Individual differences in daytime sleepiness after night sleep extension versus afternoon napping and caffeine

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INDIVIDUAL DIFFERENCES IN DAYTIME SLEEPINESS
AFTER NIGHT SLEEP EXTENSION VERSUS
AFTERNOON NAPPING AND CAFFEINE

by
Charlotte Ruth Platten

A Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy of Loughborough University

October 2008

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Abstract

Recent research has suggested that 7.5h sleep a night may not be sufficient to maintain adequate levels of alertness during the day. Two of the main arguments used in support of this theory are the ease with which many individuals fall asleep during the day and the ability of many to extend their nocturnal sleep length on demand. The first argument has been used to indicate an elevated level of daytime sleepiness, which may lead to decrements in performance throughout the waking day. The second argument uses the concept that all sleep is as a result of a physiological need, and so the ability to obtain additional sleep could indicate the repayment of a previous sleep debt.

The first part of this thesis addresses the benefit of nocturnal sleep extension in terms of objective and subjective sleepiness in a group of young, healthy adults. Individuals investigated habitually slept 7-8h a night and did not complain of daytime sleepiness, but were found to have mild to moderate levels of objectively defined daytime sleepiness according to their Standard MSLT scores. Sleep extension was compared directly to two commonly used daytime sleepiness countermeasures, an afternoon nap and a caffeinated drink. As the Standard MSLT usually finishes at 4pm, covering only approximately 1/3 of the waking day, a modified version was used to investigate afternoon and evening sleepiness.

The afternoon nap produced the only significant increase in sleep latency (increase in daily score approx. 4min), with the caffeine next effective (increase approx. 2.5min) and the sleep extension (increase approx. 1min) having least impact. Daytime performance and subjective sleepiness were not affected by any of the conditions. Significant group differences in terms of sleep latency in the Standard MSLT were not observed for the Modified MSLT and there was no significant difference between the groups in terms of initial performance and subjective sleepiness or in how they responded to the conditions. The data suggest that the individuals with short sleep latencies may be more sensitive to the afternoon dip in alertness, resulting in their short Standard MSLT scores. It is suggested that although they are able to extend their sleep, they do not suffer from a chronic sleep debt as i) they are able to perform adequately during the day without feelings of sleepiness and ii) the benefits of a night of sleep extension are limited in terms of improvement in both objective and subjective sleepiness.
The second part of the thesis investigates the ability to maintain wakefulness during the day (via the Repeated Test of Sustained Wakefulness, RTSW) and addresses the concept of "high sleepability, without sleepiness" (Harrison & Horne, 1996), exploring the possibility that certain individuals within the sample analysed may possess this trait. The effect of the RTSW condition was to increase sleep latency, with a significant increase in the 7.45pm session (p<0.01). Frequency of sleep onset was significantly reduced in the RTSW condition compared to the MSLT (p<0.03). There was no difference between the groups in terms of sleep latency, frequency of sleep onset or performance for either condition. Using the data from the MSLT and RTSW conditions, two participants in the moderate group were identified as possessing "High Sleepability with No other evidence of Sleepiness" (HSNS). These findings suggest that those with the ability to fall asleep quickly during the day are equally able to maintain adequate wakefulness when required.

In summary, it could be argued that the individuals studied suffered from a sleep debt, as they were able to extend their nocturnal sleep and exhibited signs of sleepiness during the day in situations conducive to sleep. However, sleep extension provided limited benefits and was inefficient when compared to a short afternoon nap or caffeine. For many otherwise healthy adults, there is a modest level of daytime sleepiness that can only be detected with sensitive laboratory measures, in addition to the innate ability of all humans to obtain sleep in excess of physiological needs. It is possible that this reflects a need for more sleep, or it may simply be within the bounds of what is considered 'normal' and therefore acceptable in modern society.
Keywords

Daytime Sleepiness, Performance, Sleep Extension, Napping, Caffeine, Multiple Sleep Latency Test (MSLT), Sleep Debt, Repeated Test of Sustained Wakefulness (RTSW), Individual Differences.
Acknowledgements

This thesis is dedicated to Paul.

I would like to thank Prof. Jim Horne and Dr. Clare Anderson for their continued support and guidance throughout my time at Loughborough Sleep Research Centre.

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A special thank you to my friends and family for helping me through the hard times and for being there with me to enjoy the good times.
## Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis Of Variance</td>
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<tr>
<td>ASDA</td>
<td>American Sleep Disorders Association</td>
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<tr>
<td>BL</td>
<td>Baseline Condition</td>
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<td>CAFF</td>
<td>Caffeine Condition</td>
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<tr>
<td>CPAP</td>
<td>Continuous Positive Airway Pressure</td>
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<tr>
<td>EEG</td>
<td>Electroencephalogram</td>
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<tr>
<td>EMG</td>
<td>Electromyogram</td>
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<tr>
<td>EOG</td>
<td>Electrooculogram</td>
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<tr>
<td>ESS</td>
<td>Epworth Sleepiness Scale</td>
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<tr>
<td>FFT</td>
<td>Fast Fourier Transform</td>
</tr>
<tr>
<td>G-G</td>
<td>Greenhouse-Geisser correction</td>
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<tr>
<td>HBD</td>
<td>Habitual Bedrest Duration</td>
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<tr>
<td>HSD</td>
<td>Habitual Sleep Duration</td>
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<tr>
<td>HSNS</td>
<td>High Sleepability, No Sleepiness</td>
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<tr>
<td>KSS</td>
<td>Karolinska Sleepiness Scale</td>
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<tr>
<td>MSLT</td>
<td>Multiple Sleep Latency Test</td>
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<tr>
<td>MANOVA</td>
<td>Multivariate Analysis of Variance</td>
</tr>
<tr>
<td>mild</td>
<td>mildly sleepy group</td>
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<tr>
<td>mod</td>
<td>moderately sleepy group</td>
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<tr>
<td>MWT</td>
<td>Maintenance of Wakefulness Test</td>
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<td>NAP</td>
<td>Nap condition</td>
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<tr>
<td>NSF</td>
<td>National Sleep Foundation</td>
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<td>OSA</td>
<td>Obstructive Sleep Apnoea</td>
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<td>POMS</td>
<td>Profile Of Mood States</td>
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<tr>
<td>PVT</td>
<td>Psychomotor Vigilance Test</td>
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<tr>
<td>QWB</td>
<td>Quality of Wellbeing</td>
</tr>
<tr>
<td>REM</td>
<td>Rapid Eye Movement</td>
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<tr>
<td>RT</td>
<td>Reaction Time</td>
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<tr>
<td>RTSW</td>
<td>Repeated Test of Sustained Wakefulness</td>
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<tr>
<td>SSS</td>
<td>Stanford Sleepiness Scale</td>
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<tr>
<td>s.d.</td>
<td>Standard Deviation</td>
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<tr>
<td>s.e.</td>
<td>Standard Error</td>
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<tr>
<td>SE</td>
<td>Sleep Extension condition</td>
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<tr>
<td>SE_{sp}</td>
<td>Sleep Efficiency (relative to Sleep Period)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>SOL</td>
<td>Sleep Onset Latency</td>
</tr>
<tr>
<td>SP</td>
<td>Sleep Period</td>
</tr>
<tr>
<td>TST</td>
<td>Total Sleep Time</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>WASO</td>
<td>Wake After Sleep Onset</td>
</tr>
<tr>
<td>WAVT</td>
<td>Wilkinson Auditory Vigilance Task</td>
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1 Introduction and overview of the literature

Sleep is essential to our wellbeing and the issue of how much sleep a person needs is frequently debated amongst sleep researchers. The effects of sleep deprivation are well documented and demonstrate that if an individual is denied sleep or if sleep length is curtailed, they will suffer both mentally and physically as a result (Carskadon & Dement, 1981; Dinges & Kribbs, 1991; Rosenthal, Roehrs, Rosen & Roth, 1993; Dinges et al., 1997; Howard et al., 2003; Van Dongen, Maislin, Mullington & Dinges, 2003b).

In recent times it has been suggested that we are sleeping less than we used to, voluntarily reducing the time we spend asleep in order to make way for other activities in an attempt to keep up with the pace of the 24h society that we live in (Browman, Lundh & Hetta, 1996; Spiegel, Leproult & Van Cauter, 1999; Rivkees, 2003). Some sleep researchers believe that this curtailment of sleep results in what has been termed a ‘sleep debt’ (Dement, 2005; Dinges, 2005). This sleep debt is thought to build up over time, impacting on an individual’s ability to function adequately during the daytime. Others argue that the sleep habits of adults have changed little over the years and that in general we are not suffering from any significant decrements in our daytime functioning (Horne, 2004).

Main themes covered in this section:

- Sleep in modern society: the concept of sleep debt
- Historical change in sleep habits
- Interindividual differences in sleep need
- Measuring daytime sleepiness
- Sleep extension and alternatives
- Research Questions

1.1 Sleep in modern society

1.1.1 The average sleeper: is 7-8h a night enough?

Over the last 50 years there have been many studies indicating that the average sleep obtained by healthy adults up to the age of 65y is between 7-7.5h a night (McGhie & Russell, 1962; Tune, 1969; Reyner & Horne, 1995; Groeger, Zilstra & Dijk, 2004). It
has also been shown that mortality (Kripke, Garfinkel, Wingard, Klauber & Marler, 2002; Patel, Ayas & Malhotra, 2004; Tamakoshi & Ohno, 2004) and incidence of both diabetes (Ayas et al., 2003a) and coronary heart disease (Ayas et al., 2003b) in women are at their lowest for those who sleep about 7h a night. It is therefore surprising to note a recent trend in the literature indicating that 7-8h is not sufficient and that we should aim to sleep approximately 1h more than this each night (Bonnet & Arand, 1995; Spiegel et al., 1999; Wright, Hughes, Hull & Czeisler, 2000).

