martin & Hakim, 2001; Elbaz, *et al*, 2013). Such movements may occur during periods of REM sleep where high amounts of motor activity can occur. During this phase of sleep the WS is more likely to identify REM and quantify it as sleep (Shambroom, *et al,* 2012; Tonetti, *et al,* 2013), were as such periods are likely to be quantified as awakenings by actigraphy (Pollack, *et* al, 2001; Elbaz, *et al*, 2013). Such differences in the ability to detect and record awakenings are likely going to cause overestimations of the number of awakenings by the actigraphy (Elbaz, *et al*, 2013). When observing the data from the current study, there was a lack of correlation between WS and actigraphy for measures of the number of awakenings (r = -0.21) and a significant difference between means. The Bland Altman LOA also indicated a bias or underestimation by the WS, as the limits of agreement were substantially large. The relationship between these variables also showed a negative linear trend (when the mean number of awakenings recorded by the WS and actigraphy increased, the underestimation of differences also increased concomitantly). This data consequently shows a systematic bias between the WS and actigraphy for the measurement of the number of awakenings, however, this bias is likely derived through the limitations in the detection of wake by the actigraph (Elbaz, *et al*, 2013) as opposed to any limitation associated with the WS.

The measurement limitations of actigraphy for the detection of wake may therefore also be a reason for the observed systematic bias and subsequent overestimation of total sleep time of the WS. This suggestion can be supported, when the relationship between total sleep time (TST) for the WS is compared to that of the assumed sleep time (AST) of the actigraphy (this approach removes the effects of the number of awakenings detected by the actigraph, thereby reducing the recording sensitivity issues associated with movement). This comparison yielded an almost perfect correlation (r = 0.97), narrower limits of agreement, less bias and a more consistent spread of values around zero, irrespective of the length of sleep recorded between the two measures. This comparison of assumed sleep time consequently offers a stronger relationship and closer agreement to that observed for the comparison of total sleep time (TST) provided by the actigraph. This data would therefore infer that any differences that were observed in the data between total sleep time of the WS and actigraphy were mainly caused through the impact of number awakenings recorded by the actigraph.

Within the comparison of the WS and the sleep diary data we observed very strong correlations for the quantification of total sleep time. When analysing the agreement between the WS and sleep diary for the measure of total sleep time, the WS showed only a small underestimation (mean bias = - 10 mins), with no significant differences between the devices, although there were large limits of agreement (-75 to 55 min). In the comparison of total number of awakenings recorded by the WS with the recall of awakenings provided by the sleep diary, the results were also shown to be closely related (a very strong correlation, minimal bias between means and a very narrow limit of agreement). This suggests that the wireless system has a comparable detection rate to the subjective recall of awakenings. As subjective recall of awakening requires the participant to be consciously awake for them to record an awakening (Arora, *et* al, 2013) this measure may actually be more accurate than the equivalent measure of wake recorded by the actigraph. These results combined lend further support to the suggestion that the WS is a viable device for the measure of total sleep time and number of awakenings.

It was also observed that there was a strong relationship (r = 0.69; r = 0.65 respectively) between the WS with both actigraph and sleep diary in the quantification of the time taken to initiate sleep onset. The comparison agreement between the devices showed that sleep onset is marginally overestimated by the WS in comparison to both actigraph (mean bias = +7 min, 95% LoA -28, 40 min) & sleep diary (mean bias = +9 min, 95% LoA: -24, 42 min). However the Bland Altman plots of the data also showed nonuniformity in the distribution of sleep onset latency values in both cases; that is to say that when the sleep onset recorded by the WS increased the estimation of differences between the devices became larger. This would seem to suggest increases in inaccuracies when sleep onset periods are longer. Previous investigations have also observed similar findings with an overestimation of sleep onset latency by the WS when using actigraph as a comparison (Tonetti, *et al*, 2012). The issue surrounding movement artefact impacting the data (as described above) may also offer some explanation for the slightly lower relationship and agreement that was observed between the WS and actigraph for the quantification of sleep onset latency.

It is also acknowledged that the measure of sleep onset latency is typically suboptimal for actigraph (Martin & Hakim, 2011; Elbaz, *et al*, 2013). This is due to the participant lying still in bed during the sleep onset period, despite being fully conscious (Martin & Hakim, 2011). Under such circumstances the device will recognise such periods of inactivity as “sleep” (Martin & Hakim, 2011; Elbaz, *et al*, 2013). Therefore if the participants in the current study remained motionless when initiating sleep onset, despite potentially being awake, the actigraph will quantify this period as sleep thereby leading to shortened sleep onset latency periods. However the WS optimises EEG signalling activity to establish the difference between sleep and wake (Shambroom, *et al*, 2012). This approach is deemed useful, as the determination of the EEG power frequency is an established method of assessing the transition of wakefulness to sleep and vice versa (De Genarro, *et al*, 2001). This potentially allows a more accurate differentiation of the sleep transition process whilst nullifying the limiting factor (i.e. no movement attributed as being sleep) associated with sleep onset assessment through actigraphy (Martin & Hakim, 2011; Shambroom, *et* al, 2012; Tonetti, *et al*, 2013). This could therefore provide some rationale for the observed overestimation of sleep onset latency by the WS in comparison to the actigraph device in this investigation.

There are potential limitations associated with the design of the current study as a result of the statistical approaches used (i.e the Bland Altman comparison of limits of agreement). Within an analysis of this type, there is an effect of the sample size. When the sample size is small, each participant’s values within the sample will have more weighting, compared to that of a greater population size (Hopkins, 2000). As a consequence, this will likely result in the limits of agreement being less precise. To establish agreement with more certainty to that provided in the current study more participants would be required within the data collection process. It is also likely that the choice of the comparative "gold standard" methodology (ACT, SD, FBG) would influence the outcomes within the current study design. Such field measures may only offer a surrogate for the recording of sleep compared to using polysomnography (PSG). Therefore a comparison to the actual gold standard (in this case laboratory based PSG) may yield less bias (Hopkins, 2000).

Data that is available that compares the WS with PSG suggests that the wireless system has high levels of agreement for the detection of sleep and wake (91.1% & 92.6% epoch to epoch comparative agreement) (Shambroom, *et al*, 2012). These relationships are higher than those associated with actigraphy and PSG (86.3% & 85.7%) shown within the same study (Shambroom, *et al*, 2012). Such values are also within the range (83% - 90%) typically reported for a sleep-wake comparison between actigraph and PSG (Pollak, *et al*, 2001; Kushida, *et al*, 2001). At the individual variable level, Shambroom & Colleagues (2012), showed significant underestimations of actigraphy in the pairwise comparisons with PSG for the measure of sleep onset latency (ACT: 2.4 ± 0.6 min vs PSG 12.7 ± 3.1 and 9.7 ± 2 min; mean ± SEM) and a lack of correlation (ICC: -0.07 – 0.13). Whereas the WS showed a higher correlation (ICC 0.42 – 0.50) and no significant pairwise differences for the measure of sleep onset (7.8 ± 2.4 min; mean ± SEM) in comparison to PSG. There were no pairwise differences with total sleep time between the WS and PSG and actigraphy, though the WS was shown to have stronger correlations (ICC: 0.92-0.95) compared to the correlations shown by actigraphy and PSG (ICC: 0.60 – 0.63). Lastly the actigraph was observed to significantly overestimate the number of awakenings in comparison to the measures provided by PSG (ACT: 6.73 ± 0.66 vs. PSG: 2.58 ± 0.37, mean ± SEM), which also was represented by a complete lack of correlation (ICC: -0.33 – 0.05), where as the WS showed stronger agreement (ICC: 0.60 - 0.69). This suggests that actigraphy has a lower overall performance agreement when recording sleep than the WS, when compared to PSG, and therefore is likely to have larger measurement error. Therefore the WS may offer an accurate convenient alternative methodology for the recording of sleep and wake within the studies contained within the current thesis.

3.4.1 CONCLUSION

Overall the current study would suggest the WS is particularly effective for the measure of total sleep time when compared to the assumed sleep time (which negates the limitations of actigraphy previously described) of actigraphy (the minimal bias and narrow limits of agreement displayed within in Figure 2.2.B), as well as when compared to the total sleep time recorded by the sleep diary. Additionally the WS is seemingly able to positively detect wakefulness as shown when comparing the measure of the number of awakenings to that of subjective recall within the sleep diary (as displayed within Figure 2.4.H). Furthermore, as a result of the wireless technology the WS device may optimise EEG signalling, potentially offering a more reliable means for the detection of the transition from wakefulness to sleep (SOL), total sleep time (TST) and the occurrence of awakenings (N_{Wake}) in comparison to other field measures of sleep (Shambroom, *et al*, 2012; Tonetti, *et al*, 2012; Tonetti, *et al*, 2013). Given the unique features and application of the WS, the device could also offer a unique opportunity to provide researchers with the ability to collect further information surrounding sleep (such as sleep staging architecture and evaluation of sleep quality) without the need for a laboratory setting, when multiple nights of collection are needed (Shambroom, *et al*, 2012). Taken together this information may suggest that the wireless technology used in the WS may provide a convenient reliable means to assess the sleeping patterns of populations, such as athletes during their competitive schedules without disrupting their habitual routine.

CHAPTER 4

A COMPARISON OF SLEEP DURATION AND SLEEP EFFICIENCY IN YOUTH SOCCER PLAYERS AND NON-ATHLETES

4.1 INTRODUCTION

Previous research has indicated that there is an inter-relationship between sleep and exercise. This relationship is thought to function through physiological and psychological processes. These processes are similar to those that contribute to the 24hr synchronicity of the sleep-wake cycle (Kubitz, *et al*, 1996; Atkinson & Davenne, 2007; Davenne, 2009; Chennaoui, *et al*, 2014). As a consequence, exercise is considered one of the main zeitgebers contributing to this process (Davenne, 2009; Edwards, *et al*, 2009). When exercise levels are increased, reductions in sleep onset latency and wake after sleep onset, as well as improvements in deep sleep may occur (Kubitz, *et al*, 1996; Driver & Taylor, 2000; Davenne, 2009). These benefits of exercise are thought to influence sleep through potential contributions from different physiological processes (Driver & Taylor, 2000) such as changes in thermoregulation (Atkinson & Davenne, 2007; Chennaoui, *et al*, 2014), an increased need for energy conservation (Driver & Taylor, 2000; Chennaoui, *et al*, 2014) and the need for recovery (Driver & Taylor, 2000; Davenne, 2009).

The reciprocal relationship between sleep and exercise can also be demonstrated by the influence of sleep on exercise performance (Davenne, 2009; Venter, 2012; Chennaoui, *et al*, 2014). When sleep is restricted decrements in exercise performance are observed (Reilly & Piercy, 1994; Orzyl-gryglewska, 2010; Chennaoui, *et al*, 2014). When sleep is restricted there are also changes in the typical regulation of both energy metabolism and the endocrine response (Spiegal, *et* al, 2004; Padilha, *et al*, 2011; Skein, *et al*, 2011), as well as decreases in immune function and increases in the risk of developing illness/infection Lange, *et al,* 2010). Furthermore when sleep is restricted to less than 8 hours a night, there is an increased likelihood of an occurrence of sports related injuries (Milewski, *et al*, 2014). As a result, sleep is often described as one of the most important recovery strategies available to populations such as elite athletes (Halson, 2008; Davenne, 2009; Venter, 2012).

Previous data within soccer players provided by Brand & Colleagues (2009) is the first data to suggest that chronic participation in elite adolescent soccer may actually be favourable for an individuals sleeping pattern in comparison to non-athlete controls. Their results indicated elite adolescent soccer players had shorter sleep onset, reduced awakenings and a higher total sleep quantity and quality compared to age matched controls. However this description is based on data that is collected from the subjective feedback of players. This may lead to inaccuracies of sleep data in comparison to more objective measures of sleep (Teng, *et al*, 2011). A consequent study by Brand & Colleagues (2010) suggested elite adolescent soccer players had favourable EEG sleep patterns, but not greater quantities of sleep in comparison to non-athlete controls. However this data was conducted over a one-night period of investigation. This makes the representativeness of this data questionable.

At present there is no objective data that provides a comparison of sleep in youth soccer players with non-athlete controls over consecutive nights of sleep. The current study was therefore designed to investigate the habitual sleep pattern in youth soccer players in comparison to a group of non-athletes using a wireless sleep-monitoring device. This technique will provide objective data to investigate whether elite soccer training has an impact on sleep duration and quality in comparison to that experienced by non-athlete controls. This data may also provide useful insights into the potential occurrence of sleep problems associated with chronic participation in elite youth soccer.

4.2 METHODS

4.2.1 RESEARCH APPROACH

To investigate the potential differences in sleep quantity and quality between athletic and non-athlete populations the current study attempted to compare the sleep data generated from a group of youth soccer players to that from a group of non-athlete controls. The sleep data was collected using a wireless system (WS) (Zeo Bedside Sleep Monitor, Zeo Inc.). Sleep was monitored over a habitual 6-day period during the competitive season for the youth soccer players and a habitual 6 days of sleep for the control participants. The generated data was then subsequently used as a basis for the comparison between the two populations.

4.2.2 PARTICIPANTS

Participants consisted of eight male youth soccer players (SOC) and eight male non-athlete controls (CON). Anthropometric measurements for both groups are presented within Table 3.1. The youth soccer players were full-time partaking in 6±1 training sessions (technical, tactical & conditioning) and one competitive match and recovery session per-week. The non-athlete controls were healthy and physically active at the time of the study (on average 3±2 sessions of exercise per week). All participants were informed prior to the investigation of their requirements during the study. The study was agreed and accepted by the Liverpool John Moores University Institutional Ethics Committee. Prior to any measurements, consent was agreed and participant information provided.

Table 4.1. Anthropometrical data for youth soccer players and non-athlete controls

GROUP	Age (yrs)	Height (m)	Weight (kg)
SOC	18 ± 1	1.84 ± 0.06	80 ±10
CON	24 ± 4	1.75 ± 0.03	73 ± 5

4.2.3 EXPERIMENTAL DESIGN

Once the research design was agreed and participant consent granted, each participant was provided with a WS. The youth soccer players were monitored over six nights (consisting of four training days, one match day [home fixture] and one day consisting of a recovery session). The non-athlete group were also monitored over six nights, which included their typical daily working routine. Days off were excluded from the data collection procedures, as this type of day is typically associated with a change in sleeping behaviours compared to working days (Wittmann, *et al*, 2006). This was done to minimise the potential variation caused by off days, providing a better indication within the comparison of typical schedules (i.e. training/working requirements) of both populations. Both groups were made aware that the WS was to be worn every night during the six-day period of the study. The methodological approach to the data collection for the WS is described previously (See Chapter 2, Section 2.2.4). This process was replicated for the data collection during this investigation. The assessed sleep variables included; TST, SOL and N_{WAKE} (previously investigated within Chapter 2). Additionally during any awakenings within the nights sleep the time in wake after sleep onset (WASO) was also determined. Each variable was then compared between groups to establish any differences in the sleep related parameters between the two populations. A subjective evaluation of training load was established, using an individual rating of perceived exertion (RPE). This was assessed using a modified Borg scale (1-10) (Foster, *et al*, 2001). Each participant provided this RPE following any exercise that was completed during the study period. This provided a means of quantifying and comparing the exercise profiles of the two populations over and above the data associated with the number of sessions completed. This data was useful to help establish any effects of exercise on subsequent sleep patterns between the groups.

4.2.4 EXPERIMENTAL PROCEDURES

Prior to any data collection, all participants were provided with the WS and shown how to use the device. A period of two night's sleep was used as familiarization. This allowed for each participant to become comfortable with the sleep monitoring process. Sleep was then recorded each night of the study with the WS being integrated into each participant's habitual sleeping routine. Upon days of exercise, the youth soccer player group were instructed to complete their individual RPE after 30 min of cessation of each training session / match (were applicable). During the data collection period the data provided by the elite youth soccer group was monitored and stored by an exercise professional. This professional also recorded the total session duration for each athlete. As an exercise professional was not present for exercise sessions conducted by the non-athlete control group, the individuals were subsequently instructed to fill out a training diary on any given day when exercise was completed. An example description of how to complete the diary was given so that each participant was familiar with the recording process (for an example diary see Appendix 2). The training diary was also filled out after 30 minutes of the individual's session ending to maintain consistency of the collected data between the two participant groups. Within the diary the non-athlete group recorded their overall RPE score associated with the exercise completed, the duration of the exercise period and the type of exercise performed. The information provided from both groups allowed daily training load to be subsequently calculated using the following equation: Duration x RPE = RPE_{LOAD} (arbitrary units AU) (Foster, *et al*, 2001).

