Do the sleep profiles of elite swimmers vary during periods of training, taper and competition when compared to a baseline phase of rest?

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by

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Contents

Declaration

I hereby declare that all work included in this thesis is my own and I fully understand the severity and consequences associated with plagiarism. All references that have been used within this study have been specifically acknowledged. The work within this thesis has been submitted for the award of MPhil.

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Abstract

Introduction: As sleep is paramount for the optimal performance and recovery of athletes, understanding sleep profiles is of great importance. Whilst sleep profiles of athletes from a range of sports have previously been examined, sleep profiles from solitary sports, during training and competition phases remain unknown. **Aim:** The aim of this study was to examine the sleep parameters of an elite group of swimmers (n=12) through training, taper, and competition phases in comparison to a baseline period of rest. **Results:** Within each testing phase, sleep parameters were monitored using self-report sleep diaries and wrist activity monitors and a significant difference in volume (p<0.001) and intensity (p<0.01) of swimming across testing phases was shown. There was a significant difference between phases for the time out of bed (p<0.01) and a trend for differences between conditions for sleep onset latency, with latency at its highest during competition (p=0.08). The remaining sleep parameters showed no significant difference between testing phases. There was a positive correlation between sleep onset latency and total daily nap time across the conditions (r=0.369, p=0.01) and also between ambient bedroom temperature and sleep onset latency (r=0.398, p<0.01). Athlete sleep duration was within the normative 7-8 h per night, ranging from 7.66-7.93 h across conditions. **Conclusion:** These results indicate that sleep parameters of elite swimmers show no significant variation between phases of rest, training, taper or competition. However sleep onset latency could potentially increase during competition and variables such as nap time and bedroom temperature could also have an effect.

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Abbreviations

AEC1	Aerobic capacity 1
AEC2	Aerobic capacity 2
AEC3	Aerobic capacity 3
AEP	Aerobic power
ANC	Anaerobic capacity
ANP	Anaerobic power
T_a	Ambient bedroom temperature
BBM	Beats below maximum
LA	Blood lactate
COMP	Competition phase
DALDA	Daily analyses of lifestyle demands for athletes
FI	Fragmentation index
$VLamax^2$	Glycolytic rate
LE	Light emitting
$\dot{V}O_2max$	Maximal oxygen uptake
MEQ	Morningness-eveningness questionaire
NREM	Non-rapid eye movement
PSQI	Pittsburgh sleep quality index
PSG	Polysomnography
POMS	Profile of mood states
REM	Rapid eye movement
REST-QSport	Recovery stress questionnaire for athletes
RFN	Restfulness
REST	Rest phase
SE	Sleep efficiency
SWC	Sleep wakefulness cycle
SOL	Sleep onset latency
SWS	Slow wave sleep
TAP	Taper phase
TST	Total sleep time
TTB	Total time in bed
TRAIN	Training phase

Chapter 1: Introduction

1.1. Background

For athletes, optimal recovery is integral to support the high physiological and psychological demands of training and competing at an elite level. Halson (2008) proposed that sleep was the most important recovery consideration for athletes but that the purpose of sleep and research into the quantity and quality of athlete sleep was not well understood. Halson (2014) also echoed a large percentage of current published research that has focused around stress and anxiety levels triggered by competition and how they can cause reduced sleep and poor sleep quality. Halson (2014) maintains that future research needs to place an additional emphasis on comparing the sleep of athletes during a period of competition to information gathered throughout phases of training, and to a controlled condition of rest.

Although still very novel, research thus far has shown that reduced sleep can impair glucose metabolism, immune function and appetite regulation and has the potential to impair muscle recovery (Van Cauter et al., 2008). Existing research has also indicated that reduced sleep can impair cognitive function and mood and that athletes are not achieving the normative amount of sleep (Belenky et al., 2013). On this basis, it is likely that athletes are not achieving optimal recovery during training through optimal sleep, which can have an impact on performance.

1.2. Sleep structure and function

Sleep is paramount for cognitive function and physiological functioning (Cirelli and Tononi, 2008; Walker, 2009). Humans spend on average one third of their life in a state of sleep; with the other two thirds spent in a state of wakefulness. A recent study by Maslowsky et al. (2014) used data from a United States National longitudinal study of Adolescent Health to identify average total sleep durations for adolescents, emerging adults and early adults. They identified that an average of 8.1 hours were obtained per night for the 17-26 age category. Although this study focused solely on sleep duration, it did identify that the emerging adults obtained sufficient sleep and achieved the normative 7-8 hours of sleep as proposed by Van Dogen et al. (2003) and O'Connor and Youngstedt (1995). Within literature sleep is often referred to as normative if it is above a threshold of inadequate sleep whereby proven negative implications occur. The 7-8 hour mark has been found to be normative for general populations and is often used as a guideline for how much sleep to aim to achieve. (Ferrara and Gennaro, 2001). However, this definition differs from sufficient sleep. Sufficient sleep can only be discussed individually as large individual differences exist in the need for sleep. Variables such as lifestyle demands, lifestyle stresses, and differences in individual sleep variables make sleep very specific to each person and therefore sufficient sleep can only truly be determined on a case-by-case basis (Fullagar and Barltlett, 2015).

Both sleep and wakefulness are circadian and homeostatically regulated, combining to form what is known as the sleep-wakefulness cycle (SWC) (Reinoso-Suarez, De Andrés and Garzón, 2011). The hypothalamus suprachiasmatic nucleus in the brain act as the pacemakers for the circadian rhythm of this SWC along with food intake and activity. Photic retinal stimulation by daylight acts as the precursor for nocturnal sleep through various pathways (Oren, 1991). Sleep has been categorised into two broad states, namely rapid eye movement (REM) and non-rapid eye movement (NREM) (Halson et al., 2014). The purpose of sleep is not well established or understood and therefore the functions of REM and NREM sleep remain hotly disputed within the field (Peuhkuri, Sihvola and Korpela, 2012; España and Scammell, 2011). REM sleep is associated with a high level of brain activity and subsequent vivid dreaming. In contrast, NREM sleep is associated with reduced neuronal activity and a lower brain activity (McCarley, 2007). Throughout a period of sleep, an individual will fluctuate through the two stages of REM and NREM sleep, with the cycle between the two rhythmically repeating itself every 90-120 minutes dependent upon the individual (McCarley, 2007). The NREM sleep can be further broken down into stages 1 (dozing), stage 2 (light sleep) and stage 3 (deep sleep). Electroencephalogram (EEG) recordings move from low-voltage, fast activity readings to high voltage, slow wave readings respectively. Muscle activity is also present in stage 1, however, it is significantly reduced and almost absent in stage 3 when deep sleep occurs. Most individuals spend an average of 30 minutes per cycle in the REM stage, accounting for roughly 20% of total sleep time, with stage 2 (light sleep) being the most extensive stage where most individuals will spend up to 50% of their recorded sleep time. On the basis that the young adult populations have on average 7-8 h sleep per night, research shows that 4-5 cyclic sleep episodes occur throughout this period (Reinoso-Suarez, De Andrés and Garzón, 2011).

1.3. Measurement of sleep

When monitoring or specifically measuring an individual or group of individuals sleep there are many different forms of data collection that can be used. In order to study individual stages of REM and NREM sleep (stages 1-3), commonly known as sleep architecture, polysomnography (PSG) would have to be used. Although this is the gold standard method of measurement when it comes to monitoring and objectively quantifying sleep, it is costly and would require participants to report a sleep clinic. As a result, when examining the sleep of more than one participant the non-invasive, portable, and remotely operated wrist actigraph watches in most field based studies (Sargent et al., 2014). Weis et al. (2010) found that the wrist actigraph watches have a moderate-strong association with the gold standard measurement of polysomnography (PSG) (r=0.836) when examining total sleep time (TST) and sleep efficiency SE). Sleep parameters monitored using wrist activity monitors often go hand in hand in with self-report sleep diaries, with the diaries being used to identify when a participant attempted to sleep, when the participant got out of bed, and subsequent total time spent in bed. Additional sleep variables measured using wrist actigraph watches are highlighted in the table below.

Table I. Definitions of each sleep variable measured using wrist actigraph watches

TST	Total sleep time (mins)	Total time spent sleeping determined by sleep start to sleep end minus TA
TA	Time awake	The actual time spent awake, determined from sleep start to sleep end.
SOL	Sleep onset latency (mins)	The difference between time attempted to get to sleep and sleep onset time.
SE	Sleep efficiency (%)	TST expressed as a percentage of Total time in bed
RFN	Restfulness (activity > 1)	The number of epochs >1 throughout TST minutes.
FI	Fragmentation index (%)	RFN expressed as a percentage of TST.

Additionally, self-reported measures from a sleep diary alone do have their limitations (Erlacher et al., 2011) and objective measures such as wristwatch actigraphy in combination with subjective measures, may reduce these limitations and improve the understanding of sleep disruption before competition. Self-report sleep questionnaires can also be used to assess the sleep quality and quantity of individuals; examples include the Competitive Sports and Sleep Questionnaire and the Recovery Stress Questionnaire for Athletes (REST-QSport). The subjective nature and reliance on recall/memory when using questionnaires to assess sleep variables, in addition to the challenge for participants to interpret their own sleep variables, opens the data up to individual bias (Erlacher et al., 2011; Leger, Metlaine and Choudat, 2005). There are however benefits to using questionnaires to monitor the sleep of individuals, with the primary being that data can be gathered from large groups of individuals whereby even wristwatch actigraphy may be unfeasible.

Self-report sleep questionnaires can also serve as screening tools for sleep dysfunction, with results dictating the inclusion/exclusion of participants into studies that examine sleep. The Pittsburgh sleep quality index (PSQI) has been shown to be a valid and reliable screening tool for measuring sleep dysfunction in both clinical and non-clinical populations and can be a good indicator of sleep disorders such as insomnia (Backhaus et al., 2002; Mollayeva et al., 2016). The simplicity of its administration to the participants makes it the most widely used screening questionnaire in both clinicians and researchers. If a global PSQI of >5 is found it would suggest that a participant suffers from disturbed sleep and act as an exclusion criteria from a study (Buysee et al, 1989). The Morningness-Eveningness Questionairre (MEQ) has been shown to be a useful screening tool, specifically examining circadian rhythm. The MEQ significantly correlates to the most reliable test of circadian rhythm; the dim light melatonin onset (Kantermann et al., 2015). Due to the financial demands and significant participant effort required for dim light melatonin onset, the MEQ can be used to give an indication of the peak times of alertness amongst participants.

1.4. Overview of the training systems of elite swimmers

Within a high performance swimming programme the focus of each session will often specifically target a certain energy system, achieved through manipulation of swim interval duration, rest intervals and swim speed, resulting in changes to outcomes measures that represent intensity (heart rate and blood lactate) (Olbrecht, 2000). These training modalities/energy systems are highlighted in table II. By bracketing all swimming volume into a training modality training intensity can be calculated across a periodised macro/mesoycle.

The aim of aerobic capacity training is to increase the maximum uptake of oxygen per minute inducing the physiological adaptation of an increased $\dot{V}O_2max$ (Olbrecht, 2000). The subsequent volumes of these training sets are high with intervals dependent on the event the individual swims. On the most part, the intensity is kept low but short bursts of higher intensity swimming can be performed within these sets. (See table II). Anaerobic capacity training (ANC) aims to increase the capacity to breakdown carbohydrates anaerobically causing the physiological adaptation of increased glycolytic rate ($VLamax^2$), hence it is often referred to as the lactate production training zone (Olbrecht, 2000).

Aerobic power training (AEP) aims to maximise the use of an individual's aerobic capacity causing an increase in the percentage of $\dot{V}O_2max$ that can be maintained during long distance exercises or competition efforts. These sets aim to match the competition distance and are swam at race pace or faster. The rest period between intervals will dictate the intensity of the set, with shorter periods of rest occurring in the final preparation before competition (see table II). Anaerobic power training (ANP) aims to maximise the use of an individual's anaerobic capacity by increasing the involved percentage of $VLamax^2$ that can be maintained during a high level effort in competition (Olbrecht, 2000). Much like AEP, the sets aim to match the competition distance and consist of very short repeats, but unlike aerobic power, all the repeats are carried out at maximum all-out intensity (Olbrecht, 2000).

Table II. Description of training modalities and energy systems undertaken by elite swimmers across a typical training week.

Training Modality	Energy system	Length of intervals	Expected heart rates (beats below maximum)	Expected blood lactate levels (mmol/l)	Rest between intervals (seconds)	Additional comments
AEC1 – Aerobic capacity 1	Aerobic Endurance 1	100 – 800m	<50 bbm	<2 mmol/l	10 – 40 secs	↑ $\dot{V}O_2$max
AEC2 – Aerobic capacity 2	Aerobic Endurance 2	1 - 800m	<40 bbm	2 -4 mmol/l	10 – 40 secs	↑ $\dot{V}O_2$max
AEC3 – Aerobic capacity 3	Threshold	1 - 800m	<30 bbm	3 – 6 mmol/l	10 – 40 secs	↑ $\dot{V}O_2$max
ANC – Anaerobic capacity 3	Lactate production	25 – 75m	5 – 15 bbm	8 – 15 mmol/l	(Long rest) > time than length of interval	↑ VLamax[2]
AEP – Aerobic power	$\dot{V}O_2$max	50 – 400m	5 – 20 bmm	6 – 12 mmol/l	10 – 20 secs	↑ utilisation of $\dot{V}O_2$max
ANP – Anaerobic power	Lactate tolerance	25 – 100m	0 – 10 bbm	12 – 20m mmol/l	10 – 20 secs	↑ utilisation of VLamax[2]

Chapter 2: Literature review

2.1. Consequences of reduced sleep

It has been shown that reduced sleep can impair cognitive function and mood (Belenky et al., 2013) and can also impair glucose metabolism, immune function and appetite regulation (Krueger et al., 2011; Spiegel et al., 2004; Copinschi, 2005). Van Cauter et al. (2008) showed that chronic partial sleep deprivation can result in changes to glucose metabolism through multifactorial mechanisms including decreased brain glucose utilization, alterations in growth hormone secretion and altered leptin concentrations. The same study also highlighted that lack of sleep resulted in an increased secretion of cortisol and changes in the secretion of testosterone and insulin-like growth factor 1. Van Cauter et al. (2008) proposed that these hormonal changes reduced protein synthesis and impaired muscle recovery. Sleep reduction has also been linked to reduced immune function as determined by reductions in natural killer cells, which ultimately, could affect an athlete's recovery and performance (Irwin et al., 1994; Irwin et al., 1996). It is for this reason that athletes and coaches alike are keen to further their understanding of sleep.