Spiegel et al. (1999) assessed carbohydrate metabolism and hormone profiles in a group of 11 males aged 18-27y. The participants underwent three nights of 8h sleep (Baseline, BL) followed by 6 nights of 4h sleep (Sleep Deprivation, SD) and then 7 nights of 12h sleep (Recovery, REC). Mean total sleep times obtained were 7h14m (s.e. 5min) for BL, 3h49m (2min) during SD and 9h03m (15min) during REC condition. During the SD condition the authors found an impairment of carbohydrate tolerance and found glucose effectiveness to be 30% less than that observed after the REC condition. From this they concluded that "less than 1 week of sleep curtailment in healthy young people is associated with striking alterations in metabolic and endocrine function" (Spiegel et al., 1999, p1438). It was also found that BL sympathovagal balance, subjective sleepiness and cortisol levels all fell in between the levels observed in the SD and REC conditions, "which suggests that the fully rested state may represent a better functional condition than that achieved by the "normal" 8h bedtime" (1999, p1438-1439). The authors refer to a paper by Wehr et al. (1993) highlighting that "Previous studies have shown that 8h in bed may not be sufficient to satisfy the sleep needs of normal young adults" (Spiegel et al., 1999, p1439) and that "Experimental extension of the time spent in bed to 14h per day over 1 month showed that a normal 8h a night does not meet the sleep needs of healthy young adults, who may carry a substantial sleep debt even in the absence of obvious efforts to curtail sleep (Wehr et al., 1993)." Spiegel et al. conclude that "when compared with the sleep-recovery condition, sleep debt, which is experienced by a substantial proportion of people in more-developed countries, is clearly associated with metabolic and endocrine alterations that may have physiopathological consequences in the long term" (Spiegel et al., 1999, p1439).

Looking in detail at the results obtained by Spiegel et al. (1999) it is clear that the last two days of the sleep deprivation condition had a detrimental effect on metabolic and endocrine functioning when compared to the last two days of the recovery condition. The sleep deprivation condition was set at 4h a night, however, and it could be argued
that this amount of sleep a night is not representative of that obtained in the real world and so cannot be applied to the general population as easily as the authors would have the reader believe. In addition to this, when comparing the three conditions it appears that the authors only found significant differences between the SD and the REC conditions. There appears to be no significant difference between the REC and the BL conditions and so the conclusion that 8h sleep may not be sufficient for their participants appears unfounded. Looking at subjective sleepiness as measured by the Stanford Sleepiness Scale (SSS) it can be seen that the results for the BL and REC conditions are very similar, approximately 2.5 and 2.1 (s.e. 0.2) respectively, compared with 4.4 (s.e. 0.4) for the SD condition. The increase in sleepiness is less than 0.5 of a point along the scale between the BL and REC conditions, with the SD value over double that of the REC condition, showing a much more pronounced increase in subjective sleepiness. Along with the data on cortisol and sympathovagal balance levels it could be argued that there is little difference between the BL condition of 8h a night and the REC condition of 12h a night, discrediting the argument that 8h is not sufficient for these individuals and therefore the general population. In addition, there was no control for order or stress effects during the experiment. Born (1999) has demonstrated that anticipation alone of shortened sleep causes an increase in adrenocorticotropin an hour or so before awakening, which persists for up to an hour after awakening.

In their ad-libitum sleep study published in 1975, Webb and Agnew concluded that “when sleep is freed from time limitations, it shows a sharp increase in amount and exceeds significantly the average of between 7 and 8 h that many individuals report again and again as their day-to-day sleep diet” (Webb & Agnew, 1975, p48). This conclusion appears to be in full support of the theory that 7-8h a night is not enough to meet the needs of many individuals and therefore, has often been quoted by those in favour of this theory. However, Webb and Agnew balance this view by observing that their data does not prove the existence of a chronically sleep deprived population, finally commenting that “Our regular sleep diets may be simply and sensibly keeping us from being “sleep fat”” (1975, p48).

In addition to the several studies that show mortality to be lowest in those that regularly sleep 7-8h a night (Kripke et al., 2002; Patel et al., 2004; Tamakoshi & Ohno, 2004), Aserinsky (1969) found there to be a surge in rapid eye movement density after approximately 7.5h of sleep, which led them to conclude that “some physiological function had approached saturation as a result of sleep” (Aserinsky, 1969, p153). The
advent of sleep satiation has also been shown by Punjabi, Bandeen-Roche, & Young (2003) as a levelling off of daytime sleepiness after 7.25h of sleep, determined by a lack of significant improvement in Multiple Sleep Latency Test (MSLT) scores when sleeping beyond this amount.

1.1.2 The concept of Sleep Debt

It has been suggested that a large proportion of modern society are consistently failing to meet their individual sleep need, resulting in the build up of what has been termed a ‘sleep debt’. An individual’s sleep debt can be defined as the number of hours of sleep remaining when the amount of sleep obtained is less than that required by the individual. This debt is believed by some to accumulate over time indefinitely if the individual continues to sleep less than their daily requirement (Dement & Vaughan, 1999, p73; Dement, 2005, p258), resulting in a decrement in their ability to function throughout the day (Van Dongen et al., 2003b). It is important to note here that the individual is thought by some to be unaware of this reduction in daytime performance, due to the slow build up of a chronic sleep debt over time (Dement & Vaughan, 1999, p68-73). This concept has been addressed directly by Dement in his paper on extending sleep. He suggests that because some individuals do not experience sleepiness even when under the influence of a large sleep debt, their likelihood of making sleep-related mistakes is greatly increased (2005, p258). It is possible that such an individual has lost their frame of reference, unable to remember what it feels like to be fully rested and perform adequately throughout the day, unaware that this sleep debt exists.

Many advocates of the sleep debt theory use an individuals’ inability to spontaneously terminate sleep and rise easily, without feelings of drowsiness during the day, as a further argument in favour of a chronically sleep deprived society. It is suggested that alarm clocks are relied on increasingly to aid awakening and this is interpreted by some as a sign of insufficient sleep (Webb & Agnew, 1975; Bonnet & Arand, 1995). This belief is strengthened by the fact that many individuals choose to sleep for longer at the weekends, when their alarms do not wake them (Bonnet & Arand, 1995; National Sleep Foundation, 2003; National Sleep Foundation, 2008). It has been shown that when sleep duration is extended there are benefits in terms of reduced sleepiness, improved performance and mood (Wehr et al., 1993; Engleman, Martin, Deary & Douglas, 1994). The simple ability to extend sleep beyond the norm has been cited by some as evidence of previously insufficient sleep length (Webb & Agnew, 1975; Bonnet & Arand, 1995). However, it has been suggested that a weekend lie-in may be taken for
pleasure and not simply to overcome a basic physiological need (Harrison & Horne, 1995). In addition, the improvements in daytime functioning may be of statistical significance, but it has been questioned by some how applicable these small changes are to real life situations (Harrison & Horne, 1995, p906). Taking the specific example of motor vehicle accidents, the vast majority of sleep related accidents are caused by drivers with acute sleep deprivation, during the small hours of the morning following little or no sleep that night (Langlois, Smolensky, Hsi, & Weir, 1985) and not by those who regularly sleep 7-8 hours a night.

Some studies have aimed to address perceived sleep debt by investigating how much sleep individuals obtain each night and comparing this with what they feel they need. Hublin, Kaprio, Partinen and Koskenvuo (2001) and Anderson and Horne (2008) both defined a perceived sleep debt to exist if there was a difference of 1h or more between self-reports of sleep length and sleep need. Hublin et al. (2001) found that in 1990, the prevalence of insufficient sleep was 20.4% and that 44% of individuals with insufficient sleep in 1981 also had it 9 years later. From this, it was concluded that "Insufficient sleep is a common and long-standing condition, most strongly associated with sleep/wake variables." (Hublin et al., 2001, p392). If possessing a sleep debt is detrimental to daytime performance and wellbeing and also accumulative over time, then those suffering from insufficient sleep in 1981 and still in 1990 would have accrued a sizeable debt, which would presumably have a substantial impact on their ability to function during the day. However, it appears that the only impact of this substantial sleep debt is for the individual to still feel that they are not obtaining enough sleep, in the absence of any physiological effects. In a study of 10,810 individuals in the UK, Anderson and Horne found that although about 50% of those asked expressed a desire for more sleep, this did not correlate with daytime sleepiness for either sex or for any of the age groups investigated (2008, p184). They also showed that when given the choice of extra sleep or other waking alternatives, few people opted for sleep. This led the authors to conclude that the perceived need for more sleep may be a result of the need for more "time out", as, although sleep deficit was not related to daytime sleepiness it was related to a "stressful lifestyle" (2008, p184).

1.1.3 Historical change in sleep habits

When asserting that society is sleeping less than it used to, a seminal paper by Webb & Agnew (1975) has been cited by sleep researchers (Bonnet & Arand, 1995; Spiegel et al., 1999). Referring to Webb & Agnew's paper, Spiegel et al. state that "Normal" average sleep duration has decreased from about 9h per night in 1910 to about 7.5h
Chapter 1: Introduction and overview of the literature

currently" (1999, p1435). Looking at the paper by Webb & Agnew in detail, it can be seen that the authors refer to previous work carried out by Webb (1969) showing that "nocturnal sleep length in 1910 and 1911 was 1½h longer than a comparison group reporting in 1963" (Webb & Agnew, 1975, p47). On the surface this appears to agree with the opinion purported by Spiegel et al. (1999). However, the data in question was obtained from a group of school children aged 8-17 years old (Webb, 1969; Webb & Agnew, 1975). It is well established that children sleep longer than adults and so data from this group cannot simply be used to represent the sleep habits of adults (Ohayon, Carskadon, Guilleminault & Vitello, 2004).