4.2.5 STATISTICAL ANALYSIS

The data were analysed using the R version 3.1.0 Software (The R Foundation for Statistical Computing, 2014.). For all the variables, the six-day averages were calculated for each individual across the study period and were considered for the subsequent analysis for each individual. The Shapiro-Wilk method for testing normality was conducted for each data set. Independent sample *t*-tests were then used to analyse those data (TOLO, SOL, N_{WAKE}, TST, TOFA, training frequency, duration, RPE & RPE_{LOAD}) that met the criteria of normality. These data were reported as the mean ± *sd*, or the mean difference and the 95% confidence interval (95% CI). If normality wasn't established (p <0.05 in the Shapiro-Wilk test) (WASO), then the non-parametric Mann-Whitney-Wilcoxon test was used. In this case data were reported as median and interquartile range (IQR). Finally, Cohen's *d* was calculated to show the magnitude of effect sizes associated with the dependent variables for each population (Cohen, 1988). Effect sizes (ES) were evaluated using the modified scale approach of Cohen (1992) where 0-0.19 represents a trivial effect, 0.2-0.49 represents a small effect, 0.5-0.79 a medium effect, >0.8 a large effect. For non-normally distributed variables, the probability of superiority (PS; Grissom & Kim, 2001) was used as the effect size. PS ranges from 0 to 1, where a value of 0.5 indicates no effect. The magnitude of PS was interpreted according to the proposed correspondence between PS values and Coehn's d values (Fritz, Morris, & Richler, 2012). Statistical significance was set at p < 0.05.

4.3 RESULTS

4.3.1 COMPARISON OF SLEEP

Mean ± SD sleep data for the two populations are provided in Table 4.2. The results indicate that the time of lights out was similar between the groups (~18 min difference, 95% CI: -52 to 63 min, ES 0.4 medium, p = 0.39). However the youth soccer players displayed a later time of final awakening (08:54 ± 00:14) than their non-athlete counterparts (07:34 ± 00:46); represented by a mean difference of 77 min between the two groups (95% CI: 55 to 140 min, ES 1.8 large, p < 0.01).

Table 4.2. Sleep data for the youth soccer players and non-athlete control participants presented as Mean ± SD or Median (IQR) were applicable. Cohens *d* effect size statistic is also reported (ES).

Variable	SOC	CON	ES
TOLO (hr:mm)	23:35 ± 00:20	23:53 ± 01:02	(0.4)
TOFA (hr:mm)	08:54 ± 00:14	07:34 ± 00:46 *	(1.8)
TST (min)	504 ± 22	433 ± 46 *	(2.0)
SOL (min)	23 ± 7	17 ± 11	(0.8)
WASO (min)	13 (13)	2 (5) *	(1.5)
N_{WAKE}	3 ± 2	2 ± 2	(0.4)

* Statistically significant difference in comparison to the elite youth soccer group (SOC) ($p < 0.05$)

On average, sleep onset latency was higher for the soccer players (23 ± 19 min) than that of the control group (17 ± 17 min) although the mean difference (-6 min) was not deemed significant (95% CI: -16 to 3 min, ES 0.8, medium, $p = 0.15$,). No significant differences were found between measures of number of awakenings between the subject groups as the mean was shown to be similar (~1 awakening; 95% CI: -3 to 1, ES 0.4 medium, $p = 0.43$). Despite there being no significant differences between the number of awakenings recorded each night, there was a significant difference between the groups for the time spent awake during each respective awakening. On average the soccer players spent significantly more time in wake (median: 13 min, IQR: 13 min) compared to the control group (median: 2 min, IQR: 5 min) (PS: 0.86, corresponding ES: 1.5 large, $p = 0.02$). There was also a significant difference for total sleep time between the groups, with the youth soccer players attaining significantly longer total sleep time than the control group ($p < 0.01$). The mean difference in total sleep time between the control and soccer groups was -71 minutes (95% CI: -110 to -33 min, ES 2.0 large).

4.3.2 COMPARISON OF TRAINING LOAD

Mean ± SD training load data is displayed in Table 3.3. The youth soccer players on average trained more frequently (6 ± 1) during the study period compared to the control group (3 ± 2). The mean difference was -3 sessions (95% CI: -4 to -1, ES 2.0 large, $p < 0.01$,) for this comparison. On average soccer players also trained for longer each day (73 ± 6 min) in comparison to the control group (58 ± 13 min). This was represented by a mean difference of -15 min (95% CI: - 26 to -4 min, ES 1.0 large, p = 0.01).

Table 4.3. Mean ± SD training load data for the youth soccer players and non-athlete controls. Cohens *d* effect size statistic is also reported (ES).

	SOC	CON	ES
Frequency	6 ± 1	4 ± 2 *	(2.0)
Duration (min)	73 ± 6	58 ± 13 *	(1.5)
RPE (au)	6 ± 1	5 ± 1	(1.0)
RPE_{LOAD} (au)	1004 ± 232	289 ± 109 *	(3.9)

The elite youth soccer group averaged a slightly higher RPE (6 ± 1 au) in comparison to the control group (5 ± 1 au) though this difference was not significant (95% CI: -3 to 0.4, ES 1.0 large, $p = 0.12$). When comparing the average session RPE_{LOAD}, there was a significant difference between each population group ($p < 0.01$). The soccer players who were training full time averaged a higher daily training load (1004 ± 232 au) compared to that of the control group (289 ± 109 au). This resulted in a mean difference of -714 au (95% likely range -939 to -490 au, ES 3.9 large) associated with the differences in daily average training load between populations.

4.4 DISCUSSION

The primary aim of the current study was to investigate the differences in sleep parameters between youth soccer players and a control group of non-athletes over a 6-day period. The main results of the current investigation demonstrated that the youth soccer players attained a higher total sleep time (TST) than the non-athlete controls. This was the case, despite taking longer on average to initiate sleep (SOL) and spending more time awake each night (WASO) in comparison to the non-athlete controls. Such observations are likely linked to the significantly later time of the final awakening displayed within the youth soccer players. Such characteristics would suggest that the youth soccer players have favourable circumstances that affect sleep quantity in comparison to non-athlete controls. These data may suggest that sleep efficiency in athlete populations may however be reduced, indicating that elite youth soccer training and match play may impact the quality of sleep that youth soccer players attain on a nightly basis. Such observations provide important insights into the potential factors that may affect the sleep of youth soccer players on a nightly basis.

At present there is lack of literature that investigates the sleeping pattern of athlete groups, such as elite soccer players (Leeder, *et al*, 2012; Nedelec, *et al*, 2015). Leeder and Colleagues (2012) reported that athletic populations (i.e. Elite GB athletes) exhibit a slightly lower, yet statistically similar, amount of total sleep time compared to aged matched non-athlete controls (ATH: 415 vs CON: 431 min). In contrast Brand & Colleagues (2009) suggested that chronic participation in soccer (i.e. elite level adolescent soccer training) provided a positive influence on sleep (e.g. increases in total sleep quantity) when subjectively assessed in comparison to non-athlete controls. However no study has provided objective data to support to these ideas before this current investigation. The current study shows that this population of youth soccer players attains greater amounts of total sleep time in comparison to non-athlete controls. One explanation for the differences in sleep quantity of the youth soccer players in comparison to the non-athletes may be due to a more regular sleep-awake schedule (Brand, *et al*, 2009). When investigating the displayed sleep data, it is observable that there is less variation in the time of lights out, time of final awakening and total sleep time within the youth soccer players (as evidenced by a lower standard deviation, see Table 3.2) in comparison to the non-athletes. Conversely in the observation of athletes from other elite sports populations, a larger variation of sleep measures has been observed (Leeder, *et al*, 2012). Given that the schedule imposed on the youth soccer players is likely homogenous, such consistency in the daily organization of activity may provide a rationale to the observed findings. This may suggest that the schedule of training and match play experienced by the youth soccer players within the observed period, may be an important factor in allowing a greater total sleep time to be achieved.

Within the current study the youth soccer players displayed a significantly later time of awakening in comparison to the non-athlete controls (CON: 07:34 am vs. SOC: 08:54). This may be primarily due to a later requirement to arise as a result of the soccer schedule, meaning a greater total sleep time could be achieved. In contrast the non-athletes included here, had to arise earlier to facilitate individual work commitments; this resulted in the group having a lower achievable total sleep time. This data may therefore provide some evidence to suggest that the schedule experienced by the youth soccer players is an important factor that may impact sleep. This data was, however only collected over a 6-day period, which may not be indicative of the variation in sleeping pattern across both populations over time. For example, this may not reflect changes in the schedule (i.e. away travel, congested fixtures and evening games) that typically occur across the elite soccer season (Morgans, *et al*, 2014; Nedelec, *et al*, 2015). Therefore further investigation utilising longer periods of sleep assessment seems warranted to examine if such factors can greatly impact sleep patterns in youth soccer players. Additionally each group consisted of 8 participants, which is a relatively low sample size for comparisons of this type. This may exaggerate the magnitude of the differences observed within the current study and therefore caution should be expressed when interpreting these results, as the data within the current study may not represent a larger sample of participants from the same populations. Therefore future investigations of this type should look to utilise a larger sample size to establish these findings with more accuracy.

Although the youth soccer players in the current study actually attained a greater total sleep time on average each night compared to the non-athletes, it would seem that the soccer player's sleep was less efficient. The youth soccer players averaged a sleep onset time of 23 minutes and spent a median of 17 minutes awake each night. This was greater than the times recorded for the non-athletic controls within the current study. This data is actually consistent with previous findings in elite athlete and non-athlete comparisons (Leeder, *et al*, 2012). Given that these factors may be apparent across elite sports, it is pertinent to attempt to examine the potential reasons for these trends. In the current study the youth soccer players exercised more frequently, for a longer duration and at a higher intensity than the non-athlete controls. Increased training loads that elite athletes are exposed to may cause greater levels of sleep disturbance and reduced sleep efficiency may be observed (Taylor, *et al*, 1997; Teng, *et al*, 2011). This may therefore offer a potential rationale to the observation of sleep disturbances within elite level sports, although the available data do not provide a clear understanding of the mechanism for this response (Taylor, *et al*, 1997). At present the relationship between the exercise load and the sleeping pattern of youth soccer players is largely unknown. As such it would seem relevant to complete other investigations that look to investigate this relationship more closely. Such data would provide an insight into the potential influence that the typical training loads displayed within elite youth soccer has on the sleep quantity and efficiency within youth soccer players. This may therefore increase the understanding of the underlying mechanisms that may contribute to this relationship.

4.5 CONCLUSION

Overall the current study provides objective insight into the sleeping habits of youth soccer players in relation to a non-athlete population. The current study showed the elite soccer players attained a greater total sleep quantity (TST) than that of a non-athletic control group, despite displaying a longer sleep onset and longer times spent awake on average each night. It is likely this was as a result of the relationship between the sleep schedule and planned soccer schedule experienced by the youth soccer players. This would suggest that the nature of the schedule in athlete groups might be an important determinant of sleep. The current data also provides useful insight into the sleep efficiency of youth soccer players. The current data would suggest that the sleep within the youth soccer players is less efficient than non-athlete controls. This may be due to the apparent differences in exercise load between the populations. However no data currently exists to describe this potential relationship between the training load in elite youth soccer and the impact on sleep efficiency. This therefore requires further investigation within youth soccer players during the competitive season.

CHAPTER 5

AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN SLEEP, TRAINING AND MATCH LOAD DURING A TWO-WEEK IN-SEASON PERIOD IN YOUTH SOCCER PLAYERS.

5.1 INTRODUCTION

Sleep is often described as the most efficacious recovery strategy available to athletes (Halson, 2008) and as such is thought to play a primary role in daily physiological and psychological restoration (Davenne, 2009; Venter, 2012). However sleep, and the mechanisms behind the influence of sleep are still poorly understood, particularly within the athlete population (Samuels, 2008; Leeder, *et al*, 2012). The previous chapter demonstrated that youth soccer players attain more sleep in comparison to non-athlete controls. However the youth soccer players also demonstrated lower sleep efficiency (i.e. longer time to sleep onset and longer time spent awake). Reduced sleep efficiency has also been reported within other athletic populations (Leeder, *et al*, 2012; Lastella, *et al*, 2014). These findings may indicate that this is common trend in elite sport participants.

It is likely that youth soccer players are exposed to a myriad of processes to develop fitness whilst regularly participating within competitive matches (Morgans, *et al*, 2014). Such a process may influence the scheduled exposure to high intensity loads during training phases within the competitive soccer season (Morgans, *et al*, 2014). Exposure to intensified training loads within athletic populations has been identified as a potential factor that increases the likelihood of disturbance within sleep (Taylor, *et al*, 1997; Teng, *et al*, 2011; Hausswirth, *et al*, 2014). Investigations in youth soccer players have, however, suggested that sleep is not affected by training days that are high-intensity, when compared to sleep on lower intensity training or rest days (Robey, *et al*, 2014). However this data focused on the effects of a fixed evening high-intensity training session, which attributed a "somewhat hard" subjective rating of perceived exertion. Therefore such evaluation may not account for other situations such as matches or training sessions, which likely exhibit higher intensities.

Given that there is currently a lack of data within soccer that identifies how a soccer player sleeps, it may be interesting to evaluate a period of typical training within elite youth soccer to gain a better understanding of how sleep may be influenced by soccer training and match loads across a training phase. No study to the author's knowledge has attempted to directly investigate this relationship previously. Therefore the current study was designed to provide insights into the habitual sleeping pattern of youth soccer players and to investigate how elite youth soccer training and match load may influence this process

5.2 METHODS

5.2.1 RESEARCH APPROACH

To investigate the relationship between training/match load and sleep, the habitual sleeping pattern of youth soccer players was assessed each respective night during a two-week in-season period using a WS. Training/match load was calculated using approaches that included a portable global positioning system (GPS) (STATSports Viper, Ireland), heart rate (HR) monitoring (Polar Electro, Kempele, Finland) and subjective RPE (Foster, *et al*, 2001). The collected training/match load data was then compared with that of the typical sleep pattern data of that respective night. This was done in an attempt to establish the relationship between the distribution of training and match load and the response to sleep.

5.2.2 PARTICIPANTS

Participants were ten male fulltime youth soccer players. Anthropometric characteristics are displayed in Table 5.1. The study was conducted over a two-week period in the competitive youth soccer season. During this time the participants trained a minimum of 4 days a week and participated in at least one competitive match, recovery session and day off during the weekly schedule. Prior to any measures, participant information and consent was provided. The study was agreed and accepted by the Liverpool John Moores University Institutional Ethics Committee.

Table 5.1. Anthropometric data for the youth soccer players used in the current study. Data displayed as mean ± *sd.*

Participants	Age (yrs)	Height (m)	Weight (kg)
N=10	**18 ± 1**	**1.79 ± 0.05**	**72 ± 5**

5.2.3 EXPERIMENTAL DESIGN

The current study looked to examine the relationships between sleep and the typical training and match load within a group of youth soccer players. An indication of relevant sleep parameters was established using a WS worn overnight. The players were assessed over a 14-day in-season period with the data collection procedures being integrated as part of an in-season performance monitoring strategy for the individuals. Training and match load was quantified using a GPS system with integrated HR monitoring (STATSports Viper, Ireland). The GPS device was worn in every training session and match to provide each player's physical activity profile. This was based on the positional velocity and specific distance detected through satellite signalling. The data was collected at a sampling rate of 10 Hz (Viper 2 units, STATSports Viper, Ireland). Such 10 Hz systems have previously been suggested to be a valid and reliable means of detecting the activity profile during exercise (Castellano, *et al*, 2011; Varley, *et al*, 2012). For example at constant velocity the 10 Hz system displayed lower coefficient of variation (CV) values at different speed thresholds compared to earlier 5 Hz systems (1-3 m/s, 8.3% vs 11.1% CV; 3-5 m/s, 4.3% vs. 10.6% CV; 5-8 m/s, 3.1 % vs. 3.6 % CV) (Varley, *et al*, 2012). The 10 Hz device was also shown to have CV values similar to or less than the smallest worthwhile change, therefore offering higher levels of accuracy in the detection of changes in velocity-based activities in comparison to earlier systems (Varley, *et al*, 2012). At present no validation data exists for the STATSports Viper 2 (10 Hz unit), though published data is available that has employed this technology previously (Gaudino, *et al,* 2015; Malone, *et al*, 2015, Russell, *et al*, 2015; Anderson, *et al*, 2016) To provide a measure of heart rate, a polar electro T31 HR monitor (Polar Electro, Kempele, Finland) was also worn. This equipment was selected due to its compatibility with the STATSports system. The heart rate receiver (0 - 240 bpm), integrated within the GPS Viper unit, detected the HR signal and stored the data for subsequent post session download. The youth soccer players also provided an internal response measure of the activity completed using subjective RPE collected post session. This approach was adopted to provide both indicators of both external (GPS derived measures of distance and speed) and internal load (HR and RPE).