Finally, along with the aforementioned symptoms of sleep deprivation, sleep has also been recognised as an integral component for recovery in preparation for, and from, high-intensity training (Samuels, 2008).

2.2. Sleep patterns within athletic populations

Given sleep is considered fundamental for optimum athletic performance and recovery (Leeder et al., 2012) and the importance of sleep in athletic populations is widely acknowledged, the currently novel body of literature surrounding sleep quality and quantity in elite athletes continues to grow. Within the limited literature published, study designs are diverse in relation to selected methods of data collection; some have examined sleep during training or competition, whereas others have drawn sleep comparisons between athletes and a control group of untrained or lesser-trained individuals.

Individuals in early adulthood (average age of 22 years) typically sleep approximately 8.5 hours sleep per night (Maslowsky and Ozer, 2013), thus achieving the normative 7-8 hours sleep per night (Ferrara and Genaro, 2001; Van Dongen et al., 2003; O'Connor and Youngstedt, 1995). However, previous research has indicated that athletes have a higher quality of sleep quantified by a longer sleep duration and also a higher duration of SWS when compared to a control group (Porter and Horne, 1981; Shapiro et al., 1986). A plausible suggestion for this would be that athletes required a greater amount of sleep for recovery. In accordance with these findings, Brand et al. (2010) compared male and female athletes (>18 years) that exercised on average 17.5 hours a week, against controls of the same age exercising on average 4.5 hours a week. Using the Pittsburgh Sleep Quality Index (PSQI) and recall questionnaires relating to sleep quality, the authors found that athletes reported better sleep patterns and better psychological functioning than the control population. Specifically, the athletic population was found to have a shortened sleep onset latency (SOL) and to have woken up fewer times throughout the night.

In contrast to these findings, Leeder el al. (2012) examined the sleep of 46 international level athletes for 4 days and the data was compared to an age and gender matched control group (n=20) that was monitored for the same duration. The study found that the athletes had on average 6.9 hours of sleep per night, compared with the control group that achieved 7.2 hours per night. Furthermore, Sargent, Halson and Roach (2014) examined the sleep of a group of elite Australian swimmers and found that on average, they slept for only 5.4 hours on nights preceding a morning training session and still only managed to sleep for 7.1 hours on nights preceding a rest day. Taken together, the highlighted literature shows inconsistencies and is indicative that some athletes were not achieving as much sleep as the normative amount of 7-8 hours (Ferrara and Genaro, 2001; Van Dongen et al., 2003; O'Connor and Youngstedt, 1995).

2.3. Performance effects of sleep deprivation and partial sleep restriction

Sleep deprivation refers to a period/night(s) of little or no sleep, often referred to as complete lack of sleep, whereas achieving consecutive night of less sleep than is needed is referred to as chronic sleep restriction (Van Dogen et al., 2003). Reilly and Edwards (2007) state how sleep deprivation studies entail substantially reduced sleep allowances when compared to sleep restriction studies. In their view this ensures that each participants individual difference in sleep stage architecture is somewhat controlled, by removing all sleep rather than just small percentages of sleep. Although studies widely acknowledge that reduced levels of sleep has the potential to significantly impact athlete performance, there has been published research, albeit limited, that has examined the effect of deprived sleep on the performance of athletes. Study designs commonly vary in the amount of sleep deprivation that athletes are subjected to, ranging from total sleep deprivation to acute periods of sleep restriction.

Demonstrative of this, early studies have examined the effect of sleep deprivation on maximal performance markers. Takeuchi et al. (1985) examined the effect of 64 hours of sleep deprivation on 12 male participants and found that mean vertical jump height and isokinetic extension force significantly decreased following the period of sleep deprivation. Yet in this study there was no significant impact on 40 m sprint time, isometric handgrip force or balance. Similarly, a study by Bulbulian et al. (1996) examining a range of performance markers in 24 US Marine Corps following a period of sleep deprivation found that isokinetic performance and flexion peak torque decreased following sleep deprivation but fatigue index was not affected.

Reilly and Deykin (1983) also examined the effect of partial sleep restriction on maximal performance markers and cognition. A group of well-trained men completed a range of tests including subjective state tests, psychomotor tests and tests for physical working capacity. The authors found that following 3 nights of severely restricted sleep, gross motor functions such as lung power, muscular strength and endurance running on a treadmill, were unaffected. Psychomotor functions, however, were significantly affected after just 1 night of partial sleep restriction. Finally, the findings from a later study by Reilly and Hales (1988) looking at well-trained females, echoed the common theme that when sleep was restricted to 2 hours per night, for 3 consecutive nights, gross motor functions including grip strength and anaerobic power output were less effected by sleep loss than tasks that required quicker reaction times.

Using a counterbalanced study design, Sinnerton and Reilly (1992) tested a group of 8 swimmers under both controlled and partially sleep-restricted conditions and examined the effect of partial sleep restriction on multiple markers for maximum performance. Trials were separated by 10 days and each consisted of 4 consecutive days of testing. In the sleep deprived trial, sleep was restricted between the hours of 03:00-05:30 under supervised conditions. The athletes were tested daily both in a morning (06:30) and in an evening (17:30) for 4 maximum trial efforts of 50m front crawl; 1 trial effort of 400m front crawl effort; grip and back strength using a dynamometer; resting heart rate and lung function (vital capacity and forced expiratory volume in 1-sec) using a dry spirometer (Sinnerton and Reilly, 1992). The Profile of Mood States (POMS) used found that depression, tension, confusion, fatigue and anger all significantly increased as a result of partial sleep deprivation, and vigor also significantly decreased. Yet with such a small sample size, the duration of the swim efforts were not wholly representative of a well-trained swimmer within a 19-28 year age range. The results, however, were still in keeping with that of Reilley and Deykin (1983) in that no effects of partial sleep deprivation were evidenced for dominant handgrip strength, back strength, lung function on either of the swim efforts.

Continued research into the effect of partial sleep restriction on maximal strength by Reilley and Piercy (1994) examined both submaximal and maximal weightlifting tasks and subjective state of the participants both pre and post physical activity. Eight male participants (aged 18-24) were limited to a maximum of 3 hours sleep for 3 consecutive nights following a baseline-testing day. Both submaximal and estimated maximal lifts were performed on each of the 3 days. The authors found that partial sleep deprivation across the 2 nights that had been tested had no significant effect on maximal biceps performance. However, there was a significant decrease in performance ($P>0.001$) for maximal leg press, bench press, and deadlift. Yet given that the 1 repetition max was estimated from a 20 repetition set in this study, it does raise speculation over the validity of the four ‘maximum’ lifts as a true reflection on maximum strength. The results from POMS, following each successive day of testing, showed that mood states of fatigue, confusion, and vigor were affected significantly by the sleep deprivation regimen ($p < 0.001$) but that there was no significant effect of sleep deprivation on tension, anger and depression ($p > 0\text{-}05$). Due to the performance reductions occurring after 2 successive nights of sleep deprivation, the authors hypothesised that not only did sleep deprivation have more of an effect on submaximal exercise but it also caused a cumulative fatigue effect that became more prominent the longer sleep deprivation persisted.

Adding to the body of literature on maximal strength and performance, Blumert et al. (2007) examined the effect of 24 hours of full sleep deprivation on the maximal strength of 9 United

States college level weightlifters. The lifters performed a maximal weightlifting protocol consisting of several sets of snatches, clean and jerks and front squats following the 24 hour period of sleep loss. Unlike Reilley and Piercy (1994) the authors found no significant reduction in the aforementioned performance variables (snatch, clean and jerk, front squats, total training volume or training intensity), which was indicative of no significant effect to maximal strength. The POMS assessment, however, found that fatigue, total mood disturbance, vigor, confusion, and sleepiness were all significantly altered by sleep loss and this was suggestive of negative mood disturbances.

Although maximal performance is justifiably more applicable to an athlete population, more contemporary research has examined the effect of sleep deprivation on submaximal performance as well as maximal performance (Skein et al., 2011). In a counterbalanced cross over study, Skein et al. (2011) examined the effect of a 30 hour sleep deprivation period on 10 male team-sport athletes. The authors attributed their findings to a reduction in motor unit recruitment potentially caused by lower glycogen levels found in the sleep deprivation group. In this study, sleep deprivation resulted in significant reductions in 15 m maximal sprint times. Pacing of maximal sprint efforts were also affected by sleep loss, with mean sprint times slower in the first 10 minutes and the final 10 minutes of a 50-minute self-paced intermittent-sprint exercise protocol in the sleep deprived group. Additionally, sleep deprivation also caused a significant reduction of 5% on the distance jumped on double-leg bound test.

Similarly, Oliver et al. (2009) also found that following a 24 hour sleep deprivation period that there was a reduction in the endurance running performance of the 11 male participants tested. The study, consisting of two randomised trials separated by 7 days, found that the distance covered on a 30-minute self-paced treadmill test was significantly lower (6037 m) after a night of deprived sleep in comparison to the controlled night sleep (6224 m). The authors did, however, find that the sleep deprivation had limited effect on pacing, thermoregulatory or cardio-respiratory function. They hypothesised that the difference in the 30-minute run was due to perception of effort caused by the lack of sleep and not a by a change to physiological markers (Oliver et al., 2009).

It is clear from examining the literature that there are several conflicting theories on the effect that sleep deprivation has on exercise performance, physiological markers and cognition. Earlier studies found that some elements of maximal performance were effected by sleep deprivation whilst other elements remained unaffected. A hypothesis proposed by Takeuchi et al. (1985) and supported by Bulbulian et al. (1996) suggested that the effects of sleep deprivation might be task specific, which explains why some performance markers suffer more from sleep deprivation than others. A large body of the literature found that maximal performance markers including maximal strength, maximal aerobic power, anaerobic power and lung function to be unaffected by both sleep deprivation and partial sleep restriction (Reilly and Deykin, 1983; Reilly and Hales, 1988; Sinnerton and Reilly, 1992; Blumert et al., 2007). However, more recent studies have found that both maximal and submaximal performances are significantly affected with deprivation (Skein et al., 2011; Oliver et al., 2009), with submaximal efforts affected more than maximal efforts. Skein et al. (2011) hypothesised that the combination of these changes to physiological markers, cognitive functioning and afferent feedback, all played a role in the significant decrease in maximal performance.

Research appears to be conclusive in that sleep deprivation and partial sleep restriction result in a slower and less accurate cognitive function, with decreased reaction time, specific skill execution, alertness and decision making (Reilly and Deykin, 1983; Reilly and Hales, 1988; Sinnerton and Reilly, 1992; Blumert et al., 2007; Oliver et al., 2009; Skein et al., 2011; Blumert et al., 2007). As such, team sports or individual sports with additional cognitive dimensions of fine motor skills may suffer more from sleep deprivation. (Reilly and Hales, 1988; Reilly and Peircy, 1994). Therefore despite conflicting data on acute performance variables, we know that sleep restriction can have a significantly negative impact on other variables, such as immune function, which if disrupted long term could lead to illness and injury. As well and most importantly, what was clear and consistent across the studies examining sleep deprivation and restriction was that they were underpowered and the training status of the participants was varied. Consequently, no theories can be deemed as conclusive nor can they be used to generalise what effect sleep deprivation might have on a larger scale elite athlete population.

The ecological validity of sleep deprivation models and physical performance is somewhat limited but sleep restriction models may be more applicable in the lead up to a competition, for example. Yet it would still be rare for athletes to suffer from sleep deprivation to such a large degree and because of this, future work should look to examine how the sleep quality of athletes is affected in their routine training and competition environment.