Changes in feelings of fatigue over the years have also been considered in the sleep debt debate. Bliwise (1996) presented cross-sectional data using a previously published database (Colligan, Osborne, Swenson & Offord, 1983) and reported on historical changes in daytime fatigue. He concluded that feelings of daily fatigue in men were higher in 1980 compared with those in the 1930’s (1996, p464) and that these results “were compatible with voluntary curtailment of sleep typical in modern society” (1996, p462). However, one might question how closely feelings of fatigue are linked with actual sleepiness. The implications of using different words to imply sleepiness, such as fatigue or tiredness have been debated in detail by Dement et al. (2003), Horne (2003) and Dement (2003). In the study by Bliwise, men in 1980 were more likely to feel “unrested in the morning”, have “trouble in functioning” and have less stamina (1996, p464). All of these terms are rather general, leaving room for interpretation and not necessarily specific to an individual’s sleepiness. In addition to these findings, Bliwise reported that men showed no significant differences in “restless sleep” or napping and there were no significant changes in how women felt over the time frame investigated (1996, p463). This implies that the participants in the study did not suffer from an increase in sleep problems, such as difficulty maintaining the required length or quality of sleep, but more that they were tired as a result of increasingly busy daytime schedules. It is likely that the increasing fatigue, decreasing energy and stamina are associated with the changes in daily routine and work pressure over time, rather than as a result of changes in sleep habits. This would support the findings of Anderson and Horne (2008) that the desire for more sleep often is the result of a desire for more time out.

A recent study of approximately 2000 UK inhabitants aged 16 to 93y found that the average sleep length was 7.04h (s.d. 1.55) (Groeger et al., 2004). Sleep length was found to be longest in those aged 16-24h, with an average of approximately 1h longer
than the sample average, i.e. around 8h a night. The authors noted that "Although we may not sleep less than four decades ago, when we report sleeping less we also tend to associate that lack of sleep with poor performance and quality of life" (2004, p359). This data strengthens the argument that it is not necessarily a change in sleep habits that has caused individuals to feel more fatigued, with a decrease in performance during the day, but more a shift in the work/life balance and the need for more “time out”.

1.1.4 Interindividual differences

Many of the researchers involved in the sleep debt argument fail to acknowledge the large interindividual differences in nocturnal sleep length within any given population. As with many naturally occurring phenomenon, in a population there will be a normal distribution of sleep durations about the mean value, with some individuals sleeping more or less than this mean, but still well within the bounds of what is regarded as normal. Because of this variability, when dealing with sleep need it may be more appropriate to obtain person-specific ideal sleep durations and calculate any possible sleep debt from these, rather than trying to promote a single ideal sleep length for an entire population.

Rivkees (2003) addresses individual variability in sleep need in an Editorial: Time to wake-up to the individual variation in sleep needs. In it he refers to work carried out by Aeschback et al. (2003) on long and short sleepers, stating that they "give credence to everyday observations that sleep needs vary individually and suggest that the amount of sleep we need reflects intrinsic factors" (2003, p24). He also addresses the issue of the work/life balance and an increasing reliance on alarm clocks, suggesting that it is important that individuals in modern society are “able to accommodate our normal circadian cycle and our individual sleep requirements in the name of progress and productivity” (2003, p25).

The study carried out by Aeschback et al. (2003) investigated habitual long (>9h a night) and short (<6h a night) sleepers and found there to be a difference in the length of circadian pacemaker programmes between the two groups, with the long sleepers having a longer length circadian pacemaker programme than the short sleepers. From this they concluded that “individual differences in the circadian pacemaker’s programme may contribute to the variability of sleep duration in the general population” (2003, p26).
Klerman and Dijk (2005) investigated habitual sleep duration and its relationship with sleep debt in a bedrest extension protocol on a sample of 17 individuals (10 female). They found that over the three days there was a gradual decline in total sleep time and increase in wake which they concluded "demonstrates that a sleep debt was being recovered" (2005, p1257). Also, during the third day of increased sleep opportunity the total sleep time exhibited a negative correlation with Habitual Bedrest Duration (HBD) "indicating that individuals with shorter HBD continued to sleep longer than those with longer HBD" (2005, p1257). Klerman concludes that "The most parsimonious explanation for our data is that those individuals with short HBD carry a larger sleep debt" (2005, p1258). Dinges (2005) comments on the study by Klerman noting that it provides some of the first evidence that interindividual variation in HBD may harbour substantial sleep debt, rather than just reflecting a biological variation in sleep need. He also notes that it is not known whether short sleepers carry a sleep debt, which would result in cognitive performance decrements or if they are simply able to resist the elevated sleep drive enabling cognitive performance to be maintained. Dinges observes that more days of extended sleep opportunity are required to obtain the steady state total sleep time, stating that "The absence of carefully quantified recovery sleep dose-response functions is a gaping hole in sleep science" (2005, p1210).

In their population study investigating habitual sleep duration in 273 San Diego residents (aged 40-64y), Jean-Louis, Kripke, & Ancoli-Israel, (2000) found that neither subjective nor actigraphic sleep duration were associated with health-related quality of life, as measured by the Quality of Well-being (QWB) scale. This is an important finding to consider when deciding whether or not to advocate more sleep. Although extending nocturnal sleep may result in objective improvements in sleepiness and/or daytime performance, the impact on the individual in terms of subjective improvements and quality of life may be minimal, and therefore, not worth the cost in terms of an increased nocturnal sleep latency and more awakenings during the night. Jean-Louis et al. (2000) concluded that even though there is evidence to suggest that a reduced nocturnal sleep duration is associated with fatigue, an increase in sleep duration alone is unlikely to directly improve quality of life (p1, p5).

1.2 Quantifying daytime sleepiness: The MSLT

The Multiple Sleep Latency Test (MSLT) (Richardson et al., 1978) is the most widely used and accepted method of measuring daytime sleepiness, validated by Carskadon & Dement in 1982 (1982b) and regarded as the "gold standard" by researchers and clinicians alike (Carskadon et al., 1986a; Thorpy, 1992; Geisler et al., 2006). The
MSLT is currently the only way of measuring an individual's underlying physiological sleepiness in an objective, standardised and reproducible manner. The MSLT is an extremely sensitive measure of sleepiness, affected by prior nocturnal sleep length and quality, age, time of day and the ingestion of sedative medications (Thorpy, 1992). This makes it an excellent tool in the measurement of change, for example, "following treatment or manipulations intended to alter sleepiness or alertness" (Arand et al., 2005, p139).

In the Standard MSLT, tests are performed every two hours throughout the day from 10am until either 4pm (4-session method) or 6pm (5-session method). In each session the individual lies on a bed in a dark room and is instructed to "Lie quietly, relax, close your eyes, keep them closed and try to go to sleep". The time it takes for the individual to fall asleep, from lights out is called the Sleep Onset Latency (SOL). The average SOL for the day is calculated using data from all of the sessions, enabling classification of the level of daytime sleepiness for an individual. There are two main protocols for carrying out the MSLT, i) the Clinical Standard MSLT, whereby if the individual falls asleep they are allowed to continue sleeping until 20 minutes has elapsed and ii) the Research Standard MSLT, where the individual is awoken if they fall asleep and the session terminated in order to prevent the acquisition of sleep over the course of the day. How the Standard Research MSLT is performed is covered in more detail in Chapter 2.

The MSLT is based on the fundamental assumption that the quicker a person falls asleep the sleepier they are, with classification by the American Sleep Disorders Association (ASDA, Thorpy, 1992) according to the daily MSLT score as follows:

- Av. SOL 10-15 minutes: "mild" daytime sleepiness
- Av. SOL 5-10 minutes: "moderate" daytime sleepiness
- Av. SOL 0-5 minutes: "severe" daytime sleepiness

Recent studies have presented data on normal, healthy subjects with an average MSLT SOL of less than 10 minutes, which would put them in the 'moderately sleepy' group according to the above classification system (Levine, Roehrs, Zorick & Roth 1988; Roehrs, Timms, Zwyghuizen-Doorenbos, & Roth, 1989; Manni et al., 1991; Roehrs, Shore, Panineau, Rosenthal & Roth, 1996a). Some researchers have become concerned by these findings, concluding that these individuals have elevated levels of daytime sleepiness as a result of failing to obtain sufficient night-time sleep, i.e. they
are suffering the effects of a sleep debt that they are unaware of (Carskadon & Dement, 1982a; Roehrs et al., 1989; Roehrs et al., 1990; Manni et al., 1991; Bonnet & Arand, 1995; Roehrs et al., 1996a). Bonnet and Arand note in their paper that in usual 7-8h sleepers, "nocturnal sleep periods reduced by as little as 1.3 to 1.5 hours for 1 night result in reduction of daytime alertness by as much as 32% as measured by the Multiple Sleep Latency Test (MSLT)" (1995, p908) and, using the fact that these individuals are able to sleep longer when given the opportunity, conclude that "short MSLT values in normal young adults are most likely a function of chronic partial sleep deprivation and not an indication of simple ability to fall asleep, because increasing nocturnal sleep consistently increased the following MSLT latencies" (p909).

In some instances the results of the MSLT are being used alone to diagnose asymptomatic sleepiness in otherwise healthy individuals with no reported feelings of increased sleepiness or decreased performance during the day. Researchers have shown via alternative measures of sleepiness that these individuals are not subjectively sleepy, are good, regular sleepers reporting no sleep problems and do not suffer from any deficits in maintaining vigilance (Roehrs et al., 1989; Harrison & Horne, 1996a). However, often the data from these measures is disregarded in favour of the results obtained solely from the MSLT, which, when used alone, indicate that the individual is suffering from increased daytime sleepiness. Despite the MSLT being commonly regarded as the gold standard it is unwise to use any single measure to diagnose an individual without any presenting symptoms of sleepiness or impairment in daytime performance as suffering from daytime sleepiness. As with any diagnostic tool the MSLT has limitations and as such it should be used in conjunction with other sleepiness measures in addition to other information on the individual, such as their medical history, in order to establish an accurate picture of their health.