5.2.4 EXPERIMENTAL PROCEDURES

Prior to testing each participant was briefed on the procedures associated around the data collection process. Each participant was also provided with a WS and instructed on its use. Due to the availability of this equipment (N=5) the participants were assessed over two separate in-season periods within the same month. This data provided the habitual sleeping pattern of each of the youth soccer players included within the investigation. The methodological approach to the collection of this data has been previously described (See Chapter(s) 2.2 and 3.2 of this thesis). Each participant was instructed to wear the WS on a nightly basis during their habitual training, match days and off days during the two-week period. Upon awakening the WS was detached and returned to the experimenter for subsequent analysis. The downloaded data included; TST, SOL, N_{WAKE} and WASO which have previously been utilised in the assessment of sleep within the current thesis (see Chapter 3 and 4 respectively).

During training and matches each player was required to wear the same GPS unit and HR monitor, this was done to minimise detection errors arising from inter-unit variability (Malone, *et al,* 2015). The GPS unit was located in the back of a training vest, designed and supplied by the manufacturer (STATSports, Ireland), which was fitted to the participant. The unit was located centrally across the upper thoracic region of the back between the right and left scapula. This placement allowed for the GPS unit to have clear exposure to detect the satellite signals. Each vest was based on the specific players size and was designed to fit tight to minimise movement of the unit placement. The HR monitor was also fitted to the participant around the chest underneath the training vest, directly below the pectoral muscles, with the transmitter localised centrally in relation to the sternal notch. The GPS unit was switched on 25 min before each respective training session or match-day data collection period. This allowed the unit to acquire the required GPS signals to ensure accurate data collection prior to the warm up. All units were switched off at the completion of the session and collected by a sports science practitioner for subsequent download.

The activity profile of each player was then analysed by the sports science practitioner using the STATSports Viper analysis software (STATSports Viper, STATSports, Ireland). For the training sessions, the data was clipped at the beginning of the warm up (to signify the start of the session) with the designated finish being the end of last training drill completed by each individual. This was done to formulate the metrics for the "overall training session". A similar procedure was utilised for match days, were the warm up was used as the start point and the last activity (i.e. substitution or final whistle) the individual performed in the match signifying the end point. This was done to create the "overall match day" activity. The collected GPS data during each respective training session and match included; total distance covered (TD) and high-speed running distance (HSD) (above 5.5 m/s) in meters (m), which are typically employed metrics in the expression of individual training load in soccer (Gaudino, *et al,* 2015; Malone, *et al*, 2015). Heart rate data was analysed to provide the time spent above 85% of the individuals predicted max heart rate in minutes to assess the internal response at high intensities. The time from session start to session end was used to calculate total session duration (DUR). At 30 minutes post session each of the players were required to provide their RPE rating for the session. The RPE was rated on a customised Borg scale (1 very light to 10 Maximal) (Foster, *et al,* 2001). The RPE was then multiplied by the session duration to create and overall arbitrary load (RPE_{LOAD}) (Foster, *et al*, 2001). These procedures were repeated for the duration of the study until each participant satisfied the criteria of two-weeks of data collection during the in-season period.

The collected sleep and training/match load data were then classified in relation to the number of days before and after the match (M) within the training phase. The training sessions were classified as 4 days before the match (M-4), 3 days before the match (M-3), 2 days before the match (M-2), the day before the match (M-1) and the day following the match (M+1). The days when no training or matches occurred were represented as OFF. This allowed the potential changes in sleep to be assessed across the training phase to investigate the relationship of the specific scheduled training days typically utilised in elite youth soccer as well as the particular training/match load variables collected daily during the training phase.

5.2.5 STATISTICAL ANALYSIS

The data was analysed using the statistical package R - Version 3.2.1 Software (The R Foundation for Statistical Computing, 2014) using the statistical technique of linear mixed modelling. This type of analysis was deemed a viable approach as linear mixed models are a robust methodology that is able to handle repeated measures data, with both fixed and random effects, as well as missing data (Cnaan, *et al*, 1997). To assess the effects of the specific type of day in relation to the count from the match on the habitual sleep pattern of the youth soccer players, the type of day within the training phase was treated as the predictor value, with a random intercept on the individual players. The sleep data was identified as outputs (TOLO, SOL, TST, N_{WAKE}, WASO and TOFA) within this analysis. Pairwise comparisons using Tukey's contrasts were used to compare the type of days (e.g. M-1 compared to M, M-2 etc…), to assess which days observed significant differences. Within the assessment of training load, the individual training load variables (DUR, TD, HSD, HR_{HI}, RPE and RPE_{LOAD}) were treated as predictor values, with a random intercept placed on the individual players, when assessing the effects on the outcome variables of sleep (TOLO, SOL, TST, N_{WAKE}, WASO and TOFA). As the training load variables were continuous predictors, the effects were reported as the single coefficient value with 90% confidence intervals. The interaction of schedule and training load variables was also accounted for within those outputs that displayed a significant effect of the individual predictor on the respective sleep variable. For all the analyses, statistical significance was set at the level $p < 0.10$. Effect sizes (ES) were also calculated by standardizing the differences coefficients according to the appropriate between-subjects standard deviation. Effect sizes were evaluated using the modified scale approach of <0.2 = trivial, 0.2 to 0.6 = small effect, 0.6 to 1.2 = moderate effect, 1.2 to 2.0 = large effect, and >2.0 = very large (Hopkins, 2006).

5.3 RESULTS

5.3.1 ANALYSIS OF SLEEP VARIABLES IN RELATION TO THE TYPE OF DAY WITHIN THE TRAINING PHASE

An overview of the sleep data captured on each specific type of day is displayed below in Table 5.2 and 5.3 respectively.

Table. 5.2. Overview of the habitual sleep scheduling in relation to the designated day within the training phase (i.e. M minus / plus). Data displayed as mean ± *sd.*

Countdown	OFF	M-4	M-3	M-2	M-1	M	M+1
Time of Lights Out (hr:min)	23:52 ± 01:13	23:15 ± 01:29	23:45 ± 01:14	22:53 ± 00:45	23:14 ± 01:01	23:48 ± 01:29	23:58 ± 00:47
Time of Final Awakening (hr:min)	07:29 ± 00:14	07:32 ± 00:13	08:12 ± 01:39	07:42 ± 00:44	07:53 ± 00:53	08:10 ± 01:03	07:32 ± 00:56

Table. 5.3. Overview of the habitual sleep data in relation to the type of day within the training phase (i.e. M minus / plus). Data displayed as mean ± *sd.*

Countdown	OFF	M-4	M-3	M-2	M-1	M	M+1
SOL (min)	35 ± 24	18 ± 13	42 ± 41	23 ± 17	28 ± 24	29 ± 21	27 ± 17
TST (min)	419 ± 51	478 ± 21	434 ± 104	488 ± 53*	486 ± 64*	470 ± 75	422 ± 61
N_{WAKE}	1 ± 2	1 ± 0	1 ± 2	2 ± 2	2 ± 2	2 ± 2	1 ± 2
WASO (min)	5 ± 8	3 ± 1	7 ± 10	6 ± 11	8 ± 11	9 ± 15	7 ± 13

* Statistically significant in comparison to M+1 ($p < 0.1$);

When analysing the linear mixed model to assess the relationship between the types of day across the training phase in relation to the captured sleep variables, there was an observed significant effect for total sleep time. The pairwise comparisons showed the total sleep time of the youth soccer players on M+1 was significantly lower in comparison to the days leading into the match day: M-1 (-60 (90% CI: -112 to -8) min; $p = 0.03$; ES = 0.84, moderate) and M-2 (-65 (90% CI: -2 to -129) min; $p = 0.08$; ES = 0.91, moderate). No further significant effects were observed in any of the other comparison for the type of days for TST. Lastly there were also no statistically significant differences within the pairwise comparisons between the specific type of day (M to OFF) on the TOLO, SOL, N_{WAKE}, WASO and TOFA of the youth soccer players (all $p > 0.1$).

5.3.2 ANALYSIS OF THE RELATIONSHIP BETWEEN TRAINING AND MATCH LOAD AND SLEEP

The results of the analysis showed no observed significant effects of RPE_{LOAD} on sleep onset latency, total sleep time and the number of awakenings (all $p > 0.1$). However there was a significant effect for time of lights out, were a rise in 100 au showed a 5 min (90% CI: 0.4 to 9 min) delay in the time of lights out ($p = 0.0734$, ES: 0.36, small). There was also a displayed significant effect on wake after sleep onset, were a rise in 100 au RPE_{LOAD} showed an increase of 42 s (90% CI: 0 to 84 s) in the time spent in wake ($p = 0.098$; ES: 0.29, small). There was also a significant effect on the time of final awakening; a rise of 100 au RPE_{LOAD} displayed a 6 min (90% CI: 2 to 10 min) increase in time of final awakening ($p = 0.0145$, ES: 0.48, small). RPE_{LOAD} was also broken down into the two components (RPE & Duration) to look at the specific relationship between these variables and the potential influence to sleep. When evaluating the effects of training and match duration on the sleep variable outcomes, both training and match duration

Table. 5.4. Training and Match load data (estimated from subjective RPE) averaged across the training phase for the particular count of day. Data displayed as mean ± *sd.*

Countdown	M-4	M-3	M-2	M-1	M	M+1	OFF
Duration (min)	91 ± 1	102 ± 20	105 ± 33	88 ± 14	129 ± 19	61 ± 2	NA
RPE (au)	6 ± 1	6 ± 1	5 ± 1	5 ± 1	7 ± 1	4 ± 1	NA
RPE_{LOAD} (au)	502 ± 50	590 ± 166	582 ± 120	428 ± 106	872 ± 185	264 ± 56	NA

had no subsequent effect on sleep onset latency, total sleep time, the number of awakenings, and wake after sleep onset (all $p > 0.1$). Duration did, however, have a significant effect on both time of lights out and time of final awakening; were a 10 min increase in duration displayed a 6 min (90% CI: 2 to 9 min, $p = 0.0081$, ES: 0.48, small) increase in time of lights out and a 5 min (90% CI: 2 to 8 min, $p = 0.0083$, ES: 0.47, small) increase in the time of final awakening. When RPE was used as the predictor value, no significant effects on all of the sleep variables (TOLO, SOL, TST, NWAKE, WASO and TOFA) were observed (all $p > 0.1$).

Table. 5.5. Average training and match load data obtained from GPS and Heart Rate monitoring distributed across the 14-day assessment period. Data displayed as mean ± *sd.*

Countdown	M-4	M-3	M-2	M-1	M	M+1	OFF
Total Distance (m)	5178 ± 494	6151 ± 1226	5579 ± 2169	4703 ± 839	9530 ± 2820	2924 ± 262	NA
High Speed Distance (m)	242 ± 133	197 ± 120	179 ± 101	217 ± 119	505 ± 223	28 ± 26	NA
Time in Red Zone (min)	4 ± 2	16 ± 12	17 ± 13	8 ± 6	32 ± 20	9 ± 6	NA

There was a significant increase in wake after sleep onset (40 [90% CI: 5 to 75] s; $p = 0.06$; ES: 0.33, small) as total distance increased by 1000 m. There was also a significant increase in the time of final awakening; an increase of 1000m total distance covered displayed a 4 min (90% CI: 1 to 7 min, $p = 0.0237$, ES: 0.42, small) increase in the time of final awakening. There were no significant effects of total distance on any of the other sleep variables (TOLO, SOL, TST, and N_{WAKE}, all $p > 0.1$). When evaluating the contribution of total high-speed running distance in relation to the sleep outcomes, significant effects were detected. An increase of 100 m in total high-speed running distance related to an increase in the number of awakenings observed (0.14, 90% CI: 0.03 to 0.25; $p = 0.04$; ES: 0.28, small). Additionally an increase in the time spent in wake after sleep onset (1.5 [90% CI: 0.78 to 2.3] min; $p = 0.002$; ES: 0.57, small) was also observed to be associated with a 100 m increase in high-speed running distance. It was also observed that an increase in 100 m in high-speed running distance increased the time of final awakening (9 [90% CI: 5 to 13] min; $p = 0.0009$, ES: 0.64, moderate). High-speed running distance did not subsequently affect any other sleep variable (TOLO, SOL and TST) (all, $p > 0.1$). The time spent above 85% max heart rate, which was used as a representation of an internally derived measure of high intensity load was shown to display no statistical significant effects on each of the selected sleep variables observed within the study (all $p > 0.1$).

5.4 DISCUSSION

At present there is a current lack of information surrounding the habitual sleep of youth soccer players during the competitive season, though the previous investigation within Chapter 4 suggested that the exercise load that youth soccer players are exposed to, may impact sleep efficiency. Therefore the aim of the current study was to investigate the exposure of a typical period of training and match load completed across a 14-day training phase during the competitive season on the habitual sleep pattern displayed in a sample of youth soccer players. The results of the current data indicate that total sleep time and percentage of individual average total sleep time was reduced on the day after a match (M+1) in relation to the training days preceding the match (M-1 and M-2). This may suggest that the specific type of day within the training phase may have important consequences for the amount of sleep attained by youth soccer players. Additionally when investigating the influence of the variables used to quantify training and match load in relation to sleep, an increase in total high-speed running distance (>5.5 m/s) related to a higher number of recorded awakenings and a greater duration of time spent in wake after sleep. This potentially indicates that an increase in exercise intensity may negatively impact sleep efficiency. The results of the current study offer an insight into the potential factors that may impact sleep quantity and sleep efficiency within youth soccer players. This may prove to be useful information in the formulation of a future direction of research that attempts to understand what elements of elite youth soccer influence sleep.

Previous research exploring the profile of sleep within athletes has suggested that the typical sleep pattern of an individual is influenced by the interaction of multiple physiological mechanisms that are involved in the regulation of the sleep-wake cycle (Davenne, 2009; Venter, 2012). It is also understood that the behavioural strategies used by an athlete may also play a role, as athletes are regularly exposed to a number of external factors within the sporting environment (e.g. scheduled training, travel etc…), which may alter an individuals approach to their sleep (Samuels, 2008; Sargent, *et al*, 2014). This would suggest that a complex interaction between theses two factors are likely to regulate the sleep-wake cycle. When the typical sleeping pattern of the youth soccer players was assessed across the current study period, the total sleep time was statistically lower on the night of the day after the match (M+1) in comparison to the training days preceding the match (M-2 and M-1). Such a finding suggests the type of day within the schedule of the training phase may have an influence on the sleep quantity attained by the youth soccer players. This offers evidence that contrasts with previous research within the sport of youth soccer, were no differences of sleep between training and off days were observed (Robey, *et al*, 2014). However it has been previously suggested in other athletic populations that an individuals preferred sleep-wake cycle and the distribution of the training schedule of the sport can impact the total achievable sleep time of the individual (Samuels, 2008; Lastella, *et al*, 2014; Sargent, *et al*, 2014). This may also be the case for the youth soccer players observed within the current study.

When investigating the potential mechanisms relating to the observed differences of total sleep time during the training phase within the current study, it would seem that on the nights preceding the match day (M-2 and M-1) the youth soccer players tended to display an earlier time of lights out and later time of final awakening in comparison to the M+1 nights. Though these results did not display a statistical significant difference, the change in time of lights out and final awakening may still theoretically have a practical influence on the amount of sleep obtained. Given that the youth soccer players actively went to bed earlier on the nights preceding the match day, a greater total achievable sleep time is possible. This behaviour may be a consequence of the preparation strategies for the match, as players recognise the perceived benefits of sleep on performance (Venter, 2014). Conversely the delayed time of lights out apparent on M+1 days, in addition to the resumption of the typical morning training schedule the next day (displaying an earlier final awakening), would in combination reduce the total achievable sleep time that could be obtained by the youth soccer players. Therefore it is likely within this type of day the curtailment of sleep would occur. This is a common feature displayed in sleep behaviours of other athletic populations (Samuels, 2008). This may therefore indicate that the soccer player's behavioural approach to their sleep schedule, in addition to the scheduled activities of soccer training, have important consequences for the total achievable quantity of sleep each night. Given that there is a disconnect between the displayed sleep schedule of the training days in comparison to the recovery days within the training phase, such results may also indicate a likelihood of "social jetlag" (the discrepancy between social and biological timing) amongst the observed youth soccer players, which may have implications to optimal daily function (Wittmann, *et al*, 2006). The observed decline in the total sleep time achieved on the M+1 day(s) may influence the recovery process within the soccer players (Davenne, 2009). Therefore it may be worthwhile for coaches and practitioners to consider the individual athletes behaviours when scheduling the training and rest days so that a consistent sleep-wake schedule can be achieved and the sleep needs of the individual maintained, which may also enhance the recovery process.