2.4. Sleep profile before competition

Optimal performance during important competitions is vital but pre competition stress has been shown to lead to reduced sleep and poor sleep quality. Erlacher et al. (2011) examined a number of sleep parameters in athletes across a multitude of sports in the lead up to competition. They administered a sleep questionnaire to 632 German athletes recruited from both team sports (n=225) and individual sports (n=407), with 368 of the athletes belonging to the German national supported team system. The results from the study found that the sleep of 65.8% (416) of the athletes was impaired on at least 1 night before an important competition. Athletes from individual sports (69.3%) also reported poor sleep more often than athletes from team sports (59.6%). For all of the competitions in the 12 months prior to the questionnaire being issued, the athletes reported having slept worse than normal on 21.7% of the nights preceding a competition. Of those 416 athletes that reported impaired sleep on the night before a competition, 79% of them attributed that to ‘problems falling asleep’, commonly known as sleep onset latency. These findings were supported by a recent study by Juliff, Halson and Peiffer (2015) in which 238 elite Australian athletes were recruited from a multitude of sports and asked to complete the Competitive Sport and Sleep questionnaire and PSQI. The findings revealed that 64.0% of the athletes involved in the study reported that they had slept worse on the night(s) preceding a competition 12 months prior to the study commencing and 82.1% of these participants also attributed it to ‘problems falling asleep’. Furthermore a study by Silvia et al. (2012) examined the sleep quality of elite athletes in the lead up to a major competition, using the PSQI and Epworth Sleepiness scale to evaluate the sleep of 27 Paralympic athletes ahead of the 2008 Beijing Paralympic Games. They found that 72% or 19 out of the 27 athletes suffered from poor sleep quality and increased levels of anxiety in the lead up to Games. The group classified as ‘poor sleepers’ were found to have greater SOL, whereas the ‘non-sleepy’ group demonstrated significantly greater sleep efficiency (SE) than the poor sleepers.

The highlighted findings evidence that competition phases have the potential to cause disrupted sleep in elite athletes across a range of different team and individual sports. The findings also indicate that disturbed sleep is predominantly triggered by an increased SOL. Although evidence is substantial, confounding variables such as training volume and dietary intake were not reported. Additionally, self-reported measures have their limitations (Erlacher et al., 2011) and objective measures such as wristwatch actigraphy in combination with subjective measures, may reduce these limitations and improve the understanding of sleep disruption before competition.

Wrist actigraph watches and self-report sleep diaries were used in a study by Feitze et al. (2009) to examine the sleep quantity and quality of 24 classical ballet dancers throughout a 67-day lead up to a ballet premiere. The results showed that sleep duration decreased from 418 min to 391 minutes across the 67 days and that SE decreased significantly throughout the 67 day period. In spite of this, there was no significant change in SOL over the course of the study. Lastella et al. (2015) also utilised wristwatch actigraphy to examine well-trained cyclists in the lead up to and during competition. In total, 9 days of sleep were monitored, 6 baseline, 3 proceeding competition (-3, -2, -1) and 2 days of competition and the study found concurring results that competition had a significant effect on sleep quality. The authors also found that sleep quality was at its poorest the night before competition represented by a SE of 84.9%. SOL was 36.4 min and the sleep duration was almost 1 hour less than at baseline (7.4h – 6.5h).

Given the relatively small sample size of the studies by Feitze et al. (2009), Lastella et al. (2015) and Silvia et al. (2012), in comparison to the previous two studies by Erlacher et al. (2011) and Juliff, Halson and Peiffer (2015), it would be difficult to assume transference of those findings to larger athlete groups but it does support the aforementioned findings that an athlete’s sleep cycle is increasingly likely to become disrupted in the lead up to a competition.

Although the body of research on the sleep trends remains limited, the results from published literature are indicative of disturbed sleep profiles within athletic populations prior to a competition. This suggests that sleep parameters of an athlete may differ dependent upon what period of training and/or competition they are in as put forward by Halson (2014).

2.5. Sleep profile during intensified training

Halson (2014) argued that in order to understand the complex nature of athlete sleep patterns, future research needed to focus more on the sleep of athletes during a period of competition. Equally Halson (2014) maintained that more comparisons between the quality of sleep and information gathered throughout phases of training was of great significance and needed to be acknowledged. Sargent, Halson and Roach (2014) monitored the sleep of seven international standard swimmers during a 14-day training phase used in preparation for the 2008 Beijing Olympic trials. The training phase consisted of 12 training days and 2 rest days. The findings revealed that during the training phase the swimmers slept for 5.4 hours prior to a training day, with a SE of 71%. In comparison, there was a marked difference in sleep quantity prior to a rest day with the swimmers sleeping 7.1 hours, with SE being 77%. Sargent, Halson and Roach (2014) found that the swimmers got out of bed 4 hours earlier on training days to accommodate for a 06:00 session start time when compared to rest days therefore it is possible that the differences in sleep duration were a result of these earlier start times. Although the swimmers tried to compensate for these earlier starts by going to bed approximately 2.5 hours earlier on nights preceding training, the authors proposed that both lifestyle commitments and a lack of sleepiness caused by the change to the sleep-wake cycle prevented SOL (Sargent, Halson and Roach, 2014; Spencer and Montgomery, 1997; Tucker et al., 1998; Lavie, 1986).

Similar disturbances to sleep were found by Hauswirth et al. (2014) who conducted a study on 27 well-trained triathletes. The participants were subjected to either a control (n=9) or an overload group (n=18) based upon a matched group experimental design. Both groups completed a 6 week training cycle following 3 weeks of their normal training. Following the first ‘mini taper’ week (a period of reduced volume to allow super compensation from heavy workload) of the 6 week cycle, the overreaching group was subjected to a 3 week overload phase designed to overreach the participants by increasing baseline workloads by 30%. The control group continued their normal training for the 3 weeks. Following this 3 week period of overload, 9 out of the 18 participants from the overload group were found to be functionally overreached, whilst the remaining 9 were found to be acutely fatigued, which split the over trained group into a further two groups (functionally overreached and acutely fatigued). The authors found a significant interaction effect for actual sleep time (p=0.006), SE (p=0.003) and immobile time (p=0.004) in the functionally overreached participants, as well as a progressive decrease in all three of these parameters during the overload phase when compared to baseline values. The authors also found a higher prevalence of upper tract infections in the functionally overreached.

A study conducted by Jurimaë et al. (2004) also identified an overreaching in elite athletes. In this study 21 competitive rowers were tested on a 6-day training camp consisting of an increase in workload of 100%. Using the recovery-stress-questionnaire for athletes (RESTQ-Sport) the authors found a negative correlation between training volume and sleep quality (r= -0.58). The authors postulated that the emotional and physical aspects of recovery were not adequate during the period of intensified training (Jurimaë et al., 2004). The findings suggested that high physiological and psychological stresses experienced by elite athletes, in particular elite swimmers in periods of heavy training, contributed to an increase in sleep disturbance and poor sleep quality.

2.6. Sleep profile during reduced volume/tapering period

In order to regenerate from the physiological and psychological stresses of heavy training, a period of taper or a reduced level of training load, is introduced in the lead up to a major competition to allow athletes to super compensate from their existing workload (Hellard et al., 2011). This phase of super compensation allows the positive effects of heavy training to be maximised and for fatigue to be reduced. These factors must be taken into consideration when cycles of training are planned for optimal function as although it is known that reduced volume or tapering as part of a periodisation cycle improves physical function, little is known about the effects of tapering with regards to sleep profiles (Hooper and Hackinnon, 1999; Hellard et al., 2011).

Taylor, Rogers and Driver (1997) carried out a study on 7 nationally competitive female swimmers examining sleep and psychological markers of the participants during the onset of the training phase, the peak of the training phase and the taper prior to the competition phase. PSG recordings that were obtained from the participants under laboratory conditions showed that SOL, time awake after sleep onset, total sleep time (TST) and REM sleep time showed no significant variation between each testing phase. However, the PSG results did find that following 2 weeks of reduced training (taper), the amount of SWS was significantly reduced in comparison to onset and peak training phases. The authors postulated that the reduced physical demands of tapering meant that the need for restorative SWS was subsequently reduced. As the participants only had PSG recordings taken on 1 night of each testing block, the validity of the study could arguably be brought into question.

Hauswirth et al. (2014) also examined overreaching in competitive triathletes and provided a brief insight into the sleep profile associated with tapering and demonstrated the importance of the restorative properties of a taper period. Both tested groups performed a 2 week taper following a 3 week period of either control or overload training. The 2 week taper consisted of a 50% reduction per week of respective training loads. The authors found that the reductions in TST (p=0.006), SE (p=0.003) and immobile time (p=0.004) of the functionally overreached was progressively reduced to baseline during the 2 week taper period. However, as elite swimmers have been shown to experience such a significant contrast in volume and intensity of between mesocycles, there is the potential that sleep quality and other markers associated with recovery as a result of changes to sleep patterns, could conflict heavily.

2.7. Aims and objectives

The highlighted literature demonstrates that sleep plays a role in metabolism, cognitive functioning and mood state, which can ultimately affect recovery and performance. However, a number of studies examine the sleep parameters of elite athletes for only 1-2 nights, which does mean that results are not truly representative of sleep variations across a training phase and are therefore unreliable. In addition, many studies have collated athletes from different sports and disciplines, whereas few studies have examined athletes from a solitary sport. Studying multiple sports results in sets of data being collated to produce one set of data, despite different training times, training intensities and training volumes across sports. Discrepancies between the psychological stresses caused by solitary and team sports have also been shown (Juliff, Halson and Peiffer 2015). Whilst the body of literature that examines sleep quantity and quality prior to and during competition is apparent, there is less work comparing both training, competition with a control condition in the same group of athletes or participants (Halson, 2014). Also, published research on the sleep profiles of athletes during the taper phase of athletes is limited. Since sleep plays a key role in recovery, understanding sleep parameters during the taper phase is of importance to athletes wishing to maximise adaptation and minimise fatigue prior to competition.

Consequently, the aims of this study were to:

- Examine the sleep parameters of an elite group of swimmers through a period of competition, a 14 day period training, a 14 day period of taper, and compare to sleep parameters during a phase of rest.
- Explore the impact that other known variables including screen time preceding sleep, ambient bedroom temperature and daily nap duration have on sleep parameters and overall sleep quality and quantity.

Chapter 3: Methods

3.1. Participants

Twelve national and international level swimmers participated in this study. The study was conducted during the macrocycle for the 2015/2016 competitive swim season. The data collection period commenced in November 2015 and concluded in May 2016 and this period included a competition phase for the 2016 Rio De Janeiro Olympic Games trials. Fourteen participants were recruited for the study. Two participants were not able to complete the entirety of the study due to individual circumstances. All participants were in good health and excluded from the study if they were taking medication known to influence sleep or had travelled across time zones in the 2 weeks prior to data collection commencing. The University of Stirling's Ethics Committee approved the study.

All participants were informed about the purpose and potential risks associated with the study and were asked to sign a form providing their informed consent. Participants completed a general health screening questionnaire, a Morningness-Eveningness questionnaire (MEQ) and the Pittsburgh Sleep Quality Index (PSQI) (Mollayeva et al., 2016; Juliff, Halson and Peiffer, 2015) before the study commenced. If poor sleep quality was found it would be cause for exclusion criteria from the study. The PSQI scores for the participants were 5 ± 1 (mean ± SD). The MEQ was used to give an indication of the peak times of alertness amongst the group of athletes that we were testing. The MEQ scores were 51 ± 6 (mean ± SD). Of the 12 participants, 10 were found to have intermediate levels of alertness, 1 to have moderate morning alertness and the remaining participant to have moderate evening alertness. The participant characteristics are outlined in Table III.

Table III. Participant characteristics

Participant Characteristics	Mean ± SD
Age (yr)	21 ± 2
Gender	Male (n=9)
	Female (n=3)
Stature (m)	1.83 ± 0.08
Body mass (kg)	74.3 ± 7.8
Body Mass Index (kg/m^2)	22.1 ± 1.4
Sum of skinfolds (mm)	62 ± 17
Morningness-Eveningness score	51 ± 6
Pittsburgh Sleep Quality Index score	5 ± 1

3.2. Experimental design

The data were collected at 4 different training/competition phases throughout the year. The periodised macrocycle consisted of a competitive preparation-training phase (TRAIN), a taper phase (TAP) a competition phase (COMP) and a recovery phase (REST) (see table IV.)

Athletes were asked to carry out their normal daily training programme, which was planned and delivered by the coaching staff at the University of Stirling (see Table IV). All phases were periodised with the focus on the competitive trials for the 2016 Olympic Games. It was stated by the coaching staff that there would be week long phases every 3-4 weeks of super compensation during TRAIN to support the ongoing regenerative process within the group of swimmers. As a result of this we decided to avoid this week when collecting data during TRAIN. The participants were monitored for 14 days in TRAIN, 14 days in TAP, the sum total of their days spent in competition COMP according to their last race (3-7 days) and then 3-7 days in REST (see table IV.) The breakdown for each individual's competition phase was 3 days (n=1), 5 days (n=5), 6 days (n=3) and 7 days (n=3) – all daily means were therefore calculated individually before calculating the group mean for COMP. The breakdown for each individual's rest phase (REST) was 3 days (n=1), 4 days (n=4), 5 days (n=4), and 7 days rest (n=3).

The duration of monitoring was dictated by how long each pre designed training/competition cycle was due to last. For TRAIN, TAP and REST, athletes were monitored in their home environment. For COMP, all 12 participants were monitored in a hotel environment. As the competition was held in Glasgow, United Kingdom, travel time between the home environment (Stirling, United Kingdom) and the hotel did not exceed 40 minutes.

Table IV. The characteristics of individual data collection phases.

Characteristics of testing phase	Rest	Train	Tap	Comp
Duration of testing (D)	3-7	14	14	3-7
Time of the year	April 2016	November-December 2015	March 2016	April 2016
Swimming volume (M)	0-1000 m/session. 0-4 sessions	5000 m/session. 18 sessions	3500-4500 m/session. 14-16 sessions	2500-4500 m/day. 1-2 sessions daily including warm up, races, cool downs.
Land based/gym sessions	No sessions	6 sessions	2-4 sessions	No sessions
Key training sets planned	Any swim volume to be done at AEC1.	1-2 sets of AEC2-3, 3000m each. 1-2 sets of AEP, 1200m each. Remainder of volume AEC1 work.	1 set of AEC2, 1200-1600m. 1-2 sets of ANC, 200-400m 1 set of ANP 200-600m Remainder of volume AEC1 work.	Races: AEP. 300m-1600m across competition schedule. Any additional swimming LIGHT AEC1/short bursts of speed work.