1.2.1 Limitations of the MSLT

The largest limitation of the MSLT is the assumption that the faster an individual falls asleep, the higher their level of sleepiness. As discussed earlier in this section there appear to be a number of individuals with short SOLs, without any accompanying symptoms or other indications of daytime sleepiness. The MSLT is a very sensitive test, carried out in an environment devoid of external arousing factors resulting in a situation conducive to sleep. It is possible that the MSLT may be too sensitive, highlighting levels of sleepiness present only in a very specific environment, which is unrepresentative of any real life situations that may be encountered by the individual. Harrison and Horne (1996a) suggest that this may be the case and have shown that
some normal healthy individuals, classed as severely sleepy using the MSLT are not sleepy on other tests of vigilance (the Wilkinson Auditory Task) and sleepiness (Karolinska Sleepiness Scale, KSS). In addition, due to its high sensitivity, SOLs in any MSLT session have been shown to be affected by prior activity (Kribbs, Pack & Dinges, 1994), posture (Bonnet & Arand, 2001) and instruction (Hartse, Roth & Zorick, 1982; Harrison, Bright & Horne, 1996).

As with the different sleep durations observed within a population (discussed earlier) it is highly probable that there is a normal distribution of times taken to fall asleep, with a proportion of individuals who naturally fall asleep very quickly, those that take a relatively long time, and many who fall in between these two extremes. Harrison and Horne discuss this concept in more detail, highlighting that it is not necessarily that the individuals that fall asleep very quickly are suffering from daytime sleepiness, as they are able to perform adequately during the day and have no feelings of sleepiness, but more that they have an ability to switch off and fall asleep on demand, possessing 'high sleepability, no sleepiness' (HSNS) (1996b, p16-17). It has been shown by Harrison and Horne (1996a, 1996b) that even when these individuals are given extended sleep, the low MSLT scores persist, which indicates ability to fall asleep rather than an underlying sleep debt. In addition to this, Lavie, Wollman & Pollack (1987) found that with the same amount of sleep loss some individuals fall asleep quicker than others and Drake et al. (2001) found that when restricting individuals to 6h sleep a night, sleep latencies in the MSLT were very short, but performance on the Psychomotor Vigilance Test (PVT) and feelings of ‘fatigue’ remained unchanged compared with baseline.

Another limitation of the Standard MSLT is the small proportion of the waking day that it covers. The Standard MSLT procedure requires that the last test session be at either 4pm or 6pm, depending on the protocol used. As the first session commonly begins at 10am, a large portion of the waking day is not covered by the test. Many individuals judge their sleepiness on how they feel in the early evening and decide from this whether or not they need any early night, and the Standard MSLT provides no information on sleepiness at this time. It is suggested that to more accurately assess levels of objective sleepiness throughout the waking day, measurements should be made over a greater time frame, covering the late afternoon and evening in particular, up until bedtime.
1.2.2 Maintaining wakefulness

The Maintenance of Wakefulness Test (MWT) is a modified version of the MSLT that measures the ability to remain awake under soporific conditions instead of the ability to fall asleep (Mitler, Gujavarty & Browman, 1982). It was created in order to address that in some instances it is more important to know how easily a person can stay awake than their ability to fall asleep. It is thought by some that the MWT is a more realistic test of “ability to function and maintain alertness in common situations of inactivity” and is more “representative of workplace conditions”, (Arand et al., 2005, p124). Also, with extremely short sleep latencies a floor effect is reached using the MSLT and so making the situation less soporific as in the MWT can help to avoid this problem (Doghramji et al., 1997).

A common setup for a test session in the MWT is with the subject sitting up in a chair in a quiet and dimly lit room with the instruction to remain awake (Arand et al., 2005, p124). However, for the purpose of the present study it was deemed necessary that only one parameter be changed between the two tests; the instruction given to the subject. The MWT was carried out with the subject lying in a bed in a dark, sound attenuated room, with eyes closed, in a setup identical to that of the MSLT [as used by Hartse et al. (1982)] with subjects instructed to “Lie quietly, relax, close your eyes, keep them closed, but try to remain awake”. Due to the only difference between the two tests being the different instruction, when asked to try to remain awake the test is called the Repeated Test of Sustained Wakefulness (RTSW) rather than the MWT. Hartse et al. (1982) found that changing the instruction from ‘try to go to sleep’ to ‘try to remain awake’ resulted in a significant increase in sleep latency, showing that “the latency to sleep onset under conditions of normal nocturnal sleep can be manipulated by instruction” (p115).

In the present study the MSLT and RTSW will be used. It is hoped that the direct comparison of the MSLT with the RTSW will distinguish those who are truly sleepy from those who are simply able to fall asleep quickly. It is predicted that those with high sleepability, little sleepiness will be able to fall asleep quickly in the MSLT, but remain awake or have a much increased SOL in the RTSW.

1.3 Extending nocturnal sleep

The fact that many of us are unable to spontaneously terminate sleep and rise easily, without feelings of drowsiness during the day has been used to indicate the existence
of a chronic sleep debt within society. It is also proposed that excessive use of alarm clocks is an indication of insufficient sleep (Webb & Agnew, 1975; Bonnet & Arand, 1995). To tackle this problem it is suggested that individuals extend their sleep length to avoid the build up of a sleep debt. Others argue that the idea that it should be possible to terminate sleep spontaneously if sufficient sleep is obtained beforehand is unrealistic when considering the process of sleep onset (Harrison & Horne, 1995). The act of falling asleep is not instantaneous and so it is reasonable to expect waking to occur in a similar way. In addition, there is currently no evidence to suggest that alertness on awakening is any better when more sleep is obtained the night before (Harrison & Horne, 1995, p905).

1.3.1 Sleep: a response to a basic physiological need?

It is well understood that both acute total sleep deprivation and sleep restriction can produce marked changes in an individual’s level of sleepiness and performance, in addition to physiological changes (Horne, 1977; Carskadon & Dement, 1981; Rosenthal et al., 1993; Dinges et al., 1997; Spiegel et al., 1999; Howard et al., 2003; Van Dongen et al., 2003b). The changes within the body and the brain when sleep is curtailed suggest a fundamental physiological need for sleep. This physiological need has been shown to be dependent on two main factors; a homeostatic process (process S), determined by the amount of prior wakefulness, and a circadian process (process C), which is largely independent of sleep and wake patterns and causes alternating periods of increased or decreased sleep propensity over a 24h period (Borbély, 1994).

Having established that there is a basic physiological need for sleep, it is logical to attempt to ascertain the magnitude of this need. In the maximal sleep extension study conducted by Aserinsky (1969) there was found to be a significant reduction in the proportion of time spent in Rapid Eye Movement (REM) sleep, but a large increase in the concentration of rapid eye movements in sleep beyond the first 7.5h of sleep. From this the investigators concluded that “Since REM density approaches a maximum value with 7.5-10 hr sleep, it may serve as an index of sleep satiety” (Aserinsky, 1969, p147). In agreement with this, Punjabi et al. (2003) found diminishing returns in terms of increased daytime alertness (as measured by the MSLT) for sleep durations exceeding 7.25h. These studies suggest that the basic physiological sleep requirement may be in the region of 7-7.5h a night. However, it is then important to ask the question “is all sleep taken in response to a basic physiological need?”
Much of the evidence for the sleep debt theory is based around the ability of many people to extend their nocturnal sleep when given the opportunity to, as observed by Aserinsky (1969). Population studies have shown that many people tend to extend their sleep voluntarily by having a lie-in at the weekend (Palmer, Harrison & Hiorns, 1980; National Sleep Foundation, 2003; National Sleep Foundation, 2008). The taking of this extra sleep is believed by some to occur as a result of the presence of a sleep debt, acquired before the opportunity for extra sleep was presented (Webb & Agnew, 1975; Bonnet & Arand, 1995), with sleep considered to exist solely as a result of a physiological need (increased sleep indicating a greater physiological need for sleep and vice versa). However, Harrison and Horne suggest that physiological need may not be the only reason why sleep may occur (1995, p903), drawing parallels between sleeping and eating. They hypothesise that "given the opportunity for unlimited food, many people will eat more than they need, and the same may apply to sleep" (Harrison & Horne, 1995, p903). Harrison and Horne also suggest that boredom may be a possible cause of voluntary sleep extension (Harrison & Horne, 1995, p903-904).

Animals continuously stabled have been shown to sleep more than when they are allowed to graze in an open field (Ruckebusch, 1976). Ruckebusch (1976) suggests that this extra sleep is in addition to the physiological requirements of the animal and is a "luxury form" of sleep, which has been labelled by Horne as "optional sleep" (1988, p210-215).

With specific regard to the weekend lie-in, it has been suggested that the extended sleep is more likely to be for "pleasure" rather than "making up for lost sleep" (Palmer et al., 1980). Additionally, the weekend sleep extension has been shown to be around 40 minutes for Saturday and Sunday nights for working adults in the USA (National Sleep Foundation, 2003), which, according to the predicted average 1h sleep need deficit each night, is considerably smaller than the increase necessary to eliminate the sleep debt acquired during the week.