The training induced stress placed on elite athletes has also been suggested to have influences on the mechanisms of sleep (Leeder, *et al,* 2012). Consequently the current study also attempted to monitor the particular components (i.e. GPS, HR and subjective derived measures) of training and match load to be assessed in an attempt to evaluate the potential effects that these may have on the typical sleep pattern displayed in the youth soccer players. The data from the current study showed that increases in total distance covered, subjective RPE_{LOAD} and total high-speed running distance might affect the increase in the number of awakenings and length of time spent in wake on average each night. Previously, intensified training loads (increased volume and/or intensity) have been shown to increase the level of disturbance associated with sleep and subsequently decrease the sleep efficiency of the individual (Taylor, *et al*, 1997; Driver, *et al*, 2000; Teng, *et al*, 2011; Hausswirth, *et al*, 2014). However the specific mechanisms for this relationship aren't fully understood, though it has been suggested that this occurrence may be a result of induced muscular fatigue, increased levels of muscular soreness (Taylor, *et al*, 1997; Hausswirth, *et al*, 2014) and a subsequent increase in pro-inflammatory cytokines (IL-6 and C-Reactive Protein [CRP]) (Irwin, *et al*, 2015). Increases in high-speed running distances imposed on the youth soccer players is likely to induce higher levels of muscular damage, which may consequently lead to elevated muscular fatigue and soreness, as well as higher levels of Il-6 and CRP. This may therefore offer some explanation to the observed relationship between increased high-speed running distance and increased sleep disturbance shown within the current study. However this theoretical response should be further examined in an attempt to attain greater understanding of the interactions between high-intensity exercise and the potential impact to sleep within youth soccer players.

It should be noted that within the current study an arbitrary speed threshold (>5.5 m/s) was utilised for the detection of high-speed running distance. Whilst this has been suggested to underestimate the high-intensity activities performed by slower players (as such thresholds may be set at differing points relative to the individuals physical characteristics), the use of such threshold are still appropriate to determine the between and within participant responses for the type of comparisons performed within the current study (Hunter, *et al*, 2015). Had an individualised threshold approach been taken, it could be suggested that the effects of high-speed running distance would only be amplified (given that high speed running activity would increase) and therefore would show similar outcomes to what has currently been reported. It should also be recognised that the data collection period within the current study consisted of an increased number of consecutive match fixtures within each of the two-week training phases recorded. This resulted in an increased number of observations for M-1, M and M+1 (N = >30) respectively. Consequently fewer observations were made for days OFF (N=4) and training days such as M-4 (N=6) within the current sample. Such distribution within the sample may have implications for the analysis contained within the current study and may not reflect the true nature of days such as M-4, M-3, M-2 and OFF days within the typical training phase. This may therefore suggest that further research across a longer assessment period than the period used within the current analysis may be important. A more longitudinal study design would also allow the specific assessment of varying training and match loads that may be apparent within the in-season training phase, which may not be reflective of a single 14-day period contained within the current analysis. It should also be noted that the sample size utilised within the current study is relatively small, and therefore the magnitude of the observed effects are likely influenced by the current observed sample. Therefore a larger sample is required to provide greater statistical power and to better understand the relationships that have been observed between sleep and training load within the current study.

5.4.1 CONCLUSION

The current study provides insight into the habitual sleeping pattern of youth soccer players during a two-week training phase within the competitive season. The results of this data would suggest that total sleep quantity is affected by the specific type of day within the training phase of elite youth soccer. The total sleep time was reduced on the day after the match (M+1) in comparison to the days preceding the match day. This may have implications for the psychological and physiological recovery of the youth soccer players during key restorative periods within the training phase. This response may be linked to the individual sleep scheduling behaviours of the youth soccer players. By recognising this behaviour coaches and practitioners may be able to adjust the designed schedules to facilitate extended time for the individuals to achieve their desired sleep quantities and avoid sleep curtailment. The components of soccer training and match load were also shown to influence the habitual sleep response, were increased awakenings and the time spent in wake were more notable when increases in intensity (total high-speed running distance) occurred. This may be related to increased muscle damage and fatigue associated with the exercise load. As the current study was performed over a 14-day in-season period within the elite youth soccer season, further research may be warranted to assess whether such responses to the training and match-loads are apparent during periods of varying training and match loads during different training phases within the elite youth soccer season.

CHAPTER 6

THE IMPACT OF TRAINING AND MATCH LOADS ON THE SLEEPING PATTERN OF YOUTH SOCCER PLAYERS DURING DIFFERENT IN-SEASON TRAINING PERIODS

6.1 INTRODUCTION

Chapter 4 demonstrated that the sleep of youth soccer players is less efficient than that of non-athletes, despite greater sleep quantities being observed within this comparison. In Chapter 5 we suggested that an increase in exercise intensity (i.e. high-speed running distance) might impact the level of sleep disturbance at night (e.g. greater time in wake). Such an observation may provide some explanation to the lower sleep efficiency displayed within the youth soccer players in earlier chapters. Though a recognised limitation of Chapter 5 was that the assessments of sleep and training were only conducted over a short period (14 days), in which a period of congested fixtures during the competitive soccer season was observed. This therefore resulted in a mismatch in the number of observations for each specific type of training day within the training phase microcycle. This may have had implications for the statistical observations made. The current study was designed to assess how the training and match load completed by a group of youth soccer players influenced the habitual patterns of sleep across multiple training periods. These periods displayed similar microcycle structures in terms of training days, which allowed inferences to be made over the impact of training load. Given the previous observations contained within Chapter 5 we hypothesise that the impact of training load (i.e. increase intensity will induce sleep disturbance) will also be apparent over multiple training periods.

6.2 METHODS

6.2.1 RESEARCH DESIGN

In an attempt to provide further support of the potential relationship between training and match load on the typical sleeping pattern of youth soccer players observed within Chapter 5 the current study analysed three 14-day training periods during the competitive elite youth soccer season. The typical sleeping pattern of the youth soccer players was monitored through the use of WS. In addition the training/match-play loads were also collected during this timeframe using a number of established monitoring techniques (i.e. GPS and HR). The data collected was then used to examine the relationships between the loads completed across each specific in-season soccer period and the habitual sleeping pattern for each respective night.

6.2.2 PARTICIPANTS

The sample of participants used in the current study was eight male youth soccer players. Each player was assessed over the selected time course of the competitive elite youth soccer season. Participants also shared bedrooms within the soccer academy's residence. Anthropometric characteristics (mean ± *sd*) are displayed within Table 6.1. Participants were provided with information surrounding the expectations and demands of the study, with participant consent being obtained before data collection commenced. The study was ethically approved through the Liverpool John Moores University Institutional Ethics Committee.

Table 6.1. Anthropometrical range for the eight youth soccer players (mean ± *sd*)

Sample	Age (yrs)	Height (m)	Weight (kg)	$VO2_{max}$ (ml.kg.min)
N=8	18 ± 1	1.83 ± 0.06	77 ± 11	59 ± 3

6.2.3 EXPERIMENTAL DESIGN

Once participant consent was granted, the collection of sleep pattern data using a WS was integrated alongside the typical monitoring strategy (GPS & HR) used for the youth soccer players during the competitive youth soccer season. The design of the current study replicated that used in Chapter 5 (see section 5.2.3). The comparison of the training and match load with that of the typical sleep pattern of the youth soccer players was analysed over three 14-day periods that were identified during different training phases within the youth soccer season. Each period was selected due to the consistency of the training days and match fixtures within the scheduled microcycle (1 match per week). The first two-week period (P1) was selected during pre-season. The second period (P2) was selected within the in-season training phase prior to the mid-season break. The third period (P3) was selected 3 months following P2, after the mid-season break. This was done in an attempt to address the limitation of Chapter 5, by providing a greater number of observations to assess the potential relationship between training/match load and sleep.

6.2.4 EXPERIMENTAL PROCEDURES

The methodological procedures and data output have been described previously (See Chapter 3.2 & Chapter 4.2). Sleep variables included sleep onset latency (SOL) total sleep time (TST) and time spent in wake after sleep onset (WASO) in minutes. Each participant was also provided with a 10Hz GPS unit (STATSports Viper, Ireland), a fitted vest and HR monitor as part of the elite youth academy procedures. The particular procedures of the GPS and HR monitoring have also previously been described (See Chapter 5.2). The participants were required to wear the GPS Viper unit and HR monitor during every on-field training session and match completed during the competitive season. This allowed the training and match load of each player to be analysed using the STATSports Viper analysis system (STATSports Viper, STATSports, Ireland). The data recorded included the total distance covered (TD) in meters, high-speed running distance (HSD) in meters (i.e. the total distance of running at equivalent speeds of 5.5m/s and above) and time spent above 85% of heart rate maximum (HR_{HI}). The collected data was then used to perform the comparison of the training periods and training/match loads collected in this time with that of the typical sleep pattern data of the youth soccer players.

6.2.5 STATISTICAL ANALYSIS

The data was analysed using the statistical package R - Version 3.2.1 Software (The R Foundation for Statistical Computing, 2014). All data were averaged for each individual over each training period (P1, P2 and P3 respectively), meaning three data averages per variable, per player, were included in the analysis. The data was examined using the statistical technique of linear mixed modelling. This type of analysis was deemed a viable approach, as it is able to handle repeated measures data with both fixed and random effects (Cnaan, *et al*, 1997). To assess the effects of training and match load on the habitual sleep pattern of the youth soccer players, training/match load variables (i.e. TD, HSD, HR_{HI}) were treated as single predictors. A random intercept was placed on the individual players. The sleep data was identified as the outputs (SOL, TST and WASO) within this analysis. The main outcome effects were compared and reported as the single coefficient value. Statistical significance was set at $p < 0.1$, were applicable coefficients of the condition were reported with 90% confidence intervals (90% CI).

Effect sizes (ES) were also calculated by standardizing the differences coefficients according to the appropriate between-subjects standard deviation. Effect sizes were evaluated using the modified scale approach of <0.2 = trivial, 0.2 to 0.6 = small effect, 0.6 to 1.2 = moderate effect, 1.2 to 2.0 = large effect, and >2.0 = very large (Hopkins, 2006). All other data are reported as mean ± *sd*.

6.3 RESULTS

An overview of the sleep variables and the training and match load variables collected across the three training phase periods is shown in Table 6.2.

Table 6.2. Overview of collected sleep, training and match load variables within the studied training phase periods (mean ± *sd*)

	P1 (Pre-Season)	P2 (Pre-Mid Season)	P3 (Post-Mid Season)
Sleep Variables			
SOL (min)	25 ± 10	28 ± 13	31 ± 12
TST (min)	498 ± 24	488 ± 16	473 ± 42
WASO (min)	13 ± 11	12 ± 11	7 ± 5
Training / Match Load Variables			
TD (m)	6107 ± 1202	6891 ± 683	4921 ± 480
HSD (m)	166 ± 139	168 ± 76	106 ± 77
HR_{HI} (min)	15 ± 8	21 ± 7	17 ± 5

6.3.1 SLEEP ONSET LATENCY (SOL)

Upon analysing the linear mixed model for the effects of the specific training load variables on that of sleep onset latency of the youth soccer players, a 1000m increase in average total distance covered related to a non significant effect on sleep onset latency (-1 min, 90% CI: -5 to 3 min; ES: -0.23, small; p = 0.64). Average high-speed running distance also had no statistical significant effects on the average sleep onset latency across the training periods (100m rise in HSD; -4 min, 90% CI: -10 to 0.7 min; ES: -0.66, moderate, p = 0.19) though this did display a moderate effect size. Similarly the time spent above 85% maximum HR also showed none significant small effects on the average sleep onset latency displayed by the youth soccer players. A 10 min rise in average time spent above 85% maximum heart rate related to –5 min (90% CI: -11 to 1 min; ES: -0.60, small; p = 0.19) decrease in the average sleep onset latency within the training period.

6.3.2 TOTAL SLEEP TIME (TST)

There were none significant moderate effects of average total distance covered on the total sleep time the youth soccer players achieved, were a 1000 m increase of average total distance covered related to an increased average of 8 min (90% CI: -0.4 to 16 min; ES: 0.62, moderate; p = 0.11) total sleep time within the training periods. A 100 m increase in average high-speed running distance related to an increase of 24 min (90% CI: 12 to 36 min) on average for total sleep time, which was deemed a statistical significant effect (ES: 1.3, large; $p < 0.01$). Similarly a statistical effect of the average time spent above 85% maximum HR was also observed for total sleep time, were a 10 min increase in the average time spent above 85% max HR related to a 20 min (90% CI: 6 to 32 min; ES: 0.87, moderate; p = 0.035) increase on average for total sleep time.

6.3.3 TIME SPENT IN WAKE AFTER SLEEP ONSET (WASO)

There was no observed statistical effects of the average total distance covered on the time spent awake on average across the studied period (ES: 0.48, small; p = 0.17). A 1000 m increase in total distance related to an average of 2 min (90% CI: -0.2 to 4 min) time spent awake within the training periods. There was an observed significant effect of high speed running distance increasing the time spent in wake, on average a 100m increase in daily high-speed running distance related to an increase of 5 min (90% CI: 1 to 9 min; ES: 0.88, moderate; p = 0.068) average time spent in wake within the training phase period. There was no significant effect of the time spent above 85% maximum HR on the time spent in wake on average across the studied period, were an average daily increase of 10 min in time within this HR zone related to a –4 min (90% CI: -9 to 0.2 min; ES: -0.57, small; p = 0.15) decrease in average time spent in wake.

6.4 DISCUSSION

This investigation into the influence of training load that may affect the typical sleep pattern of youth soccer players used three different 14-day training periods within the competitive youth soccer season. This approach was selected in an attempt to address some of the limitations in Chapter 5, that is to say by providing a larger number of observations across training periods within training structures that displayed the same microcycle. The results of the current study indicated that an increase in high-speed running distance was associated with a trend towards increases in the time spent in wake across the training periods. Such outcomes were similar to the observations presented in Chapter 4. Other observations between training load and sleep were also noted within the current data. An increase in high-speed running distance and the time spent above 85% of maximum heart rate were related to an increase in average total sleep time across the training periods. This finding represents novel data for the literature. Together these outcomes support the ideas in earlier chapters that the intensity of the load performed by the youth soccer players within each training period may have a negative impact on sleep quality, whilst simultaneously having a positive effect on sleep quantity. This may suggest that training load is an important contributing factor in determining sleep architecture.

Previous studies have also indicated that increased exercise intensities over a programme of training can increase the level of sleep disturbance and reduce the efficiency of sleep (Taylor, *et al*, 1997; Teng, *et al*, 2011; Hausswirth, *et al*, 2014; Killer, *et al*, 2015). Such observations have been linked to increased levels of muscular damage and increases in proinflammatory cytokines (Taylor, *et al*, 1997; Teng, *et al*, 2011; Main, *et al*, 2010; Hausswirth, *et al*, 2014; Killer, *et al*, 2015) that accompany more intense exercise challenges. Increases in proinflammatory cytokines may also be linked to an increased total sleep time (Irwin, *et al*, 2015). Given that such physiological responses may occur following high intensity training (such as high-speed running activities) these studies may provide some explanation to the results observed (i.e. increased total sleep time and concomitant increased time in wake) within the current study. Unfortunately the assessment of such physiological markers (e.g. cytokine responses) was not included within the current study and as such these ideas remain speculative. This would seem to warrant further investigation in future research.

Though the results of the present study infer increases in intensity across the training phase significantly effect the total sleep time and the time spent in wake on average of the youth soccer players, it should also be noted that training/match load is only one of many contributing factors which may impact sleep. As demonstrated in the previous chapter, the nightly sleep quantity can also be affected by both a behavioural approach to sleep and the imposed schedule within elite youth soccer (See Chapter 5.4). It is also likely within the current study that the youth soccer players will be exposed to a number of daily situations, which may consequently impact the individuals phase entrainment of circadian processes relating to the sleep-wake cycle (Samuels, 2008; Nedelec, *et al*, 2015). It is well established that the physiology of sleep is influenced by external cues (zeitgebers) that typically entrain the circadian derived rhythms within a 24-hour cycle (Reilly, *et al,* 1997; Reilly & Edwards, 2007). Though exercise is one considered zeitgeber, the sleep-wake cycle can also be influenced by other factors such as the light/dark cycle, temperature, diet and individual phenotype (Atkinson & Davenne, 2007; Samuels, 2008; Davenne, 2009; Edwards, *et al*, 2009; Venter, 2012; Facer-Childs & Brandstaetter, 2015). All of which are likely to vary across each individual within the current study and were not considered as predictors within the statistical analysis. Therefore to address these limitations, future investigations should attempt to control these confounding variables to identify if an increase in training period intensity is a mechanistic factor that influences the process of sleep physiology within youth soccer players.

It should also be noted that the participants assessed within the current study all derived from the same academy setting, meaning the loads represented here are only reflective of this youth soccer team. Therefore information from a number of elite soccer teams replicating a design similar to the current study will provide more insight into the relationships observed between exercise load and sleep within the current study. Additionally due to the limited sample size, the results of the current study may not reflect the magnitude of the effects observed in that of a larger sample derived from the same population. Given that there is a current lack of research and understanding regarding the mechanisms of sleep in soccer players, utilising a larger sample of youth soccer players will enable greater understanding of how sleep is influenced within this population.

6.4.1 CONCLUSION

Overall the main outcomes of the current study indicate that the intensity of the training load within elite youth soccer may have influences on sleep. Increases in high-speed running distance increased the amount of time spent in wake across the training phases, while increases in average high-speed running distances and time spent above 85% maximum heart rate were shown to increase total sleep time. Such results support the idea that training load (especially the exercise intensity) may have important implications for the physiology of sleep. This relationship may be a function of physiological changes associated with high-intensity efforts (e.g. increased pro-inflammatory cytokines). Future research should look to establish the factors mediating the response between increased intensity of training loads and sleep quantity and quality in large samples of players from different teams.