Aerobic capacity 1 (AEC1), Aerobic capacity 2 (AEC2), Aerobic capacity 3 (AEC3), Anaerobic capacity (ANC), Aerobic Power (AEP) and Anaerobic power (ANP).

3.3. Sleep measurement

Sleep parameters were monitored using wrist activity monitors and self-report sleep diaries. All participants were provided with an actigraph wristwatch (GeneActiv, Cambridgeshire, UK) for each of the four data collection periods and were instructed to wear the watch on the non-dominant hand at all times except when swimming or showering. Participants were also instructed to press the button on the face of the actigraph watch when they intended to go to sleep and to press the button on the face of the watch again when they woke up in the morning. Data from the actigraphy watches were sampled at 10 Hz and assessed at 60-second epochs (Weis et al., 2010). Participants were given a digital indoor thermometer and hygrometer (GearBest, China) and instructed to report their daily swim volume (m); any naps they had during the day (min); screen time after 5 pm (min) and ambient bedroom temperature (T_a) (°C) in the evening before going to sleep. Participants were also instructed to report subjective sleep quantity and quality upon awakening. The self-report sleep dairies were used in conjunction with wristwatch actigraphy to identify when a participant attempted to sleep, when the participant woke and total time in bed. Further sleep parameters were obtained through actigraphy assessment. These include Total time in bed, Total sleep time, sleep onset latency, sleep efficiency, Restfulness and fragmentation index. Further details of these sleep variables are outlined in Table III.

3.4. Statistical analysis

All data were analysed using Minitab (version 17 for Windows). For COMP and REST means were calculated for each participant based upon the number of days within each testing phase. The group means were then calculated. All data are presented as mean ± standard deviation. An Anderson-Darling test was used to determine normality of all the data ($p< 0.05$). Any data that were not normally distributed were transformed using logbase10 (log10) into normally distributed data. One-way ANOVA with Tukey post-hoc were used to test for statistical significance between the four testing phases for all the training and sleep data, with significance set as a p value of <0.05. Two-way Anova with tukey-post hoc were used to test for statistical significance between the four testing phases for an interaction effect of sleep variables and gender, with significance set as a p value of <0.05. Correlations between variables were determined using Pearson's r with a significance criterion p <0.05. Standardised effect size is reported as Cohen's *d*, using the pooled standard deviation as the denominator. Qualitative interpretation of *d* was based on the guidelines provided by Hopkins et al. (2009): 0 - 0.19 trivial; 0.20 – 0.59 small; 0.6 – 1.19 moderate; 1.20 – 1.99 large; ≥ 2.00 very large.

Chapter 4: Results

4.1. Training data

Figure I shows a significant difference between testing phases determined by a one-way ANOVA (F=35.46, p=<0.001). Mean swimming volume during the recovery phase (REST) was 645 m/day. Whilst participants were instructed to restrict their training to light swimming (low level aerobic swimming was permitted - see Table IV), 4 participants chose not to swim during this phase. Swimming volume during REST was significantly lower than all other testing phases (p<0.01). Mean daily swimming volume was highest during the competitive preparation-training phase (TRAIN), swimming on average 5393 m/day.

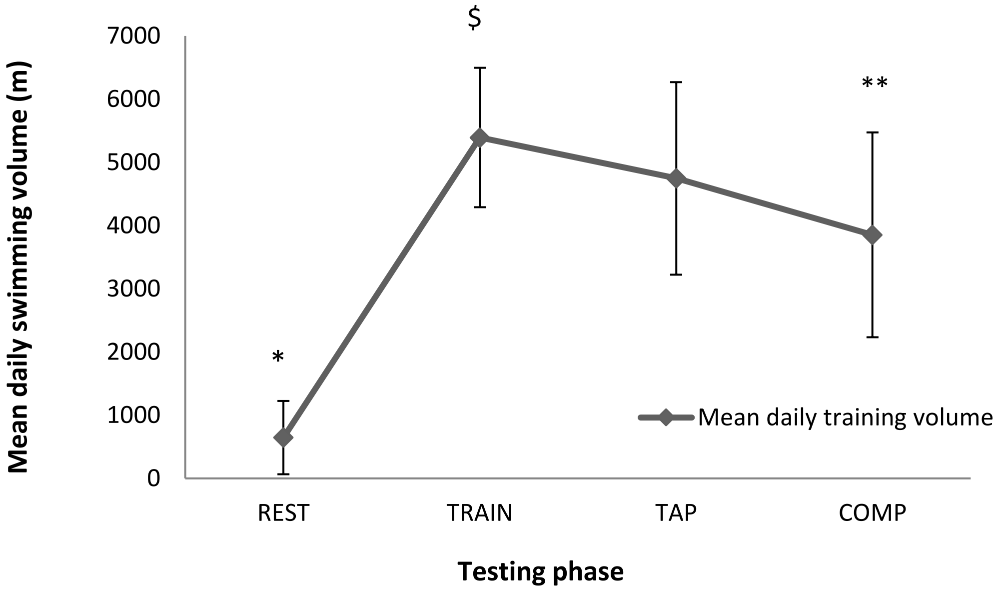

Figure I. Daily swimming volume (m)(Mean ± SD) during individual testing phases

** Significantly lower (p<0.01) than all other testing phases, **significantly lower than TRAIN (p<0.05), $significantly greater (p<0.05) than COMP.*

Tukey’s *post hoc* analysis revealed that swimming volume during TRAIN was significantly greater than swimming volume in competition (COMP) (3854 m/day) (p<0.001) but not the swimming volume during taper (TAP) (4746 m/day)(P=0.068).

Swimming intensity during the REST phase was restricted to a low intensity (aerobic capacity 1 (AEC1)) for those choosing to swim during this phase (see table IV). A one-way ANOVA showed a significant difference between the intensity of testing phases, with Tukey’s post hoc analysis revealing that swimming intensity during REST was significantly lower than all remaining testing phases (p<0.01). During TRAIN, participants swam 94.4% of the cycle at a low intensity (AEC1) whereas 3.6% of the TRAIN cycle was swam in zones 2 and 3 (AEC2 and AEC3), with the remainder focused on aerobic power (AEP). Similarly, 94% of swimming intensity during TAP was low, (AEC1) with 3.5% of total swimming at AEC2 and much of the remainder focused on AEP (1.9%). During COMP, 96.9% of swimming was at AEC1 and the remainder (3.0%) was swum at a very high intensity (Anaerobic Power (ANP)). Details of distribution of swimming intensity are presented in Table V.

Table V. Mean total swimming volume and energy zone breakdown for individual testing phases.

Training Modality	**REST (3-7 days)**		**TRAIN (14-days)**		**TAP (14-days)**		**COMP (3-7 days)**	
	Meters ± SD	**%**	**Meters ± SD**	**%**	**Meters ± SD**	**%**	**Meters ± SD**	**%**
Aerobic - AEC1	3075 ± 2683	100 ± 0.0	70954 ± 12937	94.4 ± 2.9	62591 ± 20619	94.0 ± 3.4	21954 ± 13052	96.9 ± 1.2
Aerobic - AEC2	0 ± 0	0 ± 0	1200 ± 1618	1.6 ± 2.2	1967 ± 1212	3.5 ± 2.3	0 ± 0	0 ± 0
Aerobic - AEC3	0 ± 0	0 ± 0	1750 ± 2006	2.0 ± 2.2	100 ± 346	0.1 ± 0.4	0 ± 0	0 ± 0
Anaerobic - ANC	0 ± 0	0 ± 0	16.6 ± 58	0.03 ± 0.1	16.7 ± 58	0.02 ± 0.1	0 ± 0	0 ± 0
Anaerobic - AEP	0 ± 0	0 ± 0	1500 ± 1240	1.8 ± 1.5	1466 ± 2359	1.9 ± 2.7	0 ± 0	0 ± 0
Anaerobic - ANP	0 ± 0	0 ± 0	83 ± 134	0.1 ± 0.2	300 ± 121	0.5 ± 0.2	700 ± 482	3.0 ± 1.2
Total Aerobic workload	6150 ± 5365	100 ± 0.0 88 *	73904 ± 16561	98.0 ± 7.3	64658 ± 22177	97.6 ± 6.0	21954 ± 13052	97.0 ± 1.2
Total Anaerobic workload	0 ± 0	0 ± 0 *	1600 ± 1432	2.0 ± 1.8	1783 ± 2538	2.4 ± 2.9	700 ± 482	3.0 ± 1.2
Total (M)	3075 ± 2683		75504 ± 15438		66442 ± 21326		22654 ± 13443	

Table V shows the mean TOTAL swimming volume completed in each of the four testing phases (REST, TRAIN, TAP & COMP) and percentage of different training zones - Aerobic capacity 1 (AEC1), Aerobic capacity 2 (AEC2), Aerobic capacity 3 (AEC3), Anaerobic capacity (ANC), Aerobic Power (AEP) and Anaerobic power (ANP). The total aerobic load (Metres) and total anaerobic load (Metres) are also displayed. Total aerobic workload is made up AEC1,2 & 3. Total anaerobic workload is made up of ANC, AEP & ANP. Values are expressed in meters ± Standard deviation (meters) as well as percentage ± standard deviation (%). * represents statistically lower intensity than all remaining testing phases.

4.2. Sleep data

Average measures of sleep parameters for the athletes are presented in Table VI. Time to bed was not significantly different between testing phases (F=0.15, p=0.93) with TRAIN (22:02 ± 00:28), TAP (22:24 ± 00:37), COMP (22:12 ± 00:37) and REST (23:55 ± 00:34) showing limited variability. However, there was a significant difference between testing phases for the time out of bed (F=15.41, p<0.01). Mean time out of bed during REST (09:23 ± 01:18) was significantly later than the remaining three testing phases (TRAIN 07:16 ± 00:23; TAP 07:25 ± 00:21; COMP 07:46 ± 00:36). Total time in bed (TTB) was not significantly different between testing phases (F=1.10, p=0.36) with group means ranging from 542 – 580 minutes between phases.

Table VI shows that the mean total sleep time (TST) during REST was 471 min (± 47), which was not significantly different (p=0.078) from TRAIN (459 ± 44 min), TAP (473 ± 35 min) and COMP (476 ± 42 min). These differences between testing phases were trivial/small (*d* = 0.05 – 0.40). Whilst not significant, sleep onset latency (SOL) showed a trend for differences between conditions (p=0.08). SOL during COMP (27 ± 11 min) was found to be moderately higher than all remaining testing phases. (*d* = 0.7 – 1)

Sleep efficiency (SE) did not significantly differ between conditions (p=0.23) with SE ranging from 82.3% (± 5%) during REST to 85.4% (± 5%) during TAP, and showing trivial/moderate differences between testing phases (*d* = 0 - 0.75). Restfulness (RFN) (activity >1) was found to be similar between the phases (p=0.60), which yielded similar, insignificant (p=0.49), differences to be found for fragmentation index (FI). FI was highest during TRAIN (38 ± 7 min) and lowest during lowest during REST (34 ± 6 min), with the difference found to be moderate (*d* = 0.61).

Subjective sleep quality that was recorded by the athletes showed no difference (p=0.45) between TRAIN (7.3 ± 0.9), TAP (7.7 ± 0.8), COMP (7.0 ± 1.4) and REST (7.3 ± 1.1). The total daily nap time showed no significant effect across the four testing phases (p=0.21). The increase in nap time from REST (6 ± 10 min) to TRAIN (23 ± 20 min) was the most notable, with the increase found to be moderate (*d* = 1.13).

Figure II shows the positive correlation between SOL and total daily nap time across the conditions (r=0.369, p=0.01). Mean SOL was at its lowest during REST (17 ± 9 min), which corresponded with the lowest average daily nap time of the four testing phases (6 ± 10 min per day). Similarly, mean SOL was at its highest during COMP at 27 (± 11) min, with mean daily naptime also being at the highest during COMP at 23 (± 20) min (see table VI).

Screen time before bed (mins) showed no correlation with either RFN (r=0.222, p=0.13), TST (r=0.228, p=0.12) or SOL (r=-0.127, p=0.39). Ambient bedroom temperature (T_a) (°C) showed no correlation with either RFN (r=-0.094, p=0.52) or TST (r=-0.150, p=0.31). However, Figure III shows the positive correlation between T_a and SOL (r=0.398, p<0.01). Mean SOL was at its highest during TRAIN (27 ± 11), corresponding with the highest T_a (18.6 ± 1.4°C).

Figure IV shows each participants individual mean data for the four testing phases, including the following measured variables; SOL, TST, SE, FI, screen time exposure before bed and daily nap time. It can be seen that certain individuals have varying results when compared to the group mean and standard deviation reported in Table VI. Specific individual examples include SOL values above 50 mins during COMP and TRAIN, TST values that are less than 400 mins during COMP and TRAIN, a SE score of 71% during rest and a FI score of 55% during COMP.

Table VI. Sleep data from wrist actigraph watches and sleep diaries for individual testing phases.