1.3.2 The effects of sleep extension

1.3.2.1 Sleep Latency

One of the most frequently observed effects of extending nocturnal sleep is the increase in objective sleep tendency the next day, as measured by the MSLT. Studies ranging from one night of extended sleep (Carskadon et al., 1986b) to up to seven days (Carskadon & Dement, 1979; Roehrs et al., 1989) to several weeks (Roehrs et al., 1996a; Harrison & Horne, 1996b; Kamdar, Kaplan, Kezirian & Dement, 2004) have
consistently shown significant improvements in MSLT scores following sleep extension. However, the improvement in daily MSLT score is often five minutes or less, which, although statistically significant, may not be sufficient to have any practical implications. The exception to this is a sleep extension study carried out by Roehrs et al. (1996a) on a group of 22 MSLT-defined sleepy (baseline MSLT scores ≤6min), but otherwise healthy normal subjects. Here, the daily MSLT score was increased from around 6 minutes at baseline to around 12 minutes on day 14 of the sleep extension period, a substantial increase. However, the group investigated had very short baseline MSLT scores, either in or very close to levels indicating pathological sleepiness, and so cannot be considered representative of normal, healthy individuals in general. In terms of the return for extended sleep, Punjabi et al. (2003) found that MLST improvement becomes increasingly small after 7.25h of sleep the night before. In addition, Harrison and Horne (1996b) note that the main effect of extending sleep is to reduce the magnitude of the afternoon dip in alertness and when the afternoon MSLT data is removed, the statistical increases in alertness often diminish substantially. They have also previously argued that a dip in alertness in the afternoon is normal and it is not necessarily something to be erased in order to ensure adequate daytime functioning (Harrison & Horne, 1995). However, as some individuals find a dip in alertness in the afternoon undesirable, it is important to establish the benefit of extended sleep versus other sleepiness countermeasures (such as afternoon napping or caffeine) to these individuals.

Although the general trend is for increased sleep latency with extended nightly sleep, there appears to be a subset of individuals who are either unable to extend their sleep, or if they are able to extend their sleep, it does not impact on their objective sleep tendency the next day. Engleman et al. (1994) found that despite much improved cognitive performance, mood and subjective sleepiness levels when patients with Obstructive Sleep Apnoea (OSA) used Continuous Positive Airway Pressure (CPAP), there was little improvement in their sleep latencies in the MSLT. It is possible that these individuals were still suffering from increased daytime sleepiness, or it may be that they had achieved a level of adaptation, maintaining the ability to fall asleep quickly when circumstances permit, independent of whether or not they obtained sufficient sleep the night before. In their two-week sleep extension study of sleepy (MSLT score ≤6min), but otherwise normal subjects, Roehrs et al. (1996a) found that four of the eleven sleep extension subjects were not able to increase their sleep latency beyond 10 minutes, despite obtaining an amount of extra nocturnal sleep over the 14 days comparable to the other subjects. On day 14, the mean sleep latency of
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this group was 8 minutes or less, which would class them as suffering from moderate levels of daytime sleepiness according to the American Sleep Disorders Association (ASDA, Thorpy, 1992). In their maximal sleep extension study, Kamdar et al. (2004) found that two subjects obtained relatively little extra sleep and also showed little or no improvement on the MSLT compared to the other subjects. In agreement with this finding, Harrison and Horne (1996b) identified two subjects that found it very hard to adapt to sleeping 10 hours a night for 14 nights, causing one subject to withdraw from the study as a result. It appears that these individuals may already sleep their ideal amount and therefore, when they try to sleep more during the night they are prevented from obtaining extra sleep, or if they are able to sleep, the benefits in terms of objective daytime sleepiness the next day do not occur. It is possible that these individuals possess a trait defined by Harrison and Horne (1996a) as “High sleepability, without sleepiness”. This concept is discussed in more detail in Chapter 6 of this thesis.

1.3.2.2 Performance

In addition to the observed effects on daytime sleep propensity, sleep extension has also been shown to have an impact on performance the next day, but there appears to be less agreement between investigators as to whether this impact is beneficial or detrimental. For the studies indicating improvements in performance with sleep extension, it appears that the greater the number of days of extension, the greater the benefit in terms of improved performance. Roehrs et al. (1989) found significant improvements in reaction time in the last 10min of a 40min auditory vigilance task (commencing 2.30pm) compared to baseline, but only after 6 nights of extended sleep, and Harrison and Horne (1996b) found significant improvements in a 55min Wilkinson Auditory Vigilance Task (WAVT) (commencing at 2pm) following 14 nights of sleep extended to 10h a night. Kamdar et al. (2004) observed significant improvements in Psychomotor Vigilance Test (PVT) performance in their long term sleep extension studies. However, other studies have shown there to be no effect (Belenky et al., 2003; Carskadon et al., 1986b) or even a detrimental effect (Taub, Globus, Phoebus, & Drury, 1971) of sleep extension on various performance measures.

It is important to note that with sleep extension protocols the subject is often aware that they have had extended sleep, and so any subsequent improvement in performance tasks may be due to a placebo effect. This should be taken in to account when considering the significance of any measured changes in performance as a result of sleep extension protocols.
1.3.2.3 Subjective sleepiness and mood

When considering the potential benefits of extending nocturnal sleep, it is important to consider the effect it has on subjective sleepiness, mood and wellbeing. This is particularly crucial when advocating that more sleep should be obtained by individuals in the general population, as it is how they feel during the day that will influence how effective they believe any sleep extension to be. Using the MSLT as a measure of daytime sleepiness, Carskadon and Dement (1982a) and Rosenthal et al. (1993) found that longer sleep latencies in the MSLT were associated with a greater time in bed the previous night. However, how well MSLT scores reflect subjective sleepiness is the subject of debate (Chervin, Aldrich, Pickett & Guilleminault, 1997; Johns, 2000). Wehr et al. (1993) found that after transferring from short to long nights, fatigue as measured by the Profile Of Mood States (POMS) was decreased and subjects also “felt happier and more energetic” (p849). Kamdar et al. (2004) obtained similar findings, with POMS vigour and fatigue significantly improved with extended sleep, and after spending 14h a night in bed for 4 weeks, subjects in the study carried out by Barbato et al. (1994) reported dramatic improvements in mood and energy levels. However, in their study investigating sleep length, quality and timing in a group of 30 working adults, Totterdell, Reynolds, Parkinson and Briner (1994) found that sleep duration was not the best indicator of improved mood the next day, but that it was the timing of sleep onset that proved more accurate, with the investigators noting that “Specifically, a later onset was associated with reduced cheerfulness and alertness and increased dissatisfaction with the amount of time spent alone the following day” (p473).

Other studies have reported a negative impact of sleep extension on mood. Globus (1969) identified a syndrome associated with sleeping late, characterised by feelings of being worn-out, tired, lethargic and irritable. When these feelings occurred, they persisted for about 4.4h, and they were more likely to occur after sleeping for 10 hours or more when the individual was not making up a sleep deficit. From this, Globus concluded that optimal sleep durations may have a relatively narrow bandwidth and that both too little and too much sleep can cause undesirable psycho-physiological effects (1969, p528). In 1986, Carskadon and Dement found impairments in subjective sleepiness following one night of extended sleep after a night of normal sleep, concluding that “The dissociation of SSS (Stanford Sleepiness Scale) from other subjective and objective measures when oversleeping followed a nominal schedule leaves open the possibility of a “worn out” syndrome” (1986b, p70). As they did not find deficits after sleep extension following a night of sleep restriction, this appears to agree well with the study conducted by Globus (1969), which also found the “worn-out"
syndrome to be more likely to occur after extended sleep following normal sleep, compared to after restricted sleep.

In their long term sleep extension study, Harrison and Horne found that levels of fatigue and vigour as measured by the POMS, and subjective sleepiness as measured by the Karolinska Sleepiness Scale (KSS) "were not enhanced to any degree that could be seen to benefit our subjects" (1996b, p28). This was consistent with other reports of a lack of association between MSLT scores, performance tests and subjective sleepiness (Carskadon et al. 1986a; Manni et al., 1991). Harrison and Horne also noted that even though their data did not indicate any benefits in terms of subjective sleepiness and mood, there were also no detrimental effects of extended sleep observed (1996b, p29).

1.3.2.4 Nocturnal sleep parameters

In addition to the effects observed during the daytime, increasing nocturnal sleep has been shown to have an impact on subsequent night-time sleep. Extending nocturnal sleep duration results in an increased time to fall asleep at night, more wakefulness during the night and subsequently, a reduction in sleep efficiency (Taub et al., 1971; Roehrs et al., 1996a; Harrison & Horne, 1996b). Harrison and Horne (1996b) found that in order to obtain an extra 1 hour of sleep at night, their subjects had to stay in bed for an extra 2 hours. This is an important factor to take into account when deciding whether or not to advocate more sleep, as many individuals may consider an increased time to fall asleep at night with more wakefulness during the night an unacceptable downside, outweighing the possible daytime benefits of extended sleep.

1.3.3 Alternatives to sleep extension

As discussed in the previous section, the main benefits of sleep extension appear to be a reduction in sleep propensity the next day, as measured by the MSLT, along with varying degrees of improvement in performance (if the number of nights of sleep extension is sufficient). In terms of subjective sleepiness, mood and fatigue, sleep extension has been shown to have both beneficial and detrimental effects. As noted by Harrison and Horne (1996b), many individuals are required to spend an extra two hours in bed in order to achieve an additional hour's sleep and the subsequent benefits of that sleep. It may be that a shorter period of sleep obtained in addition to a normal night's sleep could provide the same benefits in terms of increased performance and reduced sleep propensity, without the inconvenience of increased sleep onset latency and wakefulness at night and the loss of time spent trying to obtain this extra sleep.
Dinges, Orne, Whitehouse and Orne (1987) investigated the effect of a 2h nap placed at different stages in the circadian cycle over a 56h period of wakefulness and found that the nap produced improvements in cognitive performance, short-term memory and reaction time irrespective of when it was taken. However, the nap did not produce improvements in subjective sleepiness as measured by the SSS. Gillberg, Kecklund, Axelsson, & Åkerstedt (1994) subsequently looked at the effect of a 30min nap after a night of sleep restricted to 4h. Subjects in this study achieved a mean total sleep time of 19.8min (range 11-28min) in the nap, which restored objective [Electroencephalogram (EEG), defined] and subjective (KSS) sleepiness measures and vigilance performance to the levels observed at baseline. The lack of subjective improvement in the study carried out by Dinges et al. (1987) may have been due to the nap length of 2 hours resulting in unwanted sleep inertia or grogginess in those not accustomed to napping. This has been defined by Naitoh as "a reduced performance capability during a period after being suddenly awakened from sleep" (1992, p206).