CHAPTER 7

AN INVESTIGATION INTO THE APPLICATION OF A THERMOREGULATORY STRATEGY TO IMPROVE SLEEP EFFICIENCY WITHIN YOUTH SOCCER PLAYERS

7.1 INTRODUCTION

Previous investigations within the current thesis have demonstrated that youth soccer players may experience sleep related disturbances during the competitive season, such as prolonged sleep onsets and increased duration of awakenings during the night. Such disturbances may lead to a potential reduction in total sleep time in comparison to the length of time spent in bed (see previous: Chapter 3, Section 3.4; Chapter 4, Section 4.3). These sleep pattern traits are also common within other elite athlete populations (Leeder, *et al*, 2012). These data together suggest that the sleep efficiency within elite level sporting athletes may be sub-optimal. Such data would therefore warrant the implementation of potential sleep hygiene strategies in an attempt to improve sleep within athletic populations, as this may help to maximise the process of sleep.

The improvement of sleep hygiene refers to the recommendation of strategies that seek to increase the quantity and quality of sleep through the alteration of factors that could cause detriments to an individual's normal sleeping pattern (e.g. environmental conditions and individual behaviours) (Nedelec, *et al*, 2015). The circadian cycle of thermoregulation is thought to be a contributing factor to the sleep-wake process, therefore strategies that look to manipulate thermoregulatory processes may benefit sleep (Krauchi, 2007; Krauchi & Deboer, 2011). Within the sport of soccer the use of cold-water immersion has been investigated (Robey, *et al,* 2014), as this may promote changes in the thermoregulatory system (i.e. lowered core body temperature) that may facilitate favourable sleep behaviours (Murphy & Campbell, 1997; Krauchi, 2007; Krauchi & Deboer, 2011). However, direct evidence related to the benefits of cold-water immersion on sleep is somewhat lacking (Halson, *et al*, 2014; Robey, *et al*, 2014) and may be impractical for inclusion within elite sport on a daily basis, as this may attenuate adaptations from training (Frohlich, *et al*, 2014). Alternative research has also examined strategies that attempt to facilitate heat loss, using approaches such as targeted skin warming (Sung & Tochihara, 2000; Raymann, *et al*, 2005; Raymann, *et al,* 2007; Fronczek, *et al*, 2008; Raymann, *et al*, 2008). It is thought that a rapid sleep onset and facilitation of sleep is linked to an increase in the temperature of distal regions of the skin (Krauchi, 2007). Techniques such as whole body heating or distal skin heating attempt to create small elevations in skin temperature and the promotion of vasodilation of distal regions, which in turn accelerate the process of heat loss (Sung &

Tochihara, 2000; Raymann, *et al*, 2005; Raymann, *et al,* 2007; Fronczek, *et al*, 2008; Raymann, *et al*, 2008; Krauchi & Deboer, 2011). These strategies have been shown to reduce sleep onset latency and the level of disturbance during sleep (Sung & Tochihara, 2000; Raymann, *et al*, 2005; Raymann, *et al,* 2007; Fronczek, *et al*, 2008; Raymann, *et al*, 2008; Krauchi & Deboer, 2011). Therefore heating strategies of this type may act as a useful practical strategy to promote sleep related factors within athletic populations.

At present no evidence is currently available in elite level athletes, such as youth soccer players on the effectiveness of strategies that attempt to influence thermoregulatory processes through skin warming in an attempt to promote sleep. Therefore the current study was designed to manipulate skin temperature through the use of an alternative practical strategy (warm showering), which could be easily incorporated into the athlete's habitual routine. The aim of the strategy was to cause subtle increases to skin temperature before time of lights out in an attempt to reduce the sleep onset latency and level of sleep disturbance shown within youth soccer players. As a result of the showering condition we predict that there will be displayed improvements in sleep onset and reduced sleep disturbance, resulting in increased sleep quantity.

7.2 METHODS

7.2.1 RESEARCH APPROACH

To investigate the influence of a practical strategy to enhance sleep quantity and quality within youth soccer players, the current study was designed to manipulate skin temperature through the use of warm (40°C) shower before bedtime. In a randomised cross over design, participants were required to conduct both three nights of habitual sleep (CON) without showering before bedtime and a three night period that included a 10 min shower twenty minutes before bedtime. Skin temperature was assessed using iButton Thermochron sensors (Maxim/Dallas Semiconductor Corp, USA) to produce measures of distal and proximal skin temperature for both trial groups. Sleep was measured using a Zeo Sleep Manager – Bedside Sleep Management Wireless System (WS) (Zeo Inc, Newton: Mass). Through the manipulation of skin temperature it was hypothesised that improvements to sleep onset latency (SOL), the number of awakenings (N_{WAKE}) and total duration of awakenings (WASO) would be observed and consequently increase total sleep time (TST).

7.2.2 PARTICIPANTS

Participants were eleven male youth soccer players (for characteristics see Table 7.1). The soccer players were analysed during their habitual routine within the competitive academy soccer season. The participants were randomly assigned to either a control (CON) group or a shower intervention (SI) group. At the time of study some of the participants were sharing rooms (two players per room) at the elite soccer academies house of residence. Were applicable, the players included in the assessment that shared a room were assigned to different trial groups to avoid the complications of conducting the same trial at the same time. All participants completed both conditions. All participants were briefed and informed of their requirements during the study prior to any data collection for the investigation. Participant consent was also obtained prior to the start of the investigation. The study was agreed and accepted by the Liverpool John Moores University Institutional Ethics Committee.

Table 7.1. Anthropometrical range for the studied soccer players

GROUP	Age (yrs)	Height (m)	Weight (kg)
SOC	18 ± 1	1.78 ± 0.07	74 ± 10

7.2.3 EXPERIMENTAL DESIGN

Once participant consent was agreed and relevant participant information delivered, each individual was briefed on the procedures of the research and what was required during each trial. Each participant conducted both a control trial period (3 days) and a shower intervention period (3 days) during the investigation in a randomised order.. Each three-day trial was separated by a one-week period; this allowed the measurements to be taken on training load-matched days during the in-season soccer period (as shown in Fig. 7.1). The control trail was utilised to establish a baseline for habitual sleep and skin temperature before sleep. The shower intervention was conducted to manipulate skin temperature; this included two periods of skin temperature data collection (pre and post shower) to establish the change in skin temperature as a result of the shower. This enabled the subsequent effects of any changes in skin temperature on sleep to be assessed. Further details and structure of the two experimental trials are displayed below (See Figure. 7.2). Each participant was provided with all of the equipment needed to complete the measurements. This equipment included the Zeo Sleep Manager – Bedside Sleep Management Wireless System (Zeo Inc, Newton: Mass) (WS), a total of six iButton Thermochron One Wire thermistor (Maxim/Dallas Semiconductor Corp, USA), a handheld AVAX DT1 Digital LCD thermometer probe (AVAX TM, UK) and an adapted sleep and temperature diary (See Appendix 3 for example diary). The experimenter provided an instruction sheet and training on the placement and use of each measurement device. The practitioner also demonstrated how the sleep and temperature diary was to be completed each day. This was done in an attempt to minimise data collection errors during the study period. A familiarisation period of two days was provided, so the participants could become comfortable with the experimental procedures. All procedures were identical for each night of the respective trials and all devices were worn for a complete night of data collection.

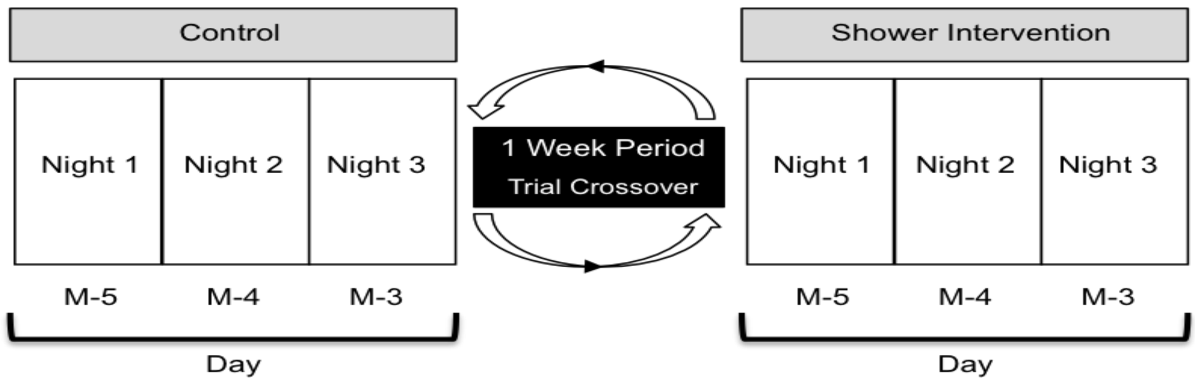


Figure 7.1. Overview of the experimental design. The example outlines the potential structure of how the trials were distributed across a period during the competitive elite youth soccer season. The countdown of (M-5, M-4, etc..) represents the distribution of the day(s) in relation to the match day (i.e. M-5 is five days before match competition). The order of days was matched to minimise variations in load for both trial periods, this was achieved by utilising a cross over period of ~1 week.

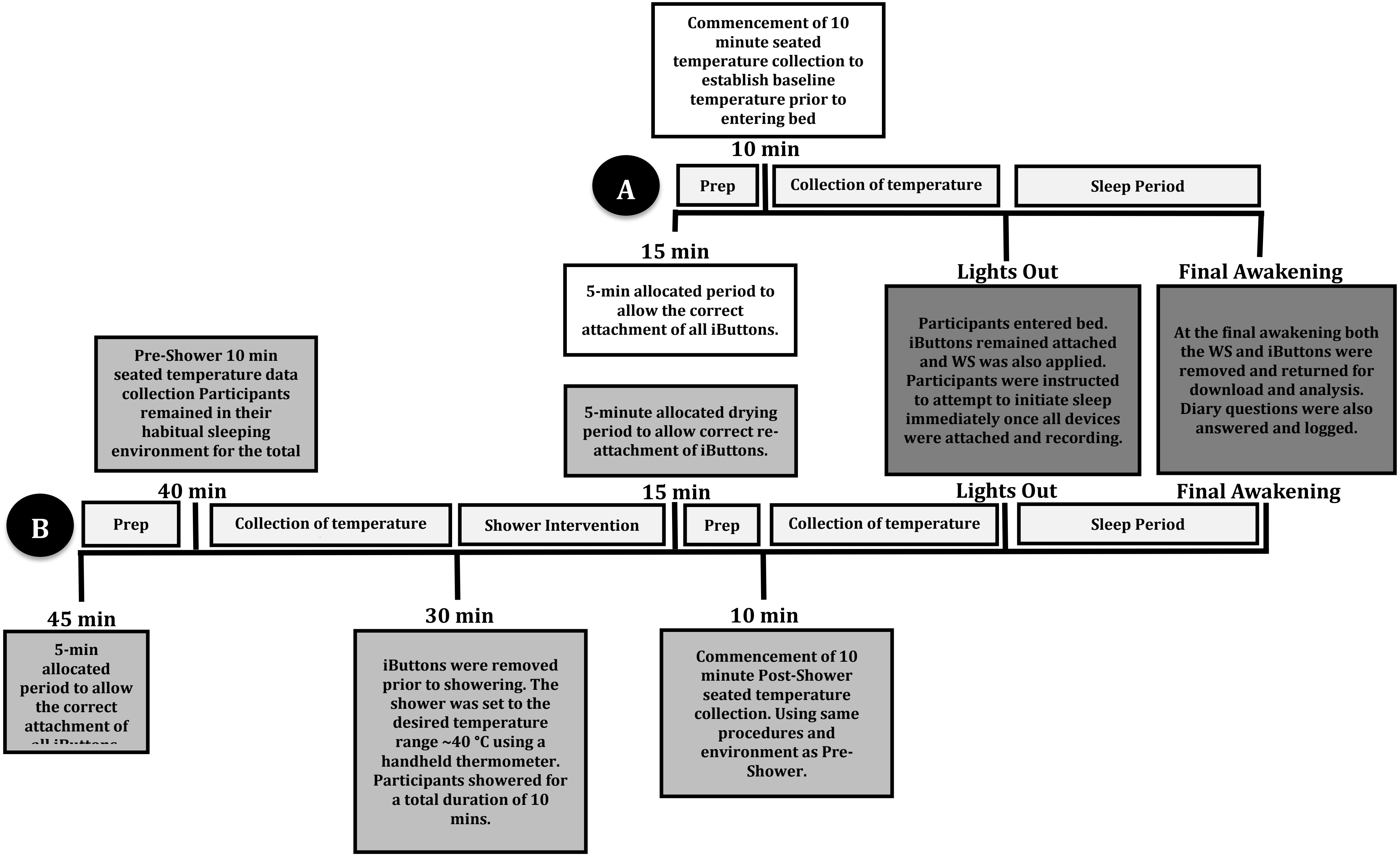


Figure 7.2. Details of the timeline of the experimental procedures. **A.** Shows the timeline of events scheduled within the control trial to establish the baseline nights of temperature and sleep. **B.** Shows the data collection associated with the shower.

7.2.4 ENVIRONMENTAL CONDITIONS

All participants resided in the elite soccer academies house of residence during the time of the study. In an attempt to standardise room temperature, participants were instructed to ensure all windows were closed and no heating devices were active on the trial days. Room temperature was established using a hand held AVAX DT1 thermometer (AVAX, UK). The temperature was recorded both prior to bed and upon awakening to establish the potential temperature range during the nights of data collection. All participants slept in their own bed, in the same room, under a 10.5 TOG duvet throughout the assessment period. Participants were also restricted to wearing underwear and the same pair of shorts (<20.5 cm leg length) during the assessment period. This allowed the accurate detection of skin temperature by ensuring any microclimate created by insulating clothing was avoided.

7.2.5 EXPERIMENTAL MEASUREMENTS

Skin Temperature: The measurement of skin temperature was performed using iButton Thermochron One Wire thermistors. Each iButton is enclosed within a stainless steel shell; the shell contains a 3V lithium battery, a semiconductor (located at the base of the shell), a 1-wire receiver/transmitter, 2kb of memory, date and time capacity as well as 512 bytes of additional sRAM. The iButton allowed the measurement of temperatures between 15-46 °C at an accuracy of 1 °C with a temperature resolution of 0.125 °C. Temperature was captured at a user defined temperature rate of 60 seconds. Each iButton was configured to start at the same time each evening (8pm) through the in-built missioning process. Participants were instructed when the iButtons were to be attached (See Figure. 7.2) and where each iButton was to be positioned (See Figure 7.3.). For ease of placement each iButton was numbered to ensure the same site was collected using the same iButton each night. Site locations are visually represented in Figure 7.3. All iButtons were applied with semiconductor touching the skin using micropourous tape. Four iButtons (two per region) were placed at the distal regions of the body, on the right hand (middle finger tip & dorsal side of the hand) and right foot (big toe tip & dorsal side of the foot). Two iButtons were also placed at more proximal regions of the thigh and abdomen.

These sites provided measures to assess the distal to proximal gradient (DPG) of skin temperature (°C) (Krauchi, *et al*, 2000) associated with each night of data collection. This gradient was calculated by subtracting the average of the distal measures by that of the average of the proximal measures (Krauchi, *et al*, 2000). When using this approach, proximal skin temperature can be higher than distal skin temperature; therefore a negative gradient may also be likely to be observed (Abe & Kodama, 2015). A rise in distal temperature to equal that of proximal temperature will signify a DPG value of zero.