Actiwatch	**REST** **Mean** ± SD (min – max)	**TRAIN** **Mean** ± SD (min – max)	**TAP** **Mean** ± SD (min – max)	**COMP** **Mean** ± SD (min – max)	**F-Value**	**P-value**
Sleep onset latency (SOL) (min)	17 ± 9 (9 -34)	19 ± 12 (5 – 20)	19 ± 6 (10 – 34)	27 ± 11 (9 – 49)	2.42	0.079
Time spent asleep (AST) (min)	471 ± 47 (410 – 570)	459 ± 44 (387 – 524)	473 ± 35 (412 – 536)	476 ± 42 (393 – 539)	0.37	0.778
Sleep efficiency (SE) (%)	82 ± 5 (71 – 89)	85 ± 5 (78 – 93)	85 ± 5 (75 – 90)	82 ± 3 (78 – 87)	1.48	0.233
Restfulness (RFN) (min)	158.9 ± 40.3 (110 – 237)	180.6 ± 44.8 (106 – 271)	176 ± 39 (98 – 245)	180.0 ± 44.6 (105 – 236)	0.63	0.602
Fragmentation index (FI) (%)	34 ± 6 (24 – 44)	38 ± 7 (25 – 52)	37 ± 7 (22 – 47)	37 ± 8 (23 – 55)	0.83	0.487
Time got into bed (hh:mm)	23:55 ± 00:54 (22:17 – 02:15)	22:22 ± 00:28 (21:57 – 23:10)	22:24 ± 00:37 (21:30 – 23:28)	22:12 ± 00:37 (21:33 – 23:22)	0.15	0.928
Time got out of bed (hh:mm)	09:23 ± 01:18 * (07:53 – 11:46)	07:25 ± 00:23 (06:45 -08:12)	07:46 ± 00:21 (07:08 – 08:14)	07:16 ± 00:36 (07:00 – 08:59)	15.41	<0.001
Sleep diary						
Total daily nap time (min)	6 ± 10 (0 -30)	23 ± 20 (0 – 59)	12 ± 16 (0 – 45)	25 ± 24 (0 – 68)	1.59	0.212
Subjective sleep score (1-10)	7.3 ± 1.1 (6.1 – 10.0)	7.3 ± 0.9 (5.5 – 8.7)	7.7 ± 0.8 (5.9 – 9.0)	7.0 ± 1.4 (4.6 – 9.8)	0.90	0.450
Screen time before bed (min)	134 ± 52 (30 – 197)	168 ± 54 (51 – 244)	167 ± 40 (91 – 229)	129 ± 55 (36 – 230)	1.98	0.131
Ambient bedroom temperature (^{O}C)	18.3 ± 1.7 (16.2 – 22.8)	18.1 ± 1.6 (16.3 – 20.7)	17.9 ± 1.3 (16.1 – 20.5)	18.6 ± 1.4 (16.3 – 20.8)	0.37	0.772

*Values are expressed as mean ± standard deviation, with individual ranges expressed in brackets below * represents statistically different from all remaining testing phases (p<0.05)*

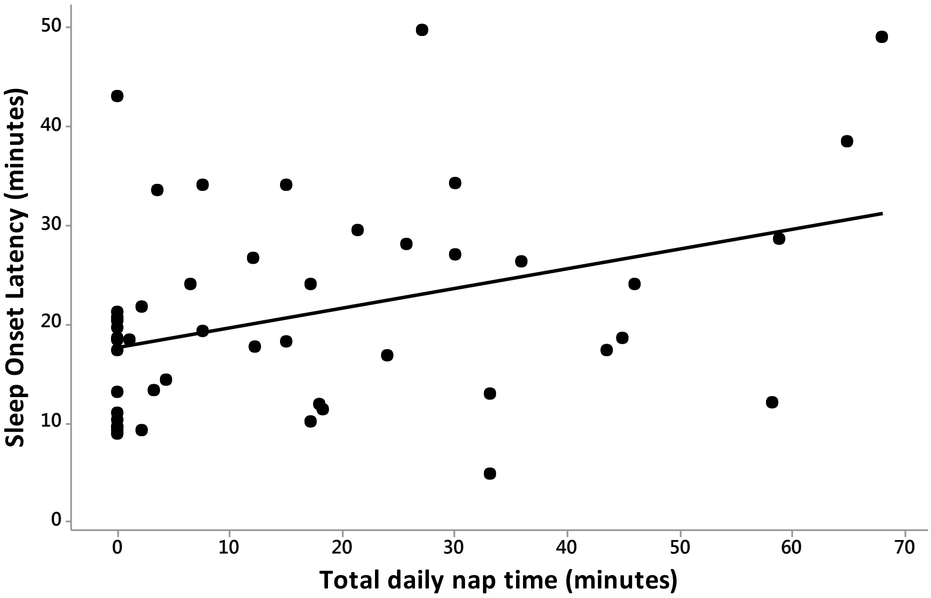

Figure II. Correlation between sleep onset latency (SOL) and total daily nap time.

The scatterplot shows the positive correlation (r=0.369, p=0.01).

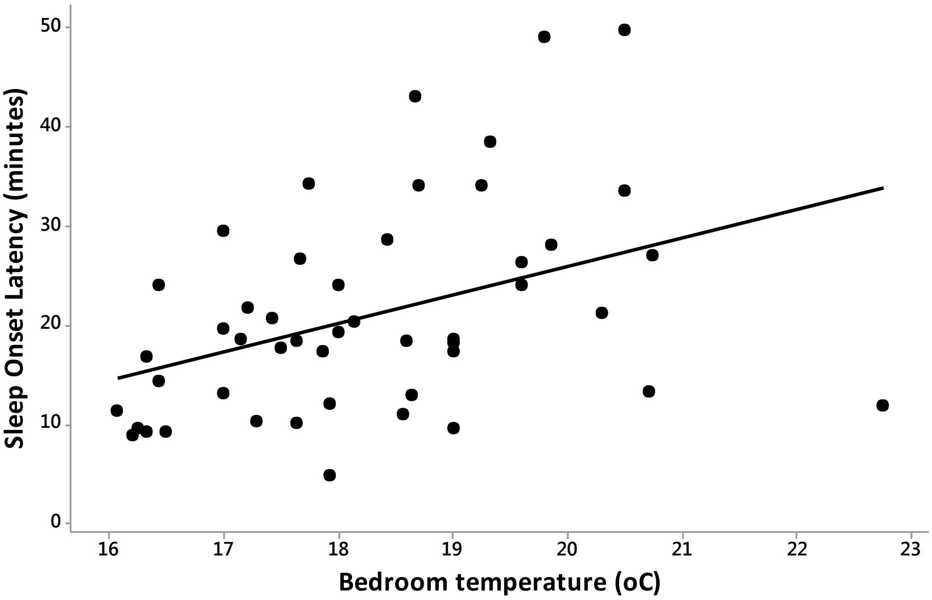

Figure III. Correlation between sleep onset latency (SOL) and ambient bedroom temperature (T_a)

The scatterplot shows the positive correlation (r=0.398, p<0.01).

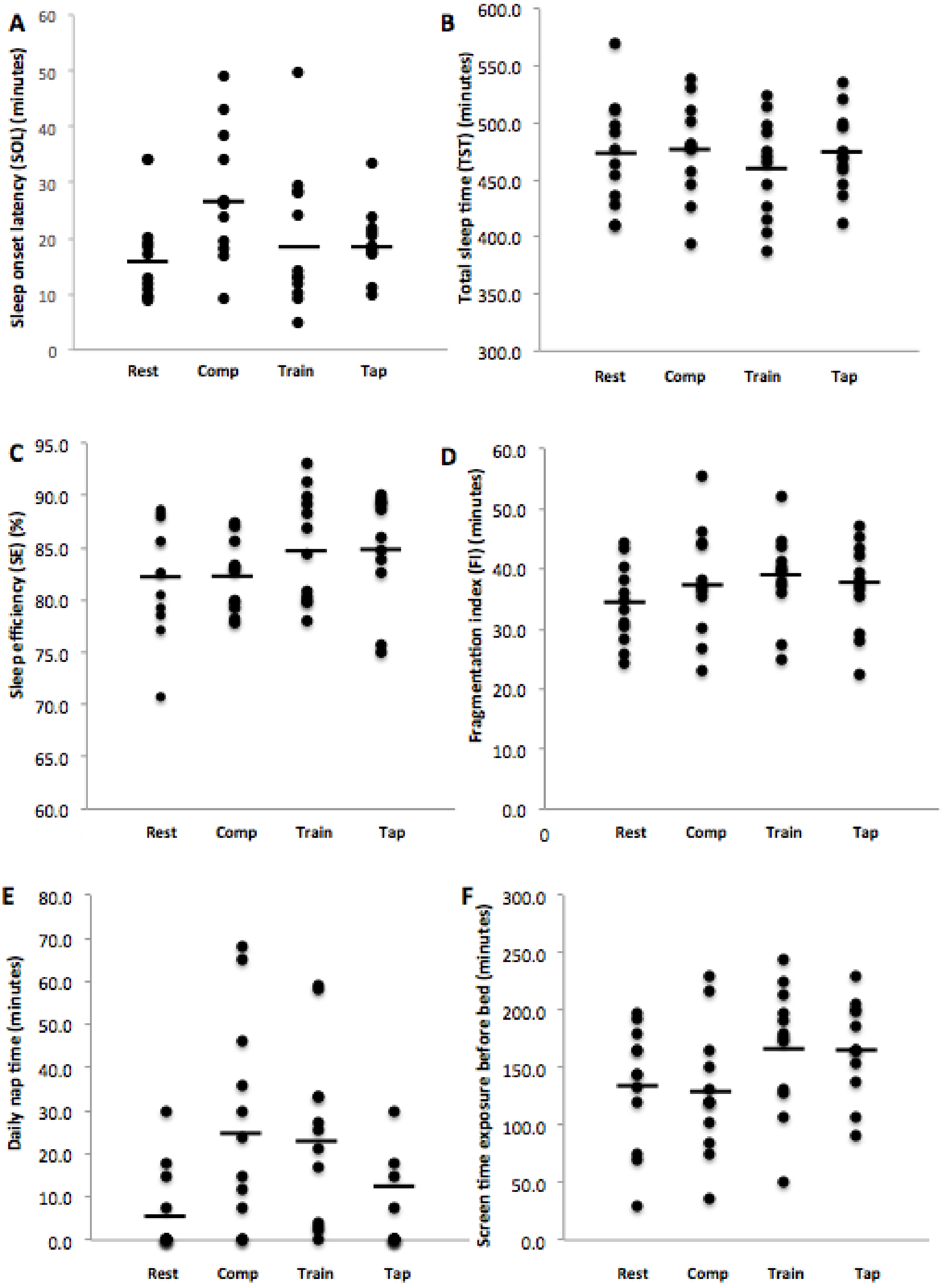

Figure IV. Mean individual participant sleep variable data displayed for each testing phase (REST, COMP, TRAIN and TAPER) along with the group mean for each testing phase. A) Sleep onset latency (SOL) B) Total sleep time (TST) C) Sleep efficiency (SE) D) Fragmentation index (FI) E) Daily nap time F) Screen time exposure before bed.

Figure IV shows the mean individual participant sleep variables throughout the 4 testing phases. Whilst there are individual outliers in some of the measured sleep variables it is important to note that the outliers are not the same participant across the sleep variables or across testing phases (REST, COMP, TRAIN and TAPER) within each variable. For example during TRAIN participant 10 had a SOL of 50 minutes, markedly higher than the group mean. However, during REST, COMP and TAP participant 10 had a SOL of 17 min, 24 min and 34 minutes respectively. Similarly, during REST participant 12 had a TST of 570 minutes but during COMP, TRAIN and TAP achieved 427 min, 427 min and 412 minutes of TST respectively.

Whilst gender differences in sleep parametres was not a primary aim of this study, other than a significant difference between genders (p=0.03) for daily nap time during TAP, all measured sleep variables showed no significant difference between genders. A two-way Anova found there to be no interaction effect between any sleep variable and gender (p>0.05).

Chapter 5: Discussion

5.1. Summary of findings

The aim of this study was to examine whether there would be any variance in the sleep profile of elite swimmers during their training (TRAIN), taper (TAP) and competition (COMP) phases, when the results were compared to a phase of rest (REST). In alignment with normative values, the athletes achieved a grouped average of 7.85 h sleep during REST, 7.93 h during COMP, 7.66 h during TRAIN and 7.88 h of sleep during TAP. However, despite a statistically significant difference in swimming volume (metres) and swimming intensity undertaken across the 4 testing phases, there was no statistical difference in the tested sleep parameters. There was a trend for sleep onset latency (SOL) to increase during the competition phase ($p=0.08$, $d= 0.70 - 1$) when compared to the other phases. We also observed a moderate positive correlation between SOL and ambient bedroom temperature (T_a) ($r=0.40$, $p<0.01$), and also between SOL and total nap time during the day (minutes) ($r=0.37$, $p=0.01$).

5.2. Sleep profiles across all testing phases

When examining the grouped average sleep data within this study we found similar sleep profiles in both training phases but we did not find any evidence of disturbed sleep in any of the training phases. Driver and Taylor (2000) previously suggested that an increase in workload at an anaerobic intensity causes sleep disruption. The authors state that high intensity exhaustive exercise cause sleep disturbance through a decrease in rapid eye movement (REM) sleep and an increase in bouts of wakefulness. Hausswirth et al. (2014) also show that sleep efficiency (SE) and sleep duration were reduced in functionally overreached male triathletes during a phase of over training. Whilst we attempted to examine sleep profiles in two distinct phases where training volume and intensity were different, the mean daily swimming volume during TRAIN was also only 647 m higher than TAP, corresponding to a 12% difference. In addition, the difference in the percentage of anaerobic workload between TRAIN and TAP was negligible (0.4%). Consequently, though the differences in training volume and intensity were statistically significant, the small variations in workload are arguably practically insignificant and unlikely to be enough to cause any changes in any of the sleep parameters. It is also unlikely that any symptoms of significant overreaching occurred, providing a plausible explanation as to why subsequent sleep disturbances were not found in this study. The assumption that the swimmers were not overreached in the TRAIN phase is supported by evidence, which shows that the athletes had similar sleep profiles to those observed during the REST phase. It is likely therefore that the predetermined training workload was sufficient to induce the functional and morphological adaptations necessary for improvement without overreaching. However, it is also possible that the 2 week training period was not long enough to discern any noticeable changes in sleep. Mackinnon et al. (1997) state that intensified training in swimmers is generally well tolerated but that symptoms of overreaching appear between 2 - 4 weeks of intensified training.