The presence of increased sleep inertia in the study carried out by Dinges et al. (1987) and to a lesser extent in those using a shorter nap length may explain the improvements observed in subjective sleepiness reported by Gillberg et al. (1994) and others following nap lengths of 20min or less (Horne & Reyner, 1996; Hayashi, Watanabe & Hori, 1999). In terms of the shortest nap length that will provide benefits, Naitoh (1992) suggests that a nap of 4 minutes is the shortest duration that will provide some recuperation.

Hayashi et al. (1999) looked specifically at the benefit of a 20min nap after a night of normal sleep in seven young adults who did not habitually nap during the day. They placed the nap at 2pm to coincide with the post-lunch dip, as it is well known that performance levels decline at this time. They note that "daytime sleepiness does increase in the afternoon even after extended night sleep, e.g. 10h of time in bed...The question arises as to whether a short daytime nap has prophylactic effects on daytime sleepiness after a full night’s sleep" (p 273). They found that all subjects were able to sleep during the nap and were in stage 2 sleep when awoken. The nap improved subjective sleepiness and performance, as well as suppressing EEG alpha activity during eyes-open wakefulness up to three hours after napping.

Although all subjects were able to obtain sleep in the nap opportunity provided in the study conducted by Hayashi et al. (1999), it may be difficult for some individuals to achieve this extra sleep during the day, as experienced by two subjects in the study carried out by Horne and Reyner (1996). Therefore, an even more convenient
alternative to an afternoon nap in the quest to increase daytime alertness could be the ingestion of caffeine in the afternoon instead. Zwyghuizen-Doorenbos, Roehrs, Lipschutz, Timms and Roth (1990) investigated the effect of 250mg of caffeine administered twice throughout the day (at 9am and 1pm, i.e. 500mg daily intake) for two days on alertness in a group of moderately (screening MSLT score 5-6min) sleepy subjects. They found that caffeine both decreased daytime sleepiness as measured by the MSLT and improved performance compared with a control group, even on a third day, when no caffeine was administered to either group. However, it is worth noting that there was a smaller improvement in sleep latency on day two compared to day one relative to baseline, which could indicate the build up of a tolerance to the alerting effects of caffeine.

The study carried out by Zwyghuizen-Doorenbos et al. (1990) involved a relatively large (500mg) daily intake of caffeine, equivalent to about six cups of standard coffee. Horne and Reyner (1996) investigated the impact of 150mg of caffeine (equivalent to two standard cups of coffee) administered at 3pm following 5h sleep the previous night and directly compared this with a 15min nap and no intervention in a simulated driving study. They found that 150mg caffeine markedly reduced driving impairment, subjective sleepiness (KSS) and EEG-defined drowsiness compared to no intervention and "for those able to take a sustained short nap, the benefits were similar to those of caffeine, but, because not all of the subjects could nap, the nap findings were more inconsistent" (p309). It appears that if a short afternoon nap is unachievable or impractical, then one or two cups of coffee consumed in the afternoon may be sufficient to counter the afternoon dip in alertness experienced by many individuals.
1.4 Research questions

Through examination of the current literature, several salient points have come to light, indicating areas where more investigation is required. The following bullet points highlight gaps in the current research, which justify the need to conduct the present study.

- Standard MSLT testing commences at 10am and finishes at either 4pm or 6pm depending on which protocol is used. This covers less than half of the waking day and so there is a need to investigate what happens later on in the evening up until bedtime,
- There have been many studies conducted investigating the effect of sleep extension, napping and caffeine individually, but none has directly compared all three interventions to compare their relative benefits,
- Often subjects with extreme MSLT scores are compared, for example, those with mean scores of 6min compared to those with mean scores of 16min. There has been no study to investigate normal, healthy subjects who reside in the “diagnostic grey area” in terms of sleep latency, i.e., between 5min and 15min daily MSLT score,
- The effect of various activities (such as reading, walking, social interaction, working quietly on a computer) on subjective sleepiness as measured by the KSS have been investigated (Eriksen, Åkerstedt, Kecklund, & Åkerstedt, 2005), but the positional effect of lying down for a short period of time versus sitting at a desk has not been investigated explicitly,
- In their population study of objective sleep tendency, Punjabi et al. (2003) comment that sleep extension has been shown to improve MSLT results in individuals with low (<6min) and normal (>12min) baseline levels [with reference to the study conducted by Roehrs et al. (1989)], but “the significance of increased the MSLT results in nonsleepy individuals beyond normative levels is unknown. Clearly, further research is necessary to determine whether extension of night-time sleep beyond 7 to 8 hours and prolongation of the daytime sleep latency have any added benefit with regard to improvement in the performance of neurobehavioral tasks, quality of life, and general health” (p682).
Using the points listed above as a guide, the following research questions were proposed:

- How do MSLT scores alter when testing commences in the afternoon (3.30pm) and carries on until the late evening (11pm)?
- Are healthy 7-8h sleepers able to extend their nocturnal sleep by up to 90mins on demand?
- Does one night of sleep extension of up to 90mins extra sleep improve objective and subjective sleepiness in normal, healthy individuals that normally sleep 7-8h a night?
- How does the impact of sleep extension on objective and subjective daytime sleepiness compare to that of a 20min afternoon nap or 150mg caffeine?
- Does a change in situation from sitting at a desk to lying down in the dark for 5mins have a measurable impact on daytime subjective sleepiness?
- Do otherwise healthy individuals with shorter daily MSLT scores (5-9min) exhibit increased subjective sleepiness and decreased performance compared to those with longer (12-15min) daily MSLT scores?
- Do the two groups defined in the previous question react differently to extending their sleep, napping or caffeine in terms of objective and subjective sleepiness?
- Do the two groups exhibit similar sleep architecture (in terms of sleep stages and EEG frequency content) during a normal night's sleep?
- Are the two groups of individuals able to increase their daytime sleep latency simply by trying to remain awake instead of trying to fall asleep?
- Is there a subset of individuals within the group with daily MSLT scores between 5-9min that possess High Sleepability, No Sleepiness, as defined by Harrison and Horne (1996a)?
2 Methodology

This chapter outlines the techniques and methods used in the recruitment of participants and the collection of data for the studies reported in chapters 3-6. Each results chapter will provide information on the specific methods used, with reference to the current chapter where necessary.

Main themes covered in this section:

- Participant selection
- The screening process: inclusion criteria
- Measuring daytime sleepiness: equipment and methods
- Study design

2.1 Participant selection

Twenty (9 male, 11 female) healthy individuals (mean age 25.9y, range 21.5 – 34.3y) who regularly slept 7-8h a night, napped less than once a week and did not suffer from any sleep disorders were recruited to take part in the study. They were non smokers, did not consume excessive caffeine (less than 4 cups of coffee a day) and did not suffer from excessive daytime sleepiness as measured by the Epworth Sleepiness Scale (ESS ≤10) (Johns, 1991). They were within the normal range of Trait Anxiety in the Spielberger State-Trait Anxiety Inventory (Spielberger, Gorsuch & Lushene, 1970) and were neither extreme morning nor extreme evening types (Horne & Ostberg, 1976).

Participants were recruited via poster and email advertisements within the Loughborough University campus. The study was approved by the University’s Ethical Advisory Committee.

2.2 Screening

Potential participants (n=194) were screened via interview and a detailed questionnaire containing questions on sleep habits and perceived sleep need, general health, daytime sleepiness as measured by the ESS (Johns, 1991) and morning/evening typology as measured by the Horne & Ostberg Questionnaire (1976). Only individuals scoring 10 or under in the ESS, indicating that they did not suffer from excessive
daytime sleepiness, were included in the study. Extreme morning or evening types were also excluded from the study.

Thirty-four (17.5%) participants were excluded at this stage of the screening process and a further 11 (5.7%) failed to return for further screening. 149 participants were recruited to take part in the next stage of the screening.

2.2.1 Daytime sleepiness and sleep habits
Participants successful at the questionnaire stage (n=149) completed the Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg, 1990) hourly whilst awake, for three days (see section 3.3.4 for more detail on the KSS). Those exhibiting little daytime sleepiness other than the 'afternoon dip' in alertness continued to the next stage of the screening process, which involved wearing a wrist actiwatch (Cambridge Neurotechnology Ltd., Cambridge) and keeping a sleep diary for three consecutive nights. Individuals exhibiting no sign of an 'afternoon dip' were excluded from the study (n=14, 7.2%).

Using sleep diaries and actigraphy together gives both subjective and objective information about an individual's sleep-wake patterns, providing information on sleep length, quality and regularity. The sleep diary is an easy and effective way of gaining subjective sleep-wake information and the actiwatch works well alongside it providing objective movement data. The software used alongside the actiwatches uses the recorded data to determine sleep onset and offset and from this calculates the Sleep Period (SP, time between initial sleep onset and final awakening).