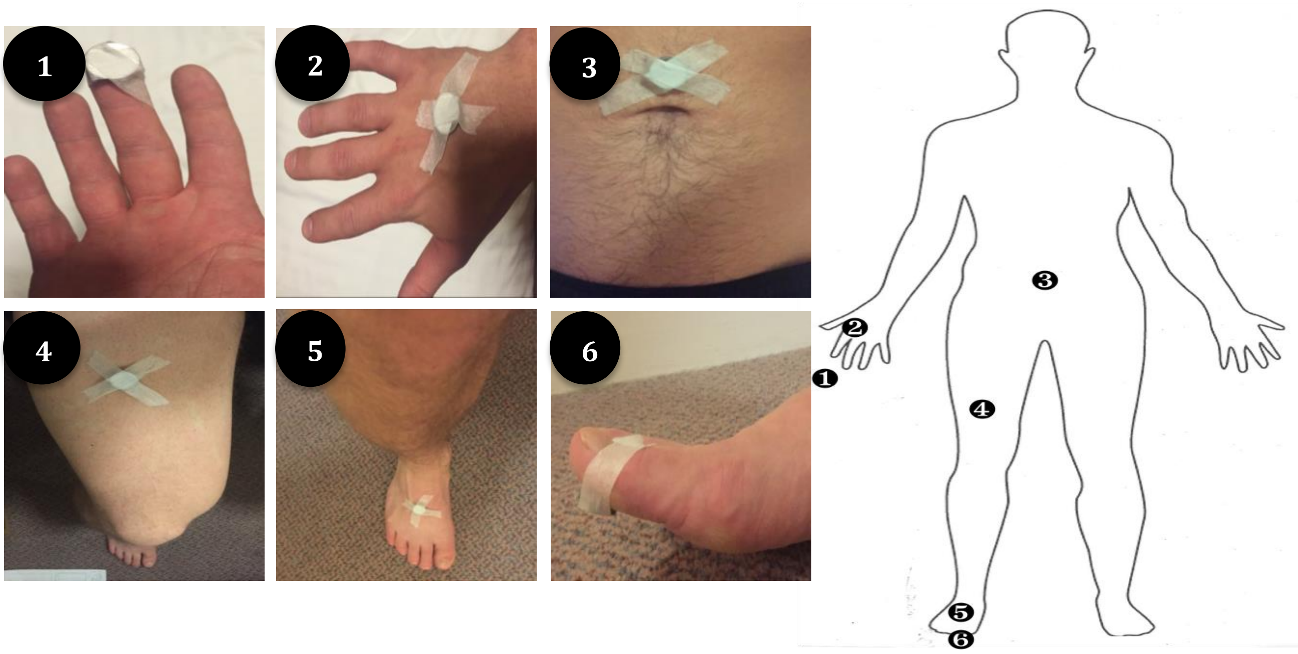


Figure 7.3. Overview showing the placement of each iButton used to assess the skin temperature of each specific body location to create measures to calculate the distal to proximal gradient (DPG). All measures were taken on one side of the body (right) excluding the measurement at the naval.

Sleep: To establish the objective measurement of sleep and sleep staging, Zeo Sleep Manager – Bedside Sleep Management Wireless System (Zeo Inc, Newton: Mass) was utilised on a nightly basis. The procedure of the WS for the capture of sleep data has previously been described (See Chapter 2 and 3, Sections 2.2.4 and 3.2.4 respectively). The WS allowed the recording of sleep data relevant for the use within the current study. This data included; total sleep time (TST), sleep onset latency (SOL) and number of awakenings (N_{WAKE}), as well as a time in wake after sleep onset (WASO). The subjective measure of sleep was also recorded using a sleep diary (SD). The methodology surrounding this approach has also been detailed previously (See Chapter 2, Section 2.2.4). The diary provided the subjective assessment of TST, SOL, N_{WAKE} and perceived sleep quality (SQ) as well as time to bed and time of the final awakening.

7.2.6 EXPERIMENTAL PROCEDURES

Before commencement of data collection, participants were briefed on the procedures of the study. Each device was also configured prior to data collection to ensure the time and date was calibrated and stored. With each participant being familiar with the data collection procedures. During the measurement period participants were instructed to ensure their chosen shorts did not cover any of the iButtons during the assessment. On the control nights of sleep the iButtons were attached 15 minutes before lights out following a 5 min period permitted for the attachment of equipment. To establish the baseline measures for both distal and proximal skin temperatures the participants were required to sit within their bedroom for a total of 10 minutes before entering bed.

Within the shower condition, data collection started 45 minutes before lights out. Again the participants were given a 5-min period to attach the equipment and were then instructed to assume the seated position in their bedroom for 10 minutes to establish the skin temperature assessment period prior to showering (Pre-Shower). The iButtons were then removed (as the iButtons are not waterproof) to allow the participant to shower freely. A 5-minute period was provided for the removal of each iButton. Within this time the participants were also instructed to adjust the shower temperature to the desired range of 40 °C. Before commencing the shower, the shower temperature was determined using a handheld waterproof digital thermometer (AVAX, UK). The participants turned on the handheld thermometer and then held the probe directly underneath the showerhead, ensuring their hand was not touching the metal conductor. The shower temperature was then determined (adjusted if necessary) and noted for each night to the nearest 0.1 °C. Participants were then instructed to set a timer using their mobile phone for a duration of ten minutes. Once the timer was set the participants proceeded to shower for the allocated 10 min period. Upon completion of the timer the participants were instructed to cease showering immediately. A subsequent period of 5 minutes was then allocated to allow drying and the correct re-application of the iButton thermistors. Once each iButton was re-attached, the participant underwent another 10-min period of temperature data collection to establish the post shower measure. Once the seated skin measure was complete, the participants were also required to record the temperature of the room using the handheld thermometer.

Once all the temperature data collection was complete the participants were instructed to enter bed as soon as possible. This prompted the attachment of the WS headband and the recording of time to bed in the sleep diary. Each participant was instructed to attempt to initiate sleep immediately at lights off. Upon awakening the WS headband was removed and docked so that data was automatically downloaded and stored. The iButton thermistors were also removed at this time. The participants also completed their sleep diary entry for the nights sleep (see appendix 1. for specific sleep diary questions). Within that same morning the participants returned all assessment tools to the sports science practitioner for subsequent download and analysis.

The iButton temperature data was downloaded using a 1-Wire iButton port attached through USB to a computer. The data was analysed using OneWireViewer Java Software for Microsoft Windows. The data was then exported into Microsoft Excel were each 60 second sample could be reviewed. Using the information provided within the temperature section of the diary, the 10-minute periods of temperature assessment were identified and clipped. The first 5 minutes of the data collection served as the detection period, allowing the device to accurately calibrate to the correct skin temperature following application (Van Marken Lichtenbelt, *et al*, 2006). The second period of 5 minutes was used for the skin temperature analysis prior to lights out within the study. After lights out the skin temperature data was averaged over 30 minute within the first 3 hours of sleep. Once the data was stored, the iButtons were then reset, allowing the restart of data collection to commence at 8pm that evening. The data provided by the WS and sleep diary were also entered into

Microsoft Excel to create a complete data set for each respective trial night. Once all data was correctly stored, each monitoring device was then handed back to the participant. The participants then proceeded to follow the same methodologies for each of the subsequent nights of the respective trial period.

7.2.7 STATISTICAL ANALYSIS

The data was analysed using the statistical package R - Version 3.2.1 Software (The R Foundation for Statistical Computing, 2014.) using the statistical technique of linear mixed modelling. The linear mixed model approach is able to handle repeated measures data, with both fixed and random effects as well as any missing data (Cnaan, *et al*, 1997)**.** This type of analysis is therefore a viable approach to assess the data within the current study. Within this analysis, the trial condition (SI vs. CON) was treated as the fixed effect, and random intercepts were used for individual players. The main outcomes of the analysis were compared using the coefficient value of the condition. In this case the CON condition was treated as the baseline within the statistical coding. Therefore the difference between the conditions SI vs. CON could be expressed as the coefficient value. This provided a means to assess the given effects of the shower intervention on the skin temperature data (distal, proximal and DPG) at selected time points the selected sleep variables outputted by the WS (TST, SOL, N_{WAKE} and WASO) and the variables contained within the sleep diary (TST, SOL, N_{WAKE} and SQ). Absolute effect sizes (ES) were calculated by dividing the coefficient value by the between-subject standard deviation of the specific variable. The magnitude thresholds were evaluated as <0.2 trivial; 0.2-0.59 small; 0.6-1.19 moderate; >1.20 large (Hopkins, 2010). Statistical significance was set at $p <$ 0.05. Coefficients of the condition were reported with 95% confidence intervals. All the other data are reported as mean ± *sd*.

7.3 RESULTS

7.3.1 SKIN TEMPERATURE PRIOR TO LIGHTS OUT

An overview of the descriptive statistics for skin temperature collected prior to lights out is shown within Table 7.2. Within the comparison of pre-shower skin temperature with that of pre-lights out within the control condition, there were no significant differences observed for distal (-0.3 °C, 95% CI: -1.3 to 0.7 °C, p = 0.55), proximal (0.2 °C, 95% CI: -0.6 to 0.9 °C, p = 0.71) and DPG (-0.4 °C, 95% CI: -1.3 to 0.4, p = 0.30). At pre-lights out, distal skin temperature was elevated by an estimated difference of 1.1 °C (95% CI: 0.1 to 2.1 °C, ES: 0.44, small, p = 0.04) with showering (39.7 °C ± 1.7 °C) compared to the control condition. Additionally showering caused a small, non-significant increase in proximal skin temperature (0.6 °C (95% CI -0.2 to 1.4 °C, ES: 0.36, small, p = 0.13) and DPG (0.6 °C, 95% CI -0.2 to 1.3 °C, ES: 0.30, small, p = 0.15) compared to the control condition. A visual representation of this data, showing the average trend over minutes, is displayed within Figure 7.4.

Table 7.2. Average skin temperature (mean ± *sd*) taken for the last 5 minutes of the respective collection period (Pre-Shower & Pre-Lights Out) for both the Control and Shower intervention.

	Control	Shower Intervention
Temperature (°C)		
(Pre-Shower)		
Distal Temperature	NA	30.7 ± 2.2
Proximal Temperature	NA	31.9 ± 1.1
DPG	NA	-1.2 ± 2.2
Temperature (°C)		
(Pre-Lights Out)		
Distal Temperature	30.9 ± 2.9	32 ± 1.8 *
Proximal Temperature	31.6 ± 2.4	32.3 ± 0.9
DPG	-0.8 ± 2.2	-0.2 ± 1.3

* Represents a significant effect of condition (p < 0.05)

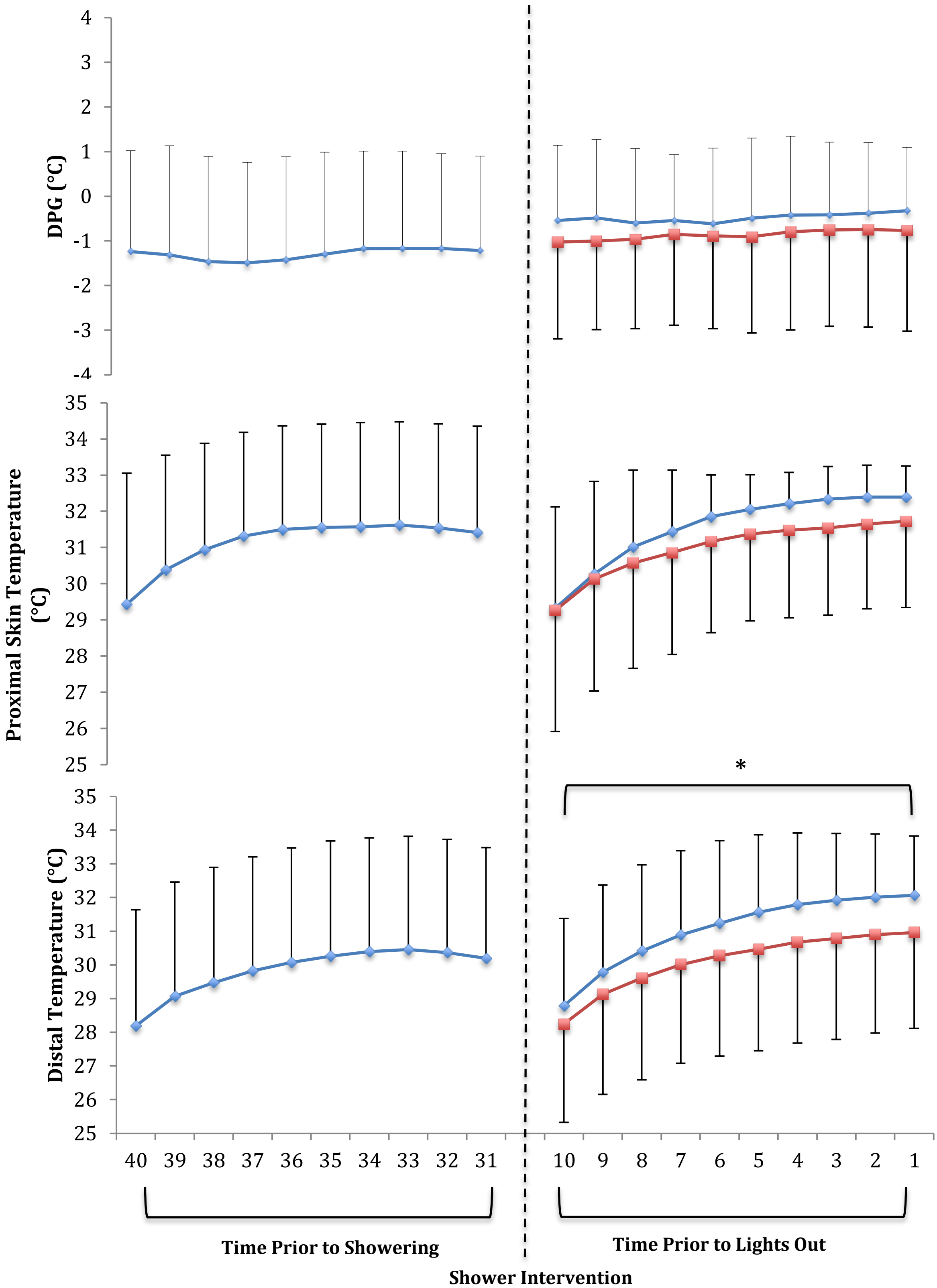


Figure 7.4. Shows the average skin temperature (distal, proximal and the DPG) collected prior to lights out. The blue line represents the data collected during the shower intervention, showing both pre shower (40 - 31 min) and post shower (10 - 1 min) measures. The red line represents the control measures taken 10 minutes prior to lights out. * Significant effect ($p < 0.05$).

7.3.2 SKIN TEMPERATURE AFTER LIGHTS OUT

U A visual representation of the data collected following lights out is shown within Figure 3. Following lights out, there was a continued significant effect of showering on distal skin temperature observed within the first 30 minutes after lights out 1.0 °C (95% CI: 0.4 to 1.5 °C, ES: 0.65, moderate, p = 0.0000042). However, this effect was no longer observed after 60 minutes (+0.0 °C, 95% CI: -0.4 to 0.4 °C, ES: -0.01, trivial, p = 0.94)

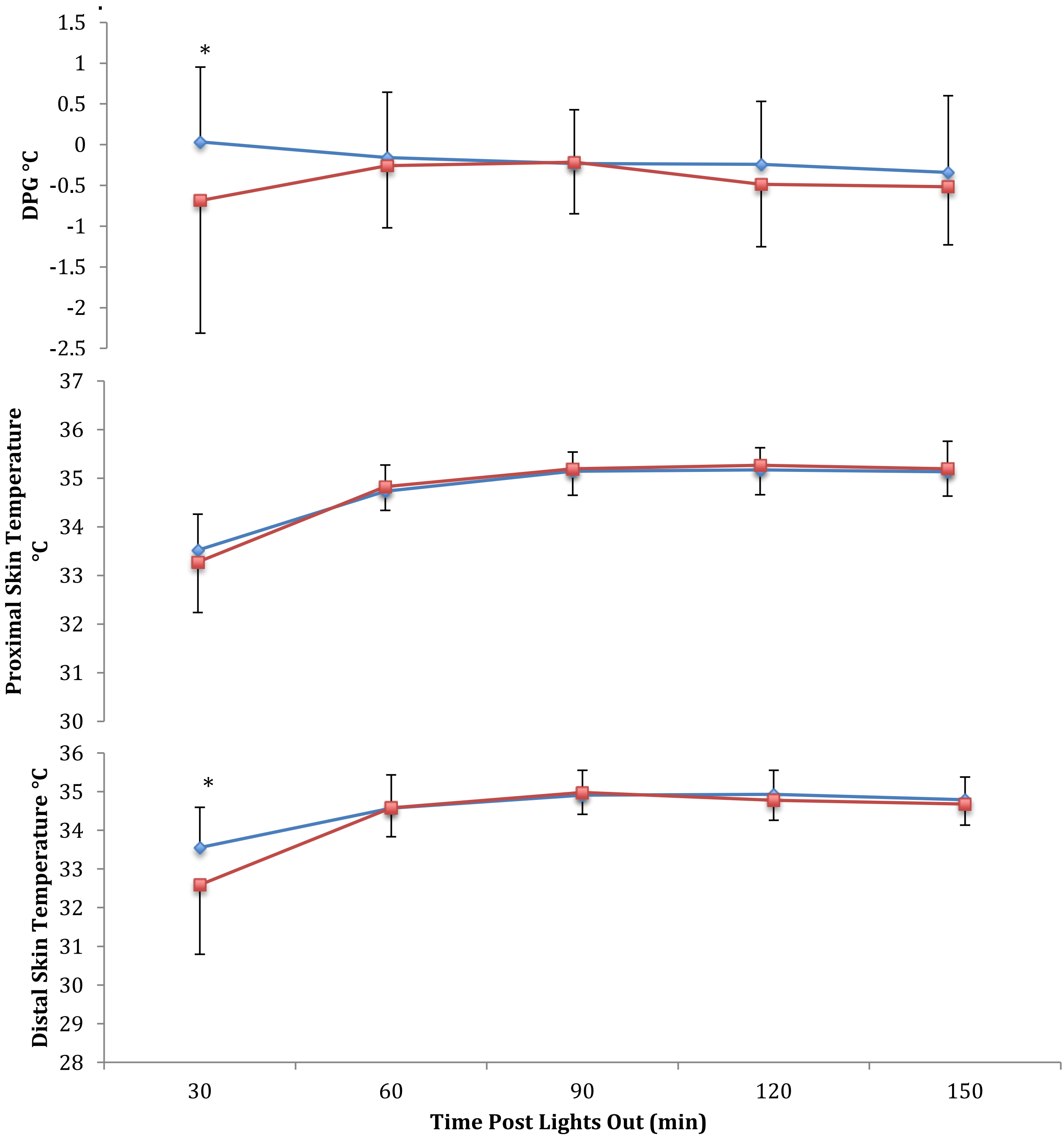


Figure 7.5. Showing the skin temperature data (distal, proximal and the DPG) averaged over 30 mins post lights out. The blue line represents the data collected during the shower intervention. The red line represents the control measures. * Significant effect of condition (p < 0.05)

The DPG also showed a significant effect of showering within the first 30 minutes after lights out (0.7 °C, 95% CI: 0.4 to 1.1 °C, ES: 0.45, small, p = 0.0024). However there were no consequent observed effects of showering on the DPG after 60 minutes of lights out (0.1 °C, 95% CI: -0.3 to 0.5 °C, ES: 0.16, trivial, p = 0.54). Proximal skin temperature showed small, non-significant effects of showering after both 30 minutes (0.2 °C, 95% CI: 0.0 to 0.5 °C, ES: 0.31, small, p = 0.10) and 60 minutes (0.1 °C, 95% CI: -0.4 to 0.1 °C, ES: -0.32, small, p = 0.38) after lights out.