5.3. Interaction between competition and sleep onset latency

Within the existing body of athlete sleep research and predominant trends associated with that, there is a strong focus on the effect that competition has on the sleep profiles of athletes. Although we found a tendency for a moderate increase in SOL during COMP (p=0.08, *d*= 0.70 – 1), no significant differences between testing phases were observed and there were no statistically significant changes in the other sleep parameters examined. These findings are not in accordance with previous studies that have assessed sleep quality and quantity with sleep and cognitive functioning questionnaires (Erlacher et al., 2011; Juliff, Halson and Peiffer, 2015). Erlacher et al. (2011) and Juliff, Halson and Peiffer (2015) found that that athletes slept worse than normal during competition and that a high percentage of the athletes who suffered from disturbed sleep attributed this to problems with SOL. Although the present study found the SOL of the swimmers to be moderately higher during COMP than in the 3 remaining testing phases, these differences were not statistically significant. A potential explanation for the difference in findings between the present study and those of Erlacher et al. (2012) and Juliff, Halson and Peiffer (2015) is the method for measuring changes in SOL. The subjective nature and reliance on recall/memory when using questionnaires to assess sleep variables, in addition to the challenge for participants to interpret their own SOL, opens the data up to individual bias. Using more accurate wristwatch actigraphy in this study, however, alleviated some of this potential bias (Erlacher et al., 2011; Leger, Metlaine and Choudat, 2005). Certainly, it is possible that the perception of poor sleep quality and quantity is greater when compared to those measured by wristwatch actigraphy.

It is also important to consider the individual means of SOL. Whilst the difference in grouped means are likely to have very little practical implications, the outliers within the group eg. Individual mean SOLs during competition of 39, 43 and 49 mIns there would likely be physiological implications incurred for these athletes. The substantial individual variations for SOL suggest that some of the athletes with shorter SOL's may be trained in sleep strategies to offset the nerves experienced during competition, and those with longer SOL's suffer with a pre competition anxiety to a greater degree (Juliff, Halson and Pieffer, 2015).

5.4. Ambient bedroom temperature

The results within this study found a moderate positive correlation between SOL and ambient bedroom temperature (T_a). These findings were of interest since it is conceivable that the temperate conditions experienced by most athletes in the study would unlikely impact on any of the sleep parameters. Research by Muzet et al. (1983) found that a T_a range from 13^oC - 23^oC caused no significant change to radiant temperature and subsequently no significant impact on the SOL of participants in a parameter controlled sleep environment. Although unknown, we speculate that evening exercise sessions could increase evening core temperature and increase the swimmers' sensitivity to T_a in relation to sleep. It is plausible that an increased environmental temperature in combination to the increased insulation of bedding supresses the necessary reduction in core temperature, responsible for influencing melatonin secretion and subsequently promoting SOL (Mizuno and Mizuno, 2012). Although further studies are required to assess the relationship between core temperature, T_a and sleep parameters, this research may prove useful to provide guidelines on T_a ranges for elite athletes looking to maximise sleep hygiene and maintain or reduce SOL.

5.5. Screen time exposure preceding sleep

In the present study screen time before bed showed no correlation to any of the sleep variables, including SOL but there has been conflicting findings in previous research examining the effects of exposure to bright LED light on sleep variables. Chang et al. (2014) found that SOL was significantly higher when participants were subjected to 4 hours of reading from a light emitting (LE) eBook vs controlled conditions. Although there was no note of a significant difference between total sleep time (TST) or SE, the authors did find that participants subjected to an LE eBook felt sleepier in the morning and sleep inertia was significantly longer than it was under controlled conditions. Higuchi et al. (2005) found that exposure to bright LED lights preceding sleep only impacted sleep variables when the LED source was an exciting computer game, rather than a source with a low mental load. Although the authors found no significant differences between the low mental load LED source and controlled conditions, only 1 night was examined so the findings are not truly representative of successive nights of LED exposure.

Electronic media/blue light exposure within this study was notably shorter than in previous studies and was most likely broken up by other activities throughout the evening, although we have no statistical data support this. Exposure ranged from 2.15 ± 0:55 h – 2.8 ± 0:54 h across testing phases. However, since we did not control screen time, it is difficult to interpret the effect that the screen time before bed had on sleep variables. Heo et al. (2017) found that exposure to conventional LED screens in comparison to supressed blue light decreased both user sleepiness and confusion-bewilderment. This, combined with previously mentioned literature suggesting that using LED devices with a suppressed blue light setting, could prove a useful future intervention to improve the sleep hygiene of athletes but more corroborative research is needed.

5.6. Sleep quality across testing phases

This study's findings show that the group mean SE was consistent across all 4 testing phases ranging between 82% to 85%. SE of healthy young adults is typically >90% (O'Connor and Youngstedt, 1995) and although our findings are notably lower than this, they were in accordance with those documented by Leeder et al. (2012) when examining the sleep profiles of elite athletes. Our results were also greater than those by Sargent, Halson and Roach (2014), who examined elite swimmers on training camp. Consequently, the combined findings show that the SE of elite athletes is lower when compared to non-athletes.

SE is calculated as total sleep time (TST) as a percentage of total time in bed (TTB), and therefore can be influenced by SOL as well as time in bed. Within this study we identified a significant change in time out of bed during REST but found no change in SE. A plausible rationale could be that TTB was not significantly different between conditions. Yet it is also worth noting that the participants in this study were specifically asked to differentiate between 'the time got into bed' and 'the time attempted to go to sleep' in the sleep diaries issued. This was in an effort to alleviate any potential discrepancy surrounding the true value of SOL. Taken together, our findings demonstrate that elite athletes have reduced SE compared to healthy controls but conceivably due to maintenance of AST and TTB, they did not change significantly in different conditions. However, it is important to consider between individual differences for SE. When examining figure IV it can be seen that there is a substantial range in individual SE scores across testing phases. For example one participant had a mean SE of 71% during REST and another 75% during TAP. This could be attributed to increased SOL, less TST, or a combination of the two. These findings further confirm the individuality of sleep and its variables; of significant importance for coaches working towards individual approaches for athlete sleep hygiene.

Fragmentation index (FI) and restfulness (RFN) did not significantly change throughout the course of the study, which indicate that sleep quality was maintained in each phase. It cannot be ruled out, however, that individual sleep stages may have been effected during the different phases of the study. Taylor, Rogers and Driver (1997) found that SOL, TST and REM sleep were comparable in competitive female swimmers in the onset of peak training, peak training and taper. Through the use of polysomnography (PSG) they found that restorative slow wave sleep (SWS) was significantly reduced following taper, as was the number of movements during sleep. Yet since RFN (activity>1) did not change between the phases within this study, we speculate that it is likely that stage 3 sleep was similar between TRAIN and TAP and that this was possibly due to lack of differences in overall volume and intensity distribution.

5.7. Sleep quantity across testing phases

The athletes tested within this study achieved on average 7.85 h sleep during REST, 7.93 h during COMP, 7.66 h during TRAIN and 7.88 h sleep during TAP. This small difference in AST across testing phases resulted in the swimmers consistently achieving sleep durations, which are in keeping with the generalised adult normative values of 7-8 hours per night (Ferrara and Genaro, 2001, O’Connor and Youngstedt, 1995; Van Dogen et al., 2003). Maslowsky and Ozer

(2013) have shown that young adults are achieving on average 8.1 hours of sleep per night. In accordance with their findings, it can be deduced that although these time differences may not be practically significant, the swimmers in this study were potentially below an age matched population of non-sporting individuals. However, individual case studies where a participant achieved significantly less sleep than the group mean could incur physiological implications. From the results it can be seen that there are athletes that achieved less than 6.5 hours of sleep during both training and competition. These athletes will undoubtedly be more at risk from suffering with symptoms associated with chronic sleep loss (Sargent et al., 2014; Irwin et al., 1994; Irwin et al., 1996)

Sargent, Halson and Roach (2014) found that on training days 5.4 h was achieved and on rest days 7.1 h of sleep achieved. The authors attributed the reduced time in bed to early wake up times for 06:00 training start time and the inability to go to sleep any early in the evening prior to training to be the cause of the low sleep durations. Within this study we observed later wake up times with the mean get up times of 07:25, 07:46 and 07:16 in TRAIN, TAP and COMP phases respectively. This additional sleep was made possible due to the later start times of morning swim sessions (between 07:30 – 08:30). The comparable bed times of the swimmers in the present study to that of Sargent, Halson and Roach (2014) but later wake up times take steps to explain the differences in sleep durations between the two studies. We propose that this additional time spent sleeping in a morning was why the participants mean sleep durations from the present study fall into the ‘normative’ range.

5.8. Limitations within the study

Irrespective of the significant findings in this study there are some limitations that must be considered. Firstly, whilst a power analysis of the study revealed that the 12 participants were sufficient for >90% statistical power, we were unable to recruit additional participants to further increase the power of the study due to the size of the training squad from which participants were selected (n=16 total). However, by selecting participants from a singular training squad the training times, training sets, total training volumes and overall mesocycle goals were kept more consistent than if the athletes were recruited from multiple training squads. With the view to provide more practical conclusions from the results of the study effect sizes (reported as Cohen's *d*) between testing phases were also reported to quantify the size of the effect rather than the statistical difference alone.

Secondly, whilst the effect of gender on sleep variables was examined it is difficult to draw valid conclusions from this data, as the female group was underpowered, again due to the limited availability of female participants within the training squad examined.

Thirdly, the study was carried out in a field-based environment. Whilst this provides results that are extremely practically valid, there were uncontrolled variables that may have influenced the findings, in addition to the intensity and volume of training. Such factors include caffeine, supplementation, alcohol, daily naptime, oral contraceptives, and seasonal effects. The field study design also resulted in testing phases having to be partially dictated by the coaching staff that designed the micro and mesocycles in preparation for the 2016 Rio De Janeiro Olympic Games trials and for that reason, the duration of REST and COMP were different to the 14 day duration of both TRAIN and TAP. Yet as the means were calculated for each testing phase prior to running statistical analysis, this limitation was to a great extent, mediated. It would also be very rare for elite swimmers to be subjected to extended periods of competition and rest so the testing phases in the present study are truly reflective of swimmers macrocycle design.

The results from this study were compared to population norms and previous literature, rather than to a matched control group. However, the nature of using elite athletes meant that it was not viable to recruit from the same population and expect the control group to forfeit both taper and/or competition. Finally, expansive subjective data that would have otherwise enabled a greater rounded understanding of athlete sleep, was to a degree limited. Through the inclusion of a Pittsburgh Sleep Quality Index (PSQI), Daily Analyses of Life Demands for Athletes (DALDA), and subjective scores for morning sleepiness, measures of cognition and mood states to accompany the objective data collected could have been obtained. Although this would have added a different and potentially enhanced dimension to the study, following a pilot study carried out on a subsection of the athletes, the overall compliance was compromised. This was due to the added workload of forms to fill in addition to sleep diaries and use of the actigraph watches, therefore the decision was made not include these.

Chapter 6: Conclusion and future research

6.1. Conclusion

To our knowledge this is the first study to examine the sleep profiles of athletes from a solitary sport and the same training group during training, taper and competition, and to compare the results to a control condition in the same group of athletes. The novelty of the study is further enhanced through the combined use of both objective wrist actigraph watches and subjective sleep diary measures, thus overcoming associated limitations with subjective measures alone.

The findings within this study suggest that the average sleep parameters of elite swimmers show no significant variation between phases of rest (REST), training (TRAIN), taper (TAP) or competition (COMP). Whilst there were individual outliers for certain sleep variables these individuals were not found to suffer chronically across multiple phases of testing. Both group mean sleep quality and quantity were consistent during TRAIN, TAP and COMP and were comparable to a controlled rest phase.

Aligning with previous findings that competition predominantly effects sleep onset latency (SOL), we found that SOL did moderately increase during competition although the increase was not statistically significant. As well, there were no subjective measures of mood states to support this within the study so the notion that SOL increases during competition was not proven. Equally, the increase in SOL showed a moderate positive correlation to both ambient bedroom temperature (T_a) and daily naptime and as a result, it would be difficult to attribute to pre-competition anxiety alone. Additionally, although training volume and intensity were significantly higher when compared to a phase of rest, we believe that the phase of training was sufficient to induce the functional and morphological adaptations necessary for improvement but not too intense as to cause sleep disturbances that are often associated with overreaching. This notion was supported by the lack of contrast in intensity and volume between training and taper phases, and the consistent sleep profiles between phases of training and rest.