2.2.1.1 Sleep diaries
Each morning upon waking the sleep diary was filled in, with the individual providing information on sleep and wake times as well as how well they felt they slept that night. See Figure 2.1 for the questions used in the sleep diary.
Last night I went to bed at...
This morning I woke up at...
This morning I got out of bed at...
Last night, I slept for a total of ... hours
Last night, I fell asleep in... minutes
Last night, I woke up... times
Last night my sleep was disturbed by...
When I woke I felt refreshed/ somewhat refreshed/ fatigued...
I slept better/worse/somewhat the same as usual
I did/did not sleep with my partner
I had difficulty staying awake during the day
I felt extremely sleepy between the hours of...... and ...

<table>
<thead>
<tr>
<th>Last night, before going to bed, I consumed alcohol (extent?)</th>
</tr>
</thead>
</table>

**Figure 2.1:**  *Sleep diary questions*

### 2.2.1.2 Actiwatch

The actiwatch comprises a movement sensor with a miniaturised computer and is worn on the wrist in the style of a wristwatch (see Figure 2.2). The actiwatch is programmed to start recording at 9pm and records continually throughout the day and night, storing movement data every 30s.

[Figure 2.2: Neurotec actiwatch as it would be worn by a participant, along with the reader and software used to download data.]

The actiwatch is worn on the non-dominant wrist at all times, except in situations when it may become wet or damaged, during showering or exercise, for example. The participant is requested to make a note in the sleep diary if the actiwatch is removed at any time, along with why and for how long. A button on the actiwatch is pressed by the wearer once when retiring to bed to sleep and once upon waking each day that it is worn, which places a marker on the recording. Verbal instructions were given to the
participant on how to use the actiwatch, along with a written instruction sheet (see Appendix 1). Once worn for the required amount of time, the data was downloaded and visually inspected.

Participants with extreme bedtimes (n=13, 6.7%), irregular sleep patterns (n=13, 6.7%) or those who regularly slept outside the 7-8h range (n=32, 16.5%) were excluded from the study. A further 16 individuals (8.2%) failed to return after this stage of the screening.

2.2.2 Screening day

Those successfully completing the earlier screening measures were invited to spend a day at Loughborough Sleep Research Centre, from 9am until 5pm (n=61). Each participant was given information about the day and signed a consent form to enable testing to take place (see Appendix 2). The night before testing the participant wore an actiwatch, kept a sleep diary and was requested to sleep their usual sleep length (i.e. 7-8h). On the morning of testing the actiwatch was downloaded and checked alongside the sleep diary to ensure that the participant had obtained between 7-8 hours of good quality sleep.

At 9.30am, Ag-AgCl reusable electrodes were carefully applied to the head and face using the 10-20 system in the montage accepted for the Standard MSLT (detailed in section 2.3.1). Testing commenced at 10am with the first session of the Standard MSLT. Subsequent MSLT sessions were at 12pm, 2pm and 4pm. For more detail on the procedure for the Standard (research) MSLT see section 2.3.1. At 10.40am the participant carried out the PVT for 20min in order to eliminate any practice effects in the main PVT session, which was carried out at 4.30pm for 30min. Subjective levels of sleepiness were assessed by way of the KSS, administered when the participant was in bed immediately before each MSLT session commenced. Whilst at the Sleep Centre the participant was required to provide a urine sample, which was tested for the presence of recreational drugs (Surescreen Diagnostics, 6 drug multitest). Throughout the day the participant remained in the centre avoiding exercise, with a standard meal provided at lunchtime (1pm) and a scheduled coffee/tea (decaffeinated) break in the afternoon (3pm). Figure 2.3 shows the schedule for the screening day.
Chapter 2: Methodology

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Participant arrives, actiwatch checked</td>
</tr>
<tr>
<td>09:30</td>
<td>Electrodes attached</td>
</tr>
<tr>
<td>10:00</td>
<td>KSS, MSLT session</td>
</tr>
<tr>
<td>10:40</td>
<td>20min PVT practice</td>
</tr>
<tr>
<td>12:00</td>
<td>KSS, MSLT session</td>
</tr>
<tr>
<td>13:00</td>
<td>Lunch break</td>
</tr>
<tr>
<td>14:00</td>
<td>KSS, MSLT session</td>
</tr>
<tr>
<td>15:00</td>
<td>Coffee break</td>
</tr>
<tr>
<td>16:00</td>
<td>KSS, MSLT session</td>
</tr>
<tr>
<td>16:30</td>
<td>30min PVT</td>
</tr>
<tr>
<td>17:00</td>
<td>Participant leaves</td>
</tr>
</tbody>
</table>

Figure 2.3: *Screening day schedule*

Participants obtaining a mean Sleep Onset Latency (SOL) outside the required range of 5-9min or 12-15min were excluded from the study (n=32, 16.5%), along with those obtaining abnormally poor PVT scores in the first 10 minutes of the test at 4.30pm (normative data presented by Jewett, Dijk, Kronauer, & Dinges, 1999; Drake et al., 2001; Belenky et al., 2003) (n=0). Individuals giving a positive result on the drugs test were also excluded from the study (n=2, 1.0%).

Participants successfully completing the screening day were divided into those classed (according to their SOL in the Standard MSLT) as mildly sleepy (average SOL 12-15min) and moderately sleepy (average SOL 5-9min) as determined by the American Sleep Disorders Association (ASDA) (Thorpy, 1992).

### 2.2.3 Overnight EEG study

The final stage in the screening process was a night of polysomnography recorded in the participant's own home. This was carried out in order to confirm that the individual did not suffer from any sleep related disorders (n=23).

Polysomnography involves the measurement of brain activity (Electroencephalogram, EEG), eye movements (Electrooculogram, EOG) and muscle activity (Electromyogram, EMG) using (Ag-AgCl reusable) electrodes. Specific points were located and marked out on the participant's skull in accordance with the Rechtschaffen & Kales (1968) International 10-20 system, as shown in Figure 2.4.
Figure 2.4: The electrode positions (montage used highlighted in red) in accordance with The International 10-20 system (Rechtschaffen & Kales, 1968).

Five bi-polar EEG channels were recorded, $F_{p1}$-$F_3$, $F_{p2}$-$F_4$, $C_4$-$A_2$, $O_1$-$P_3$ and $O_2$-$P_4$, along with bilateral EOG (left and right outer canthus, referenced to $A_1$) and submental EMG. Careful skin preparation was carried out to ensure that electrode impedance remained below 5kΩ, reducing signal noise to a minimum. EEG and EOG data were sampled at 100Hz and EMG at 200Hz. High and low bandpass filters were set at 0.3Hz and 30Hz, respectively, with a notch filter applied at 50Hz to reduce electrical noise. Once applied to the scalp the electrodes were connected to an Embla A10 ambulatory unit (Embla Flaga hf. Medical Devices), which was pre-programmed to record from 8pm that evening until 9am the next day, i.e. continuously for 13 hours.
A sleep diary for the recording night was completed by all participants in order to gain information on how well they slept compared with a typical night. On completion of the overnight recording the data was downloaded and manually scored into sleep stages in 30s epochs by an experienced scorer. The following definitions were used:

- Sleep Onset Latency (SOL): the time from lights out to the first 30s epochs of stage 1 sleep or one 30s epoch of any other sleep stage,
- Sleep Period (SP): time from sleep onset until final awakening,
- Total Sleep Time (TST): SP minus any interim wakefulness,
- Sleep Efficiency (SE<sub>SP</sub>): TST as a percentage of SP

Each recording was inspected for sleep disturbances, early onset REM (an indicator of narcolepsy), excessive muscle activity and any other abnormal sleep architecture. In addition, each individual’s SE<sub>SP</sub> over the course of the night was calculated. Those with a SE<sub>SP</sub> of less than 85% were excluded from the study. No participants were excluded from the study on account of their overnight EEG recording.

2.2.3.1 Determining nocturnal sleep period

Overnight EEG prior to the main study test days was not carried out as it was important that prior nocturnal sleep was as representative as possible of a ‘normal’ night’s sleep. Carrying out EEG recordings the night before test days may have presented a possible confound to the study. However, as a quality control measure, 6 participants wore actiwatches on their EEG screening night so that the consistency between the two modalities could be ascertained.

![Figure 2.5: Comparison of Sleep Period (SP) as measured by overnight EEG and actiwatch (n=6).](image)
A Pearson correlation showed sleep period as measured via the overnight EEG to be significantly correlated to the sleep period recorded by the actiwatch \((r=0.93, p=0.004, r^2=0.86)\). This high correlation (shown graphically in Figure 2.5) provided confidence in the use of actiwatches alone to accurately determine sleep period the night before and after each of the study conditions.

### 2.3 Measuring daytime sleepiness

As discussed in Chapter 1, the MSLT is a standardised, validated objective measure of sleepiness (Carskadon et al., 1986a), based on the fundamental assumption that the quicker a person falls asleep during the test sessions, the higher their level of sleepiness. The following sections describe the procedure for carrying out the Standard (research) MSLT and how this has been altered for use in the present research to become what has been termed the Modified MSLT.

#### 2.3.1 The Standard MSLT

In the Standard MSLT, tests are performed throughout the day from 10am until either 4pm (4-session protocol) or 6pm (5-session protocol). The Standard research MSLT (4-session) is carried out as follows:

The night before the test the subject is requested to refrain from drinking alcohol or caffeine after 10pm, to wear an actiwatch and keep a sleep diary overnight. On the day of the test the participant arrives at the Sleep Research Centre at 9am, having had a light breakfast at home. At 9.30am, after careful skin preparation, electrodes to measure brain activity by way of the Electroencephalogram (EEG), eye movements (Electrooculogram, EOG) and muscle activity (Electromyogram, EMG) are applied to the head and face. The Rechtschaffen & Kales (1968) International 10-20 system was used to locate specific points on the skull where the electrodes are to be attached (as shown in Figure 2.4). Two EEG channels are recorded, \(C_4-A_2, C_3-A_1\), along with bilateral EOG (left and right outer canthus, referenced to \(F_p\)) and submental EMG. Often an occipital EEG channel is recorded in addition to the central channels to assist in the detection of alpha (8-11Hz) activity. However, in this study, excellent recordings with a high signal to noise ratio were consistently obtained for the two central channels, enabling alpha activity to be easily identified on these channels alone. Electrode impedances are checked and required to be below 5k\(\Omega\), ensuring that signal noise is kept to a minimum, reducing interference of the electrophysiological signals.
Five minutes before the first MSLT session the subject enters the bedroom and the electrodes are attached to the EEG recording equipment (Embla N7000). The room is comfortable, temperature controlled, dimly lit (10lux) and sound attenuated. At 10am the subject is instructed to “Lie quietly, relax, close your eyes, keep them closed and try to go to sleep”. The lights are turned out and the bedroom door is closed, signalling the start of the test. The participant has up to 20 minutes to fall asleep, after which the session is terminated if sleep onset does not occur. The sleep onset criterion is defined as the first 30s epoch of stage 1 sleep or of any other sleep stage (Rechtschaffen & Kales, 1968) and the Sleep Onset Latency (SOL) is the time from lights out to sleep onset. If sleep onset does occur the participant is awoken after three consecutive 30s epochs of stage 1 sleep or after one 30s epoch of any other sleep stage have elapsed. Subsequent sessions are at 12pm, 2pm and 4pm. In between test sessions the participant remains in the sleep centre, avoiding exercise and caffeinated drinks. Standard light meals are provided throughout the day.

The average SOL for the day is calculated using data from the four sessions, enabling classification of the level of daytime sleepiness. Carskadon et al. (1986a, p523) state that "adult normal control volunteers usually score in the range 10-20min" and defines that an average sleep latency of < 5min indicates a "pathological level of daytime sleepiness". It is also mentioned that "scores between pathological and normal ranges have become known as a diagnostic grey area" (Carskadon et al., 1986a, p523; van den Hoed et al., 1981). An average sleep latency of 10-15 minutes is classed as “mild”, 5-10 minutes as “moderate” and 0-5 minutes as "severe" daytime sleepiness by the ASDA (Thorpy, 1992).

### 2.3.2 The Modified MSLT

The Modified MSLT was developed for the purpose of this study to investigate objective sleepiness later on in the day than that covered by the Standard MSLT. The Modified MSLT is identical to the Standard MSLT in every way except for the times at which it is administered. Instead of test sessions two-hourly from 10am, the Modified MSLT sessions are at 3.30pm, 5pm, 7.45pm and 11pm. Ideally, the sessions would be two hours apart as in the Standard MSLT protocol, but due to the timing of other tests, carried out on the same day and following pilot testing, the times chosen were the most practical for the testing schedule.
2.3.3 Performance: The PVT

The Psychomotor Vigilance Test (PVT) is one of the most common methods of measuring performance (Dinges & Kribbs, 1991). The PVT is a sustained-attention, simple reaction time task, requiring the individual to respond by pressing a button with the forefinger or thumb of their dominant hand to a visual stimulus presented randomly with an inter-stimulus interval of between 2 and 12 seconds. The display viewed by the participant during the test is shown in Figure 2.6.

![Display on the monitor screen during the PVT. A ms counter appears periodically in the red box (showing 241ms here), which the participant responds to as quickly as possible by pressing a designated button.](image)

The PVT is easy to perform, dull and monotonous, with any practice effects minimised by sufficient training in the test beforehand (Dinges & Kribbs, 1991, p115; Dinges et al., 1997). It is a proven sensitive and effective way to measure sleepiness (Dinges & Powell, 1985; Horne, 1988b; Dinges & Kribbs, 1991, p97-128), and has been shown to be sensitive to sleep deprivation, partial sleep loss and circadian variation in performance efficiency (Dinges et al., 1987; Jewett et al., 1999).

The PVT is carried out in a sound attenuated, visually unexciting room in order to reduce unwanted noise and distraction, so that the participant may concentrate fully on the task. The longer the PVT is performed for, the more sensitive it becomes to any sleepiness experienced by the individual carrying out the test (Dinges & Kribbs, 1991, p108-112). Therefore, when using the PVT to measure performance in well-rested individuals (as in the research of the present study) the length of the test is extended (in this case from the usual 10 minutes to 30 minutes). On completion of the test the data is scrutinised for lapses, which are defined as any Reaction Time (RT) ≥500ms. The number of lapses in any test session is a good indicator of the level of sleepiness an individual is experiencing, with a higher number of lapses indicating greater sleepiness (Dinges & Kribbs, 1991, p102-106; Van Dongen et al. 2003b; Horne, 2004).
The lapses and any response errors are removed from the data and from the remaining data the mean RT is calculated.

2.3.4 Subjective sleepiness: The KSS

The Karolinska Sleepiness Scale (KSS) is a widely used introspective measure of sleepiness (Åkerstedt & Gillberg, 1990). It was chosen for use in the present research as it is quick and simple to administer, giving an instant indication of the level of subjective sleepiness experienced by an individual. The KSS requires the individual to rate how sleepy they feel at any given moment on a scale from 1 (Extremely alert) through to 9 (Very sleepy, great effort to keep awake, fighting sleep), see Figure 2.7.

<table>
<thead>
<tr>
<th></th>
<th>Extremely alert</th>
<th>Very alert</th>
<th>Alert</th>
<th>Rather alert</th>
<th>Neither alert nor sleepy</th>
<th>Some signs of sleepiness</th>
<th>Sleepy, but no effort to keep awake</th>
<th>Sleepy, some effort to keep awake</th>
<th>Very sleepy, great effort to keep awake, fighting sleep</th>
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<tbody>
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<td></td>
</tr>
</tbody>
</table>

Figure 2.7: The Karolinska Sleepiness Scale (Åkerstedt & Gillberg, 1990).

One drawback of the KSS is the "comparatively coarse scale of the measurement", which can "be relatively non-discriminating when applied to non-pathological populations" (Monk, 1991, p48). In addition, as with any subjective measurements the participant is totally relied upon for an accurate reading and different individuals will rate themselves relative to different positions on the scale. However, if the experimenter takes time to build a good rapport with the participant then the likelihood of obtaining honest readings should be increased. Also, if a repeated measures design is used, as in the present study, each participant behaves as their own control, enabling any change in subjective sleepiness to be measured accurately. The KSS has also been validated against EEG activity, with EEG changes occurring when point 7 is reached on the KSS, indicating that individuals have a good insight into their level of sleepiness (Åkerstedt & Gillberg, 1990; Baulk, Reyner & Horne, 2001).
2.4 Study design

23 participants (10 male) successfully completed all screening measures. After reading the study information sheet and having had any questions answered, all 23 participants agreed to take part in the research and confirmed this by signing a consent form. One participant was excluded during the course of the main study for failing to follow instructions and two participants pulled out of the study part way through for reasons not relating to the study. In total, 20 participants (9 male) completed the study.

Participants attended the Sleep Research Centre one day a week for four consecutive weeks in order to carry out each condition. The order in which each participant underwent the conditions was counterbalanced to account for any possible order effects and is shown in Table 2.1.

Table 2.1: Table showing the order in which each participant underwent the four conditions.

<table>
<thead>
<tr>
<th>PARTICIPANT NUMBER</th>
<th>CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WEEK 1</td>
</tr>
<tr>
<td>1-5</td>
<td>1</td>
</tr>
<tr>
<td>6-10</td>
<td>2</td>
</tr>
<tr>
<td>11-15</td>
<td>3</td>
</tr>
<tr>
<td>16-20</td>
<td>4</td>
</tr>
</tbody>
</table>

Condition 1: Baseline condition
A standard control comprising a normal night’s sleep without any extra sleep, using the Modified MSLT the next day.

Condition 2: Sleep Extension
A night of extended sleep using the Modified MSLT the next day.

The sleep extension was carried out at home and verified by actimetry. The participant was asked to try and sleep 90 minutes beyond their normal sleep length, retiring to bed at their usual time. All participants were requested to stay in bed for this extra time even if they did not sleep during it.
Condition 3: Nap

Condition 1 with the addition of an afternoon nap at 14:30.

For this condition the participant retired at 14:30 (to a bedroom in the sleep laboratory) and was instructed to relax and go to sleep. The nap length was restricted to a maximum of 20 minutes to avoid unwanted sleep inertia and began at the onset of the first 30s of stage 1 sleep or any other sleep stage, as defined by Rechtschaffen & Kales (1968). If no sleep was obtained within 30 minutes the session was terminated. For all other conditions the subject read quietly in the bedroom from 14:30-15:00.

Condition 4: Caffeine

Condition 1 with 150mg of caffeine (equivalent to two average cups of coffee) added to decaffeinated coffee, given at 14:15. Decaffeinated coffee was given blind to the participants in all other conditions.

The participants wore an actiwatch and kept a sleep diary the night before each day at the centre. They were requested to avoid caffeinated or alcoholic drinks the night before testing and had breakfast at home before coming into the centre at 10:30. On arrival at the Sleep Research Centre the participant's actiwatch was downloaded and visually inspected to ensure that they had achieved sufficient sleep length and quality to undergo testing that day i.e. 7-8h of undisturbed sleep. Standard meals were provided for the participant whilst at the centre and during this time they avoided exercise. At the end of the day, when all testing was complete, participants were taken home via taxi. The testing schedule for each day is shown in Figure 2.8.
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:30</td>
<td>ARRIVE</td>
</tr>
<tr>
<td>10:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>11:00 - 11:30</td>
<td>PVT</td>
</tr>
<tr>
<td>11:50</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>12:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>13:00 - 13:30</td>
<td>PVT</td>
</tr>
<tr>
<td>13:50</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>14:15</