7.3.3 OVERVIEW OF SLEEP

Mean ± *sd* outputs of the WS for both trial periods are displayed in Table 3. Showering enhanced sleep onset latency by approximately -7 min (95% CI: -13 to -2 min, ES: -0.55, small, p = 0.007) compared to the control condition. In contrast, showering had a moderate non-significant effect on total sleep time (-18 min, 95% CI: -48 to 11 min, ES: -0.63, moderate, p = 0.23) and a small, non-significant effect on the time spent in wake after sleep onset (-1 min, 95% CI: -4 to 2 min, ES: -0.20, small, p = 0.37) in comparison to the control condition. There were no observed effects of showering on the number of awakenings (0, 95% CI: -1 to 2, ES: -0.10, trivial, p = 0.76) in comparison to the control condition.

Table 7.3. Overview of objective sleep variables. Data displayed as mean ± *sd*.

WS Sleep Variable	Control	Shower Intervention
SOL (min)	24 ± 15	17 ± 15 *
TST (min)	488 ± 65	469 ± 54
N_{WAKE}	2 ± 2	2 ± 2
WASO (min)	6 ± 9	5 ± 6

* Represents a significant effect of condition (p < 0.05)

7.3.4 SUBJECTIVE ASSESSMENT OF SLEEP

When analysing the information provided by the participants in their subjective sleep diary, the results showed that there were no significant effects of the showering intervention on all the perceived sleep outcomes (TST, SOL, N_{WAKE} and SQ) (p > 0.05). An overview of the data is displayed in Table 7.4.

Table 7. 4. Overview of subjective sleep diary outputs in the comparison of the control baseline nights of sleep (CON) and the shower intervention (SI) (mean ± *sd*). The data also shows the outputs of the linear mixed model (coefficient, 95% CI and level of significance)

Sleep Diary Variable	CON	SI	Coefficient	95% CI	*P value*
Time of Lights out (hr:mm)	23:54 ± 00:36	23:53 ± 00:43			
Time of final Awakening (hr:mm)	08:34 ± 00:48	08:09 ± 00:48			
TST (min)	501 ± 63	479 ± 51	-22	-50 to 6	0.13
SOL (min)	20 ± 11	17 ± 11	-3	-8 to 1	0.1
N_{WAKE}	1 ± 2	2 ± 2	0.03	-1 to 1	0.9
SQ Rating (1-5)	3 ± 1	3 ± 1	0	-0.4 to 0.4	1

7.4 DISCUSSION

An evaluation of sleep within youth soccer players during the competitive soccer season in this thesis has highlighted potential sleep disturbances. Therefore the current study was designed in an attempt to manipulate skin temperature prior to bedtime within a group of youth soccer players in an attempt to facilitate sleep onset, as well as improve factors relating to sleep quantity and sleep quality. The results of the current study indicate a significant thermoregulatory effect of a 10-minute warm shower intervention, performed 20 minutes before bedtime in comparison to a control condition. A rise in distal skin temperature was observed before lights out and was also apparent during the first 30-min period after lights out. The shower intervention condition and the associated thermoregulatory changes seemed to have a significant effect on the sleep onset latency of youth soccer players. Therefore the first hypothesis that changes in skin temperature before lights out would facilitate sleep onset is accepted. The shower intervention did not influence any other variable relating to either sleep quantity or quality observed within the current study. This would suggest that warm showering may have acute effects that relate to sleep propensity, which may not extend throughout the night and therefore influence total sleep architecture. Therefore this may offer a practical strategy to youth soccer players who have difficulties initiating sleep onset.

Previous research on the relationship between thermoregulation and sleep has indicated that there is a subsequent effect of skin temperature on sleep (Raymann, *et al*, 2008; Krauchi & Deboer, 2011). This has been evidenced using a variety of passive heating strategies, which successfully elevate skin temperature and positively transfer these changes to the properties of sleep in healthy young and old participants (Sung & Tochihara, 2000; Raymann, *et al*, 2005; Raymann, *et al,* 2007; Raymann, *et al,* 2008; Krauchi & Deboer, 2011). Within the current study a shower intervention lasting a duration of 10 minutes, performed 20 minutes before bedtime, at a temperature range of 39.7 °C ± 1.7 °C was performed to elevate skin temperature. This was deemed a practically viable strategy to be implemented within the habitual setting. The results of the current study showed no significant changes (despite a small rise in temperature of 0.6 °C on average) in either proximal skin temperature or the DPG prior to lights out. The results did however show a statistically significant effect on the DPG 30 min following lights out. The distal skin temperature was statistically affected by the showering condition both before and after lights out (up to 30 min), with the distal skin temperature increasing by 1 °C on average in comparison to baseline measures of temperature under normal sleep routine conditions. Such a rise in distal temperature (hands and feet) is often associated with vasodilation of the periphery and the opening of arteriovenous anastomoses (AVAs), permitting increased levels of heat dissipation from the body and a lowering of core body temperature (Krauchi, 2000). Suggesting the shower intervention can be practically used to facilitate this process.

Increases in distal temperature and the DPG have previously been linked to a faster time to achieve sleep onset (Krauchi *et al*, 1999; Krauchi, *et al*, 2000). This may be due to thermophysiological induced feedback that may phase advance circadian derived processes of thermoregulation (e.g. the decline in core body temperature), which in turn will likely influence mechanisms of the sleep-wake cycle (i.e. increased sleep propensity, reduced vigilance) (Murphy & Campbell, 1997; Krauchi, 2007; Krauchi & Deboer, 2011, Romeijn, *et al*, 2012). The results of the current study also demonstrate a significant effect of showering on the process of sleep onset. The output of sleep onset latency from the WS was reduced on average by 7.5 min when the youth soccer players showered before bed. Although the subjective report of sleep onset latency from the sleep diary was not deemed statistically different between conditions, which may relate to the inaccuracies of subjective recall and underestimation of sleep onset by the sleep diary in relation to the WS (Chapter, 3). This data may therefore infer that the heat load induced by the shower intervention facilitated the process of heat loss and increased sleep propensity. This in turn reduced the time taken to establish sleep onset within the youth soccer players. Such data may suggest that warm showering prior to bedtime is a viable strategy to promote sleep propensity in youth soccer players who have sleep onset latency difficulties.

The shower intervention did not cause any subsequent effects on any of the other variables related to sleep (TST, N_{WAKE}, WASO, and SQ). During sleep humans create an insulated microclimate (between 34 – 36 °C) through the use of bed covers to maintain a high level of skin blood flow whilst reducing the transfer of heat to the environment (Van Someran, 2006). Such values can be seen within the current study for skin temperature (Figure 6.4). One explanation as to why the skin temperature manipulation of the shower did not affect any further properties of sleep may be attributed to the development of this microclimate. This is supported by Sung & Tochihara (2000), who observed that the sleep promoting effects of passive heating (whole body or foot bathing at 40 °C) before bedtime were moderated after ~2 hrs of being in bed. The current data is again in broad agreement with these ideas as the effects of the experimental condition here are seemingly dissipated within 60 minutes of lights out, as both conditions display similar temperature values from this time point (Figure 7.4.). This would suggest that heating of this type is only likely to affect the early stages of sleep as opposed to the whole night of sleep (Sung & Tochihara; Raymann, *et al*, 2008). This may also provide an additional explanation to the observed reduction of sleep onset latency (early part of sleep) and why no further impact was made within the sleep variables collected within the current study.

Though the present study infers that the rise in distal skin temperature induced by the shower intervention reduces the sleep onset latency of youth soccer players, it would seem that this response is also related to a combined relationship with other thermoregulatory mechanisms (Krauchi & Deboer, 2011; Romeijn, *et al*, 2012). Typically humans initiate sleep when they reach the maximal trough in the circadian derived rhythm of core body temperature (Murphy & Campbell, 1997). Though an increase in distal skin temperature caused through the shower intervention may indicate increased heat dissipation and infer a reduction in core body temperature (Krauchi, 2000), the actual response of core body temperature in relation to this particular shower intervention remains unknown. Assessment of core body temperature should therefore be investigated within future research in an attempt to gain greater understanding of the mechanisms associated with the shower intervention.

It is also likely that the heating of the skin induces thermal afferent feedback to areas of the brain (Romeijn, *et al*, 2012). A review conducted by Van Someran (2000), shows that specific brain regions that relate the control of sleep and wakefulness are sensitive to the 24 h regulation of temperature. The preoptic area of the anterior hypothalamus (POAH) has been suggested as one such area that plays a key role in both temperature regulation and sleep (Van Someran, 2000). Skin warming and the increase in peripheral skin blood flow has been suggested to increase the firing rate of specific warm sensitive neurons (WSNs), which relay feedback to brain regions such as the POAH and in turn promote a sleep like firing pattern of the brain (Van Someran, 2000; Raymann, *et al*, 2005). The observed rise in distal skin temperature within the current study could suggest an increase in peripheral blood flow (Krauchi, 2000), which in turn may promote the maximal firing rate of the WSNs (Van Someran, 2000). If this suggestion were true, then it is likely that an induced firing pattern of sleep-promoting behaviour of the brain would be favoured and thus sleep onset would be promoted under such conditions (Van Someran, 2000; Romeijn, *et al*, 2012). Such firing patterns of the brain may also be influenced by the thermal input (i.e the specific site of skin warming) (Romeijn, *et al*, 2012). It is likely that during the shower intervention the temperature of the skin of the head would also be increased. Such heating of this area may directly warm the areas of the brain (e.g. POAH) that promote sleep (Romeijn, *et al*, 2012) or further stimulate neuronal feedback mechanisms that may promote sleep onset. (Van Someran, 2000). However due to the applied nature of the study and the limited amount of equipment, the exact response of the neuroanatomical pathways detailed by Van Someran (2000) in relation to the thermally induced changes of the shower intervention cannot be quantified. Future research optimising techniques of neuroimaging (to outline the thermal influences of the shower intervention in relation to key areas of the brain that control sleep and temperature) and thermal imaging (to establish which areas of the body are influenced by thermal induced changes) could be utilised to further the understanding of how such mechanisms may be influenced by the shower intervention.

It should be noted that the current study was limited to 10 youth soccer players who were assessed during the in-season period. Therefore the results contained within the current study should be interpreted with caution given that these are indicative of a relatively small sample size (Hopkins, 2002). Therefore future investigations should look to implement a strategy such as warm showering before lights out within a larger sample population of youth soccer players to provide further evidence to the findings contained within the current study. Additionally these findings may not reflect in-season periods that may cause further disturbance to elite soccer player's sleep (i.e. away travel and night time fixtures). Therefore future research should also look to establish the relevance of this intervention during such periods, to assess if the positive benefits are also transferable to these situations that may occur within elite soccer. The current study is also the first to utilise this type of shower intervention within the applied setting, therefore future research could also manipulate the timing (when the strategy is employed), duration (length of the shower) and temperature of the shower intervention to assess if the effects on sleep are further pronounced as a result of the changes.

7.4.1 CONCLUSION

The current study is the first to assess the use of a 10-minute warm shower 20 min prior to lights out to manipulate skin temperature in an attempt to promote the process of sleep onset latency and improve sleep quantity and quality in youth soccer players. Through the use of a ~40°C shower intervention, increases in distal temperature and a subsequent reduction in sleep onset were observed in relation to control conditions. However, no subsequent effects were observed on the improvement of sleep quantity and quality. Therefore showering prior to lights out may be a useful strategy to reduce sleep onset times in youth soccer players that display long sleep onset latencies. However further investigation is warranted to understand the potential mechanisms relating to the effects of showering using more sophisticated approaches to monitor temperature. Additionally further studies utilising larger samples of youth soccer players over different periods within the elite youth soccer season are needed to investigate the benefits of this strategy further. Manipulating the timing, duration and temperature of the shower intervention can also further extend the research, which may determine whether this strategy has an optimal approach to improve sleep within youth soccer players.

CHAPTER 8

SYNTHESIS OF FINDINGS

8.1 INTRODUCTION

The current chapter looks to provide a summary of the outcomes of the research contained within the chapters of the current thesis. Firstly the aims and objectives will be revisited to evaluate if the project has achieved its purpose. The outcomes of research will then be discussed more broadly to explore the methodological and theoretical contributions this research may make to the wider area. The practical recommendations associated to the current findings are also given. Upon completing this review process future research will be recommended.

8.2 EVALUATION OF AIMS AND OBJECTIVES

The primary aim of the present thesis was to investigate the habitual sleeping pattern of youth soccer players during the competitive elite youth soccer season. This was done to attain an understanding of the typical sleeping patterns of youth soccer players and how the dynamics of the sport may influence sleep. This aim was subsequently met through the completion of four separate studies contained within chapters 4-7.

The assessment of sleep within youth soccer players was completed within the "real world" setting. The methodological validity of a commercially available wireless home sleep-monitoring device (WS) was therefore evaluated via its comparison to other established field measures of sleep monitoring (actigraphy and sleep diaries). This investigation was conducted in chapter 3 to fulfil the first objective. The results demonstrated that the recorded sleep onset, total sleep time and number of awakenings produced by the WS were comparable to other established field methodologies. Therefore it was deemed that the WS provided a valid means for the collection of sleep pattern within the habitual environment and so therefore was able to be used within subsequent investigations within the thesis.

To fulfil the aim of quantifying the typical sleeping pattern of youth soccer players during the competitive season, four separate practical investigations (contained in chapters 4-7) were completed. Firstly a comparison of sleep was made within youth soccer players and individuals from a non-athlete population sample (Chapter 4). The results of this study demonstrated that the youth soccer players attained greater sleep quantities than the non-athletes. Despite a greater quantity of sleep on average, the youth soccer players were also shown to take longer to initiate sleep and evidenced more sleep disturbances. Such results suggested the sleep efficiency of the youth soccer players was lower than their non-athlete counterparts. It was suggested that the schedule of elite youth soccer and the training loads completed by the youth soccer players may be important factors to consider in the understanding of how the sleep of these athletes is influenced.

Potential factors that may effect sleep in youth soccer players were highlighted within chapter 3. Subsequent chapters (4 and 5) looked to provide a deeper understanding of these. In chapter 4, over a 14-day period of sleep assessment it was demonstrated that changes in the sleep quantity of the athletes were observed on days preceding the match in relation to days following the match day. This evidence suggested that changes in sleep quantity maybe related to the youth soccer player's behavioural approach to their sleep schedule. This study also demonstrated that increases in daily exercise intensity (specifically high-speed running distance) were likely to increase the number of awakenings and time spent in wake each night. Such an outcome was further explored over longer periods (3 x 14 days) of recording (Chapter 5). Chapter 5 also provided evidence that indicates increases in exercise intensity across training periods might relate to a greater time spent in wake. However, increases in exercise intensity also related to a greater total sleep times within the youth soccer players. Therefore sleep quantity may also be influenced by physiological mechanisms induced through soccer training and match load, as well as the youth soccer player's behavioural approach.