In a sport such as swimming where early session start times are common practice, it was found that the offset of training times as proposed by Sargent, Halson and Roach (2014) allowed the swimmers in this study to achieve sleep quantities that are in keeping with the normative 7-8 h per night and potentially offset disturbed sleep (Ferrara and Genaro, 2001, O'Connor and Youngstedt, 1995; Van Dogen et al., 2003). However, coaches should also closely monitor each athlete's sleep independently as this study found substantial individual variations in certain sleep variables, stressing the need for individual analysis of sleep. In order for coaches to ensure their athletes have the best chance at achieving optimal sleep and recovery, they could look to both offset early morning training times by 90-120 mins where possible and design training phases that provide the stimulus for adaptation but not so much so that overreaching is induced. The findings suggest that this could alleviate reductions in immune function, cognitive capacity and muscle recovery associated with reduced sleep. In order to promote optimal evening sleep, athletes should closely monitor the effect that daytime napping has on evening SOL and also closely monitor evening screen time and T_a to improve sleep hygiene.

6.2. Directions for future research

The complexity of sleep in the transition between intensified training through a period of taper leading into competition is still unclear and future research should look to investigate this. The current study found considerable individual variations for sleep variables, and as such future research should implement interventions to sleep on an individual level rather than a group level. Based upon the finding of this study there is also scope for future research into the relationship between core and ambient temperature in the sleep environment, and LED exposure preceding sleep would provide athletes with more information on how to improve sleep hygiene thus maximising recovery. In order to better understand the effect of training phases on athlete sleep profiles and validate or challenge existing studies, more contemporary research accounting for individual training volume and intensity, and controlling variables such as nap duration, caffeine intake and screen time exposure would allow for more comprehensive findings to be obtained.

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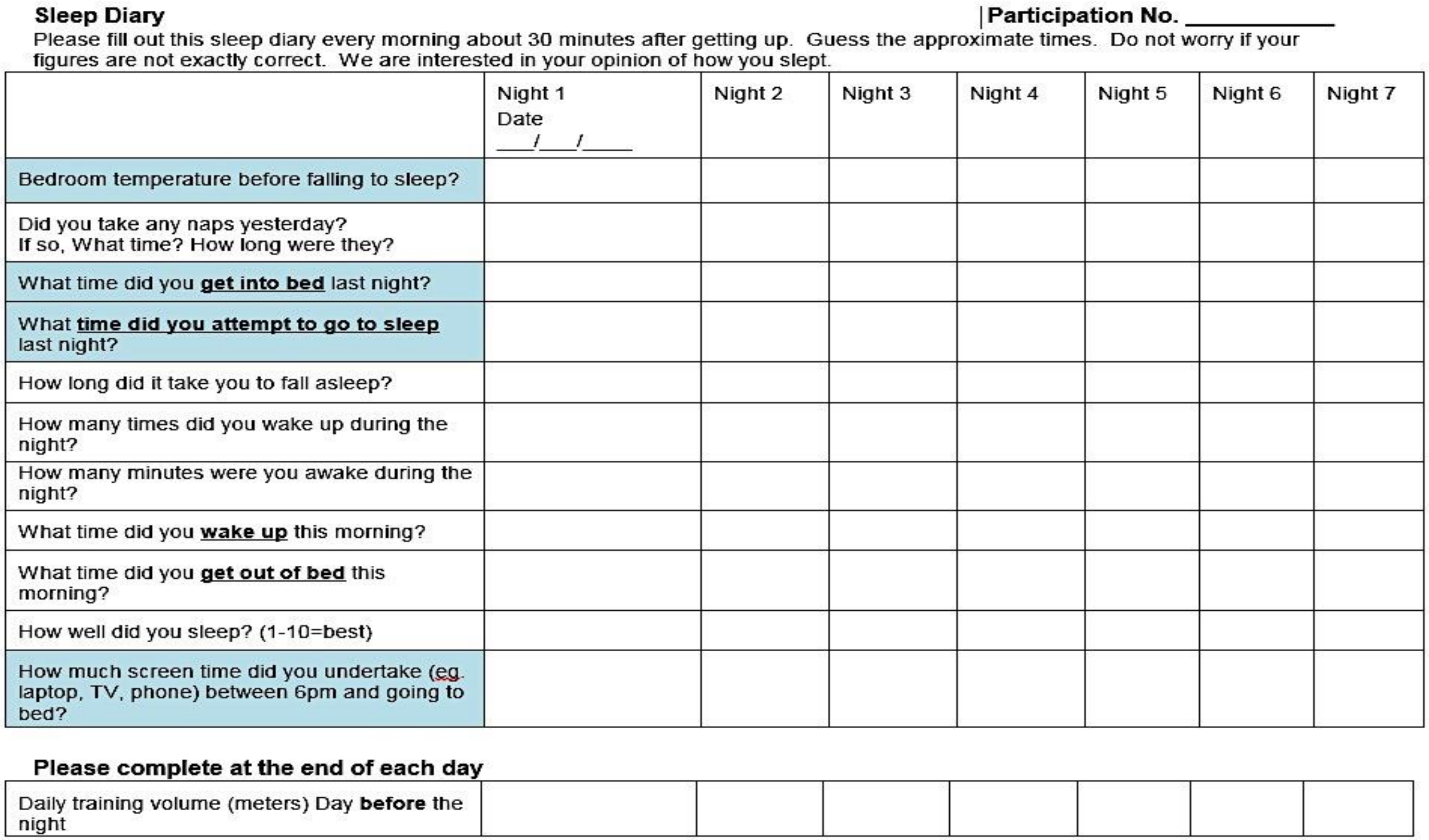
Appendices

Appendix 1 Sleep diary



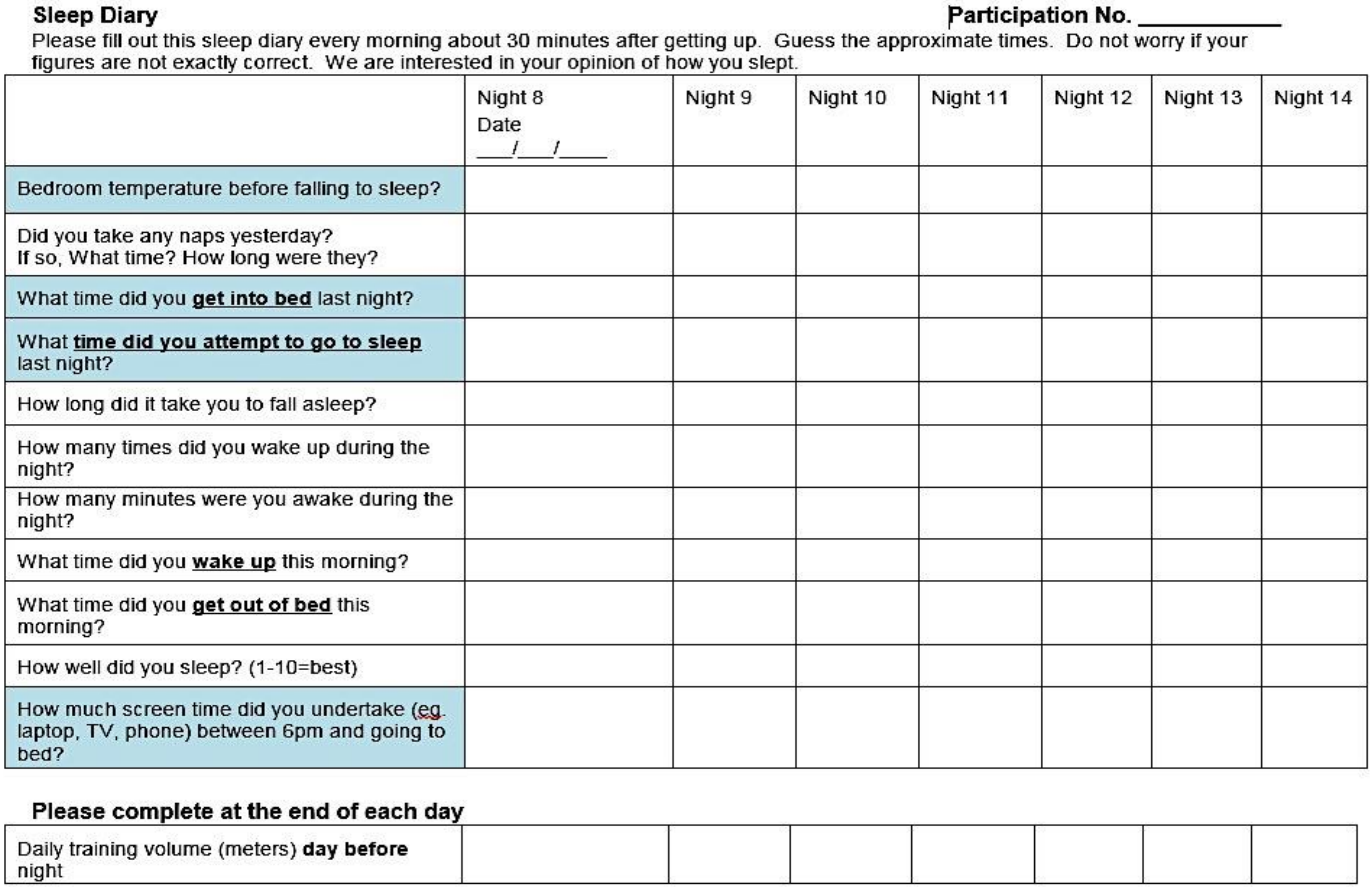
Sleep Diary |**Participation No. ____________**

Please fill out this sleep diary every morning about 30 minutes after getting up. Guess the approximate times. Do not worry if your figures are not exactly correct. We are interested in your opinion of how you slept.

	Night 1 Date ___/___/____	Night 2	Night 3	Night 4	Night 5	Night 6	Night 7
Bedroom temperature before falling to sleep?							
Did you take any naps yesterday? If so, What time? How long were they?							
What time did you **get into bed** last night?							
What **time did you attempt to go to sleep** last night?							
How long did it take you to fall asleep?							
How many times did you wake up during the night?							
How many minutes were you awake during the night?							
What time did you **wake up** this morning?							
What time did you **get out of bed** this morning?							
How well did you sleep? (1-10=best)							
How much screen time did you undertake (eg. laptop, TV, phone) between 6pm and going to bed?							

Please complete at the end of each day

Daily training volume (meters) Day **before** the night							



Sleep Diary **Participation No. ___________**

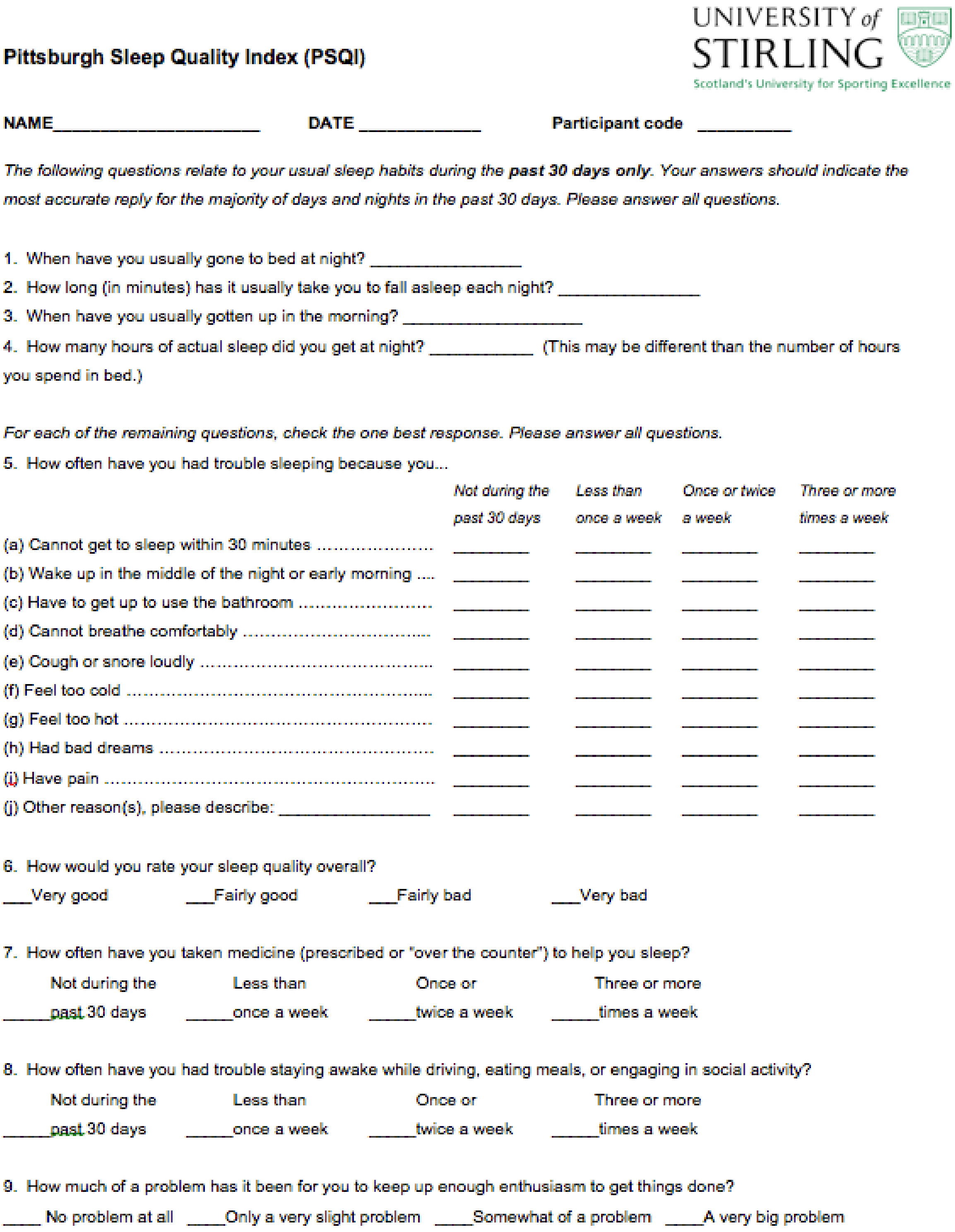
Please fill out this sleep diary every morning about 30 minutes after getting up. Guess the approximate times. Do not worry if your figures are not exactly correct. We are interested in your opinion of how you slept.

	Night 8 Date ___/___/_____	Night 9	Night 10	Night 11	Night 12	Night 13	Night 14
Bedroom temperature before falling to sleep?							
Did you take any naps yesterday? If so, What time? How long were they?							
What time did you **get into bed** last night?							
What **time did you attempt to go to sleep** last night?							
How long did it take you to fall asleep?							
How many times did you wake up during the night?							
How many minutes were you awake during the night?							
What time did you **wake up** this morning?							
What time did you **get out of bed** this morning?							
How well did you sleep? (1-10=best)							
How much screen time did you undertake (eg. laptop, TV, phone) between 6pm and going to bed?							

Please complete at the end of each day

Daily training volume (meters) **day before** night							

Appendix 2 Pittsburgh Sleep Quality Index



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Pittsburgh Sleep Quality Index (PSQI)

NAME______________________ **DATE** ____________ **Participant code** __________

*The following questions relate to your usual sleep habits during the **past 30 days only**. Your answers should indicate the most accurate reply for the majority of days and nights in the past 30 days. Please answer all questions.*

1. When have you usually gone to bed at night? ________________
2. How long (in minutes) has it usually take you to fall asleep each night? _______________
3. When have you usually gotten up in the morning? ___________________
4. How many hours of actual sleep did you get at night? ___________ (This may be different than the number of hours you spend in bed.)

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

5. How often have you had trouble sleeping because you...

	Not during the past 30 days	*Less than once a week*	*Once or twice a week*	*Three or more times a week*
(a) Cannot get to sleep within 30 minutes …………………	________	________	________	________
(b) Wake up in the middle of the night or early morning ….	________	________	________	________
(c) Have to get up to use the bathroom ……………………	________	________	________	________
(d) Cannot breathe comfortably ……………………………	________	________	________	________
(e) Cough or snore loudly ……………………………………	________	________	________	________
(f) Feel too cold ………………………………………………	________	________	________	________
(g) Feel too hot ………………………………………………	________	________	________	________
(h) Had bad dreams …………………………………………	________	________	________	________
(i) Have pain …………………………………………………	________	________	________	________
(j) Other reason(s), please describe: ________________	________	________	________	________

6. How would you rate your sleep quality overall?

___Very good ___Fairly good ___Fairly bad ___Very bad

7. How often have you taken medicine (prescribed or "over the counter") to help you sleep?

_____Not during the past 30 days _____Less than once a week _____Once or twice a week _____Three or more times a week

8. How often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

_____Not during the past 30 days _____Less than once a week _____Once or twice a week _____Three or more times a week

9. How much of a problem has it been for you to keep up enough enthusiasm to get things done?

____ No problem at all ____Only a very slight problem ____Somewhat of a problem ____A very big problem

Appendix 3 Morningness-Eveningness Questionnaire (MEQ)

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
Self-Assessment Version (MEQ-SA)[1]

Participant number: _____________ Date: __________

For each question, please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks.

1. *Approximately* what time would you get up if you were entirely free to plan your day?

[5] 5:00 am – 6:30 am *(05:00–06:30 h)*
[4] 6:30 am – 7:45 am *(06:30–07:45 h)*
[3] 7:45 am – 9:45 am *(07:45–09:45 h)*
[2] 9:45 am – 11:00 am *(09:45–11:00 h)*
[1] 11:00 am – 12 noon *(11:00–12:00 h)*

2. *Approximately* what time would you go to bed if you were entirely free to plan your evening?

[5] 8:00 pm – 9:00 pm *(20:00–21:00 h)*
[4] 9:00 pm – 10:15 pm *(21:00–22:15 h)*
[3] 10:15 pm – 12:30 am *(22:15–00:30 h)*
[2] 12:30 am –1:45 am *(00:30–01:45 h)*
[1] 1:45 am – 3:00 am *(01:45–03:00 h)*

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

[4] Not at all
[3] Slightly
[2] Somewhat
[1] Very much

---

[1] Some stem questions and item choices have been rephrased from the original instrument (Horne and Östberg, 1976) to conform with spoken American English. Discrete item choices have been substituted for continuous graphic scales. Prepared by Terman M, Rifkin JB, Jacobs J, White TM (2001), New York State Psychiatric Institute, 1051 Riverside Drive, Unit 50, New York, NY, 10032. January 2008 version. Supported by NIH Grant MH42931. *See also:* automated version (AutoMEQ)at www.cet.org. Horne JA and Östberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. International Journal of Chronobiology, 1976: 4, 97-100.

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
Page 2

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?

[1] Very difficult
[2] Somewhat difficult
[3] Fairly easy
[4] Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?

[1] Not at all alert
[2] Slightly alert
[3] Fairly alert
[4] Very alert

6. How hungry do you feel during the first half hour after you wake up?

[1] Not at all hungry
[2] Slightly hungry
[3] Fairly hungry
[4] Very hungry

7. During the first half hour after you wake up in the morning, how do you feel?

[1] Very tired
[2] Fairly tired
[3] Fairly refreshed
[4] Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

[4] Seldom or never later
[3] Less that 1 hour later
[2] 1-2 hours later
[1] More than 2 hours later

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
Page 3

9. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 am *(07-08 h).* Bearing in mind nothing but your own internal “clock,” how do you think you would perform?

[4] Would be in good form
[3] Would be in reasonable form
[2] Would find it difficult
[1] Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

[5] 8:00 pm – 9:00 pm *(20:00–21:00 h)*
[4] 9:00 pm – 10:15 pm *(21:00–22:15 h)*
[3] 10:15 pm – 12:45 am *(22:15–00:45 h)*
[2] 12:45 am – 2:00 am *(00:45–02:00 h)*
[1] 2:00 am – 3:00 am *(02:00–03:00 h)*

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your “internal clock,” which one of the four testing times would you choose?

[6] 8 am – 10 am *(08–10 h)*
[4] 11 am – 1 pm *(11–13 h)*
[2] 3 pm – 5 pm *(15–17 h)*
[0] 7 pm – 9 pm *(19–21 h)*

12. If you got into bed at 11 pm *(23 h),* how tired would you be?

[0] Not at all tired
[2] A little tired
[3] Fairly tired
[5] Very tired

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
Page 4

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

[4] Will wake up at usual time, but will not fall back asleep
[3] Will wake up at usual time and will doze thereafter
[2] Will wake up at usual time, but will fall asleep again
[1] Will not wake up until later than usual

14. One night you have to remain awake between 4-6 am *(04-06 h)* in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

[1] Would not go to bed until the watch is over
[2] Would take a nap before and sleep after
[3] Would take a good sleep before and nap after
[4] Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal “clock,” which of the following times would you choose?

[4] 8 am –10 am *(08–10 h)*
[3] 11 am – 1 pm *(11–13 h)*
[2] 3 pm – 5 pm *(15–17 h)*
[1] 7 pm – 9 pm *(19–21 h)*

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 pm *(22-23 h).* Bearing in mind only your internal “clock,” how well do you think you would perform?

[1] Would be in good form
[2] Would be in reasonable form
[3] Would find it difficult
[4] Would find it very difficult

MORNINGNESS-EVENINGNESS QUESTIONNAIRE
Page 5

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At *approximately* what time would you choose to begin?

[5] 5 hours starting between 4 – 8 am *(05–08 h)*
[4] 5 hours starting between 8 – 9 am *(08–09 h)*
[3] 5 hours starting between 9 am – 2 pm *(09–14 h)*
[2] 5 hours starting between 2 – 5 pm *(14–17 h)*
[1] 5 hours starting between 5 pm – 4 am *(17–04 h)*

18. At *approximately* what time of day do you usually feel your best?

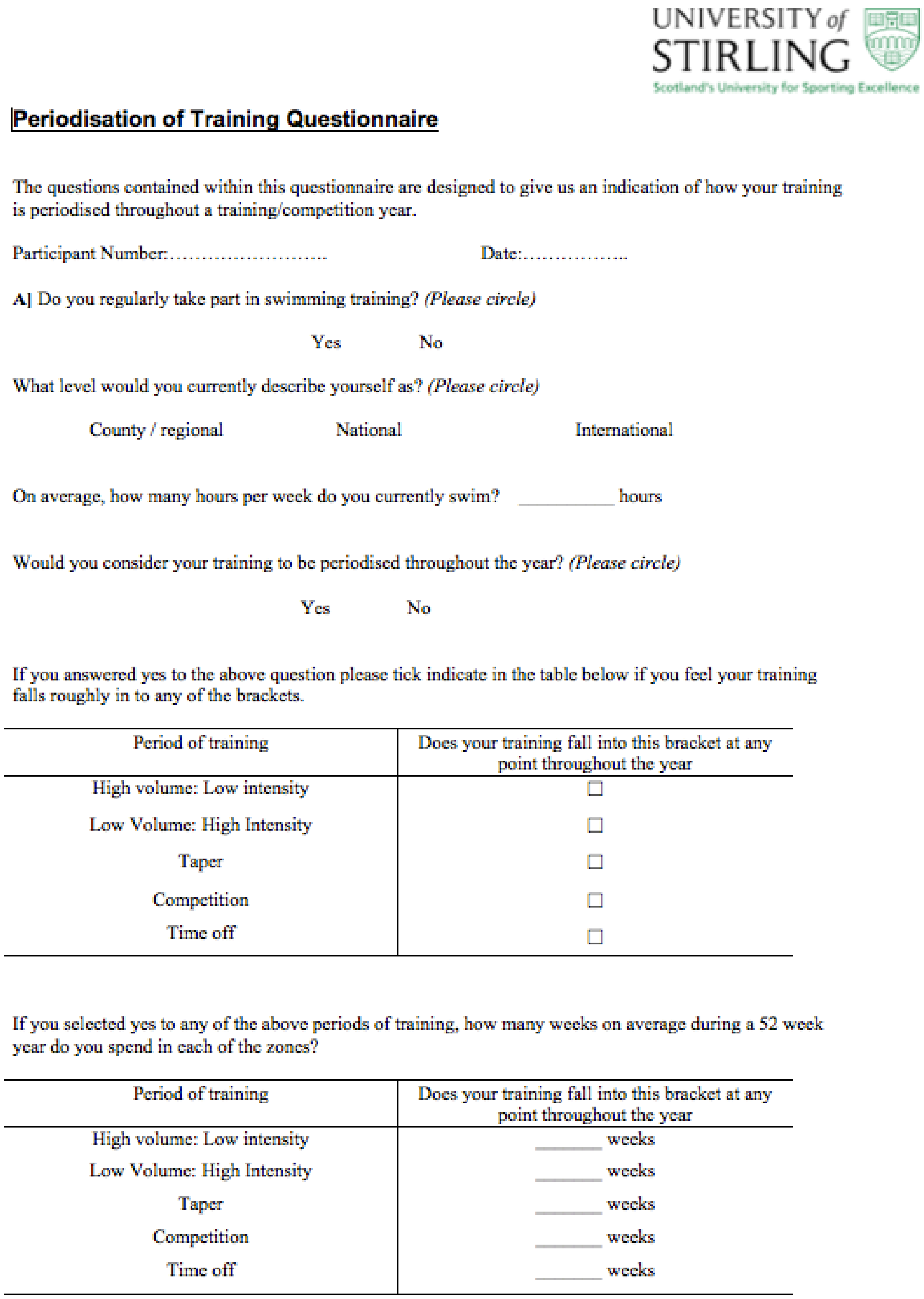
[5] 5 – 8 am *(05–08 h)*
[4] 8 – 10 am *(08–10 h)*
[3] 10 am – 5 pm *(10–17 h)*
[2] 5 – 10 pm *(17–22 h)*
[1] 10 pm – 5 am *(22–05 h)*

19. One hears about “morning types” and “evening types.” Which one of these types do you consider yourself to be?

[6] Definitely a morning type
[4] Rather more a morning type than an evening type
[2] Rather more an evening type than a morning type
[1] Definitely an evening type

_____ **Total points for all 19 questions**

Appendix 4 Periodisation of training questionnaire



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Periodisation of Training Questionnaire

The questions contained within this questionnaire are designed to give us an indication of how your training is periodised throughout a training/competition year.

Participant Number:…………………….. Date:……………..

A] Do you regularly take part in swimming training? *(Please circle)*

Yes No

What level would you currently describe yourself as? *(Please circle)*

County / regional National International

On average, how many hours per week do you currently swim? __________ hours

Would you consider your training to be periodised throughout the year? *(Please circle)*

Yes No

If you answered yes to the above question please tick indicate in the table below if you feel your training falls roughly in to any of the brackets.

Period of training	Does your training fall into this bracket at any point throughout the year
High volume: Low intensity	☐
Low Volume: High Intensity	☐
Taper	☐
Competition	☐
Time off	☐

If you selected yes to any of the above periods of training, how many weeks on average during a 52 week year do you spend in each of the zones?

Period of training	Does your training fall into this bracket at any point throughout the year
High volume: Low intensity	_______ weeks
Low Volume: High Intensity	_______ weeks
Taper	_______ weeks
Competition	_______ weeks
Time off	_______ weeks