Chapters 3, 4, and 5 provided indications that the sleep of youth soccer player might be inefficient. This was a result of the long sleep onset latencies and increased time in wake displayed within the youth soccer players observed within these investigations. Such observations provided a rationale to try and improve sleep through the application of a practical sleep hygiene strategy within youth soccer players (Chapter 7). The skin temperature of youth soccer players was manipulated using a warm shower (10 min at ~40°C) before lights out, in an attempt to improve the efficiency of sleep and extend sleep quantity, by altering the player's thermoregulatory processes. The results of this study demonstrated that skin temperature changes could be induced using a 10-minute shower intervention before lights out and that this was subsequently related to shorter sleep onset latencies. The total sleep architecture did however remain unchanged following the initiation of sleep. Such results provide positive evidence that suggests warm showering before bed can reduce the time taken to initiate sleep in youth soccer players that display long sleep onset latencies, though these will not reduce the level of sleep disturbance observed during sleep.

8.3 GENERAL DISCUSSION

At present there is a small amount of data in the literature that provides information as to how the mechanisms of sleep may be influenced by sports such as soccer (Nedelec, *et al*, 2015). This is despite the current consensus, that sleep is the most efficacious recovery strategy available to the soccer player (Halson, 2008) and has an important role in the attainment of optimal performance (Davenne, 2009). This lack of research therefore provided a rationale for the present thesis, which was designed to investigate the habitual sleeping pattern of youth soccer players during the competitive youth soccer season. Through the investigations in this thesis (Chapters 4-7), the typical sleep patterns of youth soccer players were quantified objectively using a WS, which was shown to be a viable device for the detection of sleep within the habitual setting of players (Chapter 3). This enabled an analysis to be conducted that attempted to identify some factors that may be influential in the process of sleep within this population. The outcomes from the present findings and those available in the current literature to date have consequently been combined to provide a theoretical framework of how these factors may shape our understanding of how sleep is influenced within soccer players. This represents an attempt to summarise the overall outcomes from the thesis.

The potential for youth soccer players to attain greater sleep quantities as a consequence of the soccer schedule (i.e. soccer players were facilitated with a later time of final awakening [TOFA]) was presented in Chapter 4. Such observations provided evidence that the schedule completed by the youth soccer players might have a positive influence on the total achievable sleep time in comparison to non-athletes (who's schedule may restrict total achievable sleep time as a result of an early morning awakening). The importance of the externally imposed schedule was also demonstrated in Chapter 5 when the youth soccer players attained more sleep quantity in the training days preceding the match (M-1 & M-2) than on recovery days following the match day (M+1). Such results also suggested that the sleep behaviours of youth soccer players alter in relation to the specific type of day within the scheduled training period (e.g. M+1 displayed a later time of lights out [TOLA]). Therefore the externally imposed soccer schedule and the internally derived behaviour of the soccer player towards their sleep scheduling seems to be determining factors for the total achievable sleep quantity (presented in Fig 8.1).

The behavioural factors relating to sleep scheduling may also be influenced by the specific individuals phase entrainment of the sleep-wake cycle (i.e. morning vs. evening chronotype) (Samuels, 2008; Facer-Childs & Brandstaetter, 2015). These chronotypes lead individuals to have a distinct preferred sleep tendency (i.e. TOLO & TOFA) i.e. evening types who go to bed later and prefer to rise later in the morning (Samuels, 2008; Facer-Childs & Brandstaetter, 2015). These individual attributes are however unlikely to be considered within the current scheduling of youth soccer squads. This has the potential to result in a mismatch between the preferred sleep schedule of the individual and the imposed soccer schedule (Nedelec, *et al*, 2015). Such a situation seemed to be displayed in Chapter 5 when the resumption of the typical morning training schedule resulted in an earlier morning awakening (TOFA) following the recovery day (M+1) (which displayed a later time of lights out TOLO). This explained the observed reduction in the total sleep time achieved by the youth soccer players. It would therefore seem pertinent to consider the behavioural processes that impact sleep, as this may result in restricted sleep quantities. This may have implications for the process of recovery and attainment of optimal performance (Davenne, 2009). Through sleep monitoring the identification of factors that may have implications for sleep can be evaluated retrospectively and then potentially avoided in the future. This can be achieved through thoughtful consideration of how the schedule of sport and the sleep schedule of the individual interact (Fig 8.1).

It should also be noted that the collected data within the present thesis was only reflective of the behaviours and schedules derived from small samples of youth soccer players from the same fulltime youth soccer academy. This means the observed findings may only be indicative of the individuals studied and the processes of this soccer environment, which may not reflect other soccer teams. Therefore this should be investigated within more soccer teams to provide greater understanding of the interaction between internally and externally derived schedules within soccer players and how this may affect the total achievable sleep time (Fig. 8.1)

Through the integration of sleep monitoring into the typical procedures of the youth soccer academy within Chapter(s) 5 & 6 it was possible to evaluate the associations between sleep and the imposed training and match load (considered physiological factors) within the competitive youth soccer season. From this analysis it was highlighted that increases in high-speed running distance may result in an increase in sleep disturbance. This indicated that the intensity of the training load is an important factor influencing sleep. Such suggestions have also been previously highlighted in other elite athlete populations when training volumes and intensities have been increased (Taylor, *et al*, 1997; Teng, *et al*, 2011; Hausswirth, *et al*, 2014; Killer, *et al*, 2015). A suggested theory to explain this outcome was that increases in high-speed running distance might increase the level of fatigue, muscular soreness, muscular damage and pro-inflammatory cytokine responses (Main, *et al,* 2010; Hausswirth, *et al*, 2014; Killer, *et al*, 2015).

This may suggest that sleep disturbances occur when the need for the recovery of physiological systems is greater following higher training loads. In Chapter 6 the increased training intensity (higher high-speed running distance & time spent above 85% maximum heart rate) over three 14-day training periods also related to an increased total sleep time of the youth soccer players. This may also relate to the increased fatigue and tiredness and/or proinflammatory responses displayed after exercise of this type (Davenne, 2009; Irwin, *et al*, 2015). However, these suggestions are at present theoretical and would require further research to understand whether these processes may be the reason for the trends within the current thesis. Given that the training loads presented within the current thesis are only reflective of the training processes of the same soccer academy, it is important that larger samples of soccer players are investigated to establish whether such factors influence sleep across the elite soccer population or are only relevant to the findings within the current thesis.

The investigations in Chapters 4 to 6 also identified lowered sleep efficiency within the youth soccer players (i.e. long sleep onset latencies and increased sleep disturbances). Reduced sleep efficiencies are also apparent within other athletic populations (Leeder, *et al*, 2012; Lastella, *et al*, 2014). Therefore this provided a rationale to attempt to improve the sleep efficiency of the youth soccer players in Chapter 7. This was done using a practical strategy (warm showering for 10 min, at 40°C, 20 min before lights out) in an attempt to manipulate thermoregulatory properties relating to skin temperature. The observed outcomes of this study suggested that the shower intervention was successful in elevating distal skin temperature (+1°C), which subsequently related to a decrease in sleep onset latency (-7 min), compared to baseline measures within the youth soccer players. No other sleep variables were affected as a consequence of this intervention. Therefore the results of this study provided positive support to the shower intervention as a viable practical strategy to improve sleep onset in soccer players that display long sleep onset latencies. However the shower intervention did not improve sleep fragmentation. Therefore other strategies should also be investigated in an attempt to influence sleep disturbances and sleep quantity within soccer players.

8.4 CONCLUSIONS

From the results of the investigations in the thesis and the current available evidence to date the suggested factors that influence the process of sleep within youth soccer players have been categorised as being both behaviourally and physiologically derived. These interactions have subsequently been collated and are highlighted within Figure 8.1. This model also provides a number of theoretical factors relating to the sleep of youth soccer players. However these factors are poorly established within the current literature, despite the potential relevance of these theoretical suggestions. Therefore the model presented in Figure 8.1 may serve as a guide for future investigations. Given the suggested importance of sleep within the process of recovery and attainment of optimal athletic performance (Davenne, 2009; Leeder, *et al*, 2012; Venter, *et al*, 2012), it seems important that sleep evaluations are performed longitudinally within larger samples of soccer players. This will enable data to be captured to further the understanding of the mechanisms underpinning the typical sleeping patterns of the soccer player and how factors relating to sleep may impact the process of recovery and soccer performance.

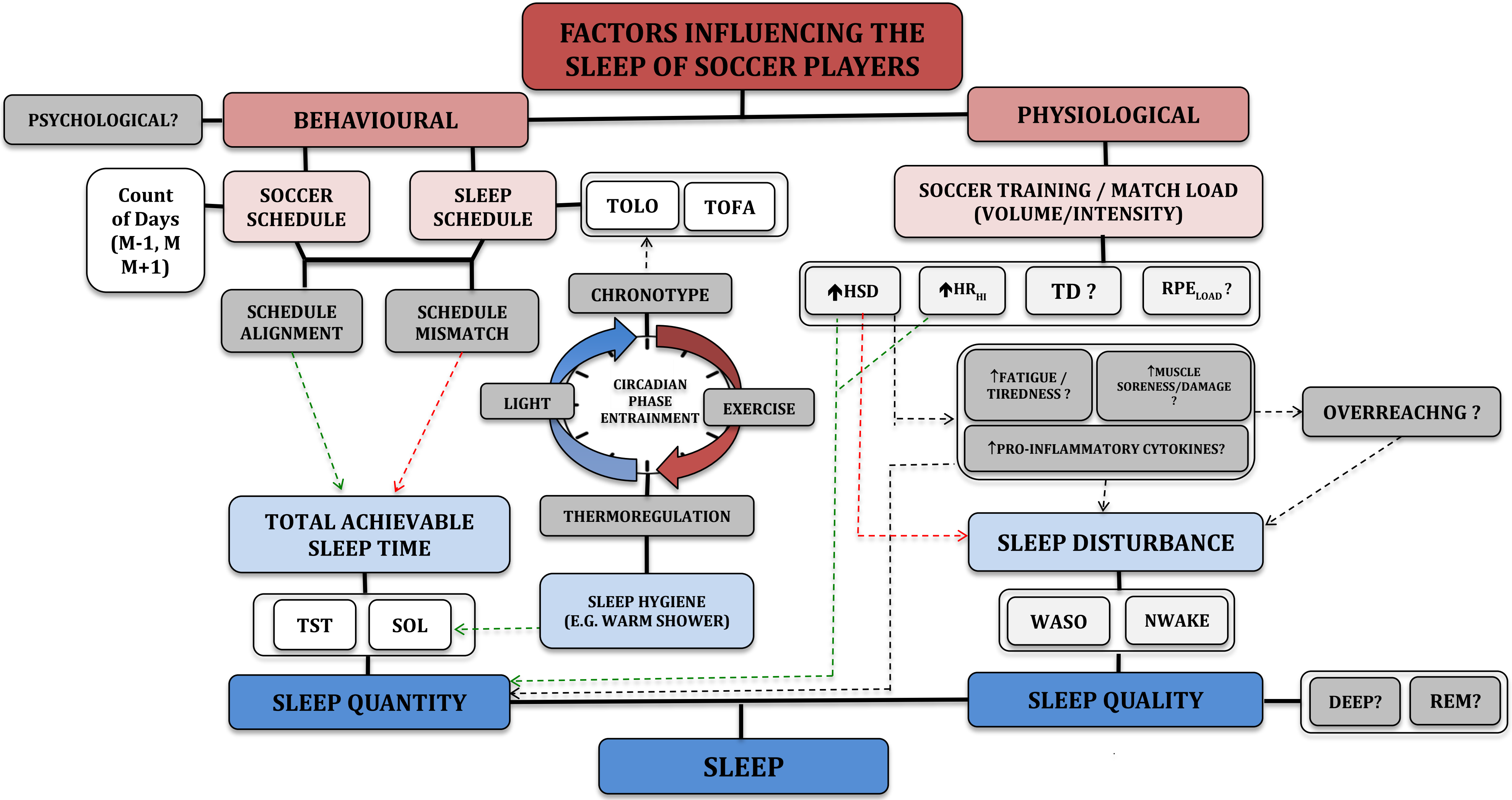


Figure 8.1. Theoretical model representing the potential factors (filled red boxes) that may influence sleep outcomes (filled blue boxes) within youth soccer players. The green dashed lined arrows represent potential positive links derived from the outcomes of the current thesis. Alternatively the red dashed lined arrows represent those links that may have a negative influence on the mechanistic outcome as outlined within the current thesis. Black dashed lines represent the possible interactions relating to soccer, based on the theoretical concepts based in the current literature (Davenne, 2009; Nedelec, *et al*, 2015). The filled grey boxes represent theoretical concepts related to the presented outcomes, which require further research within soccer players.
(Abbreviations; **TOLO**: Time of Lights Out, **TOFA**: Time of Final Awakening, **TST**: Total Sleep Time, **SOL**: Sleep Onset Latency, **WASO**: Wake After Sleep Onset, **NWAKE**: Number of Awakenings, **HSD**: High-Speed Distance [>5 m/s], **HR_{HI}**: Time spent above 85% Max Heart Rate, **TD**: Total Distance, **RPE_{LOAD}**: Perceived training Load)

8.5 DIRECTION OF FUTURE RESEARCH

As a function of the investigations contained within the present thesis a number of theoretical outcomes have been displayed within the observation of sleep within youth soccer players. Given the lack of literature that currently provides data on the typical sleeping pattern of soccer players and the observed limitations of the current thesis a direction of future research is warranted to provide further analysis to that which is displayed within the present thesis.

1) It is important that future research looks to quantify sleep in a larger population sample of soccer players. Such investigations should look to evaluate the behavioural (typical sleep habits and the soccer schedule) and physiological (training/match load) factors, which may impact sleep within this larger sample of soccer players so that a greater statistical magnitude of effect can be established. This will provide further evidence that can contribute to the strength of the theoretical model presented in Figure 8.1.

2) Further research is also required to investigate how increased exercise intensity impacts sleep and how this may reflect on the physiological status of the athlete. Therefore the physiological status of the soccer player should be established and how this relates to changes in sleep over intensified periods of training load within soccer.

3) Given the inter-individual differences in sleep, future research should also look to identify were sleep problems exist within soccer players and look to utilize practical interventions to develop individualised sleep hygiene strategies.

4) The practical strategy of warm showering could be one such utilised method to improve sleep hygiene for soccer players. Research could therefore investigate how such a strategy can be optimised to address the observed sleep related problems within soccer players and other populations displaying sleep difficulties.

CHAPTER 9

APPENDIX

Appendix 1. Adapted Sleep Diary used in Chapter 3 and 7

Sleep Diary							
Date:							
What time did you go to bed?							
What time did you try to go to sleep?							
How long did it take you to fall asleep?							
How many times did you wake up? (not counting final awakening)							
In total how long did these awakenings last?							
What time was your final awakening?							
What time did you get out of bed?							
How would you rate the quality of your sleep? (circle one)	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good
Total number of naps?							
In Total how long did the nap(s) last for?							

Appendix 2. Training Load Diary used in Chapter 4

Name:
Age:
Height:
Weight:

Date:	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Type of Training (e.g. Cardiovascular, Strength, Sport specific)							
Duration of Training (min)							
Rate of Perceived Exertion (RPE)							

RPE Key Guide

0 – Nothing at all
0.5 – Very, very light
1 – Very light
2 – Fairly light
3 – Moderate
4 – Somewhat hard
5 – Hard
6 –
7 – Very hard
8 –
9 –
10 – Very very hard (maximal)

Appendix 3. Temperature Data Collection Diary used in Chapter 7

Shower Group

ATTACH - SIT (10 min) - DETTACH
(Max 5 min Transition)

SHOWER (10 min @ ~40 °C)
(Max 5 min Transition)

ATTACH - SIT (10 min) - BED - SLEEP

WRITE TIMINGS HERE →

AS WELL AS WEARING THE ZEO AT NIGHT

ANSWER THE ADDITIONAL SLEEP QUESTIONS

WRITE INFO & TIMINGS HERE →

Diary			
Date:			
What time did you apply the Buttons & Sit down?			
What time did you get in the Shower?			
What time did you reapply the Buttons after Showering?			
What time did you get into bed?			
How long did it take you to fall asleep?			
How many times did you wake up in the night?			
What time did you wake up?			
What time did you get out of bed?			
How would you rate the quality of your sleep? (circle one)	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good	Very Poor Poor Average Good Very Good

THERMOMETER

BEFORE SHOWERING CHECK THE TEMPERATURE IS CORRECT
AIM FOR 40 °C
RANGE - 39 - 41 °C
HOLD THERMOMETER UNDER SHOWER UNTIL IT SHOWS A STABLE TEMP
RECORD THIS HERE →

KEEP THE SHOWER THE SAME EACH NIGHT

CHECK THE ROOM TEMPERATURE BEFORE YOU GET INTO BED
JUST HOLD THE THERMOMETER OUT IN THE AIR - RECORD THIS HERE →

TURN OFF THE THERMOMETER OVERNIGHT

WHEN YOU WAKE UP CHECK THE ROOM TEMPERATURE AGAIN

RECORD THIS HERE →

Temperature Log Write Temperature in °C			
Date:			
Shower Temperature			
Room Temperature (Night)			
Room Temperature (Morning)			

CHAPTER 10

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10. REFERENCES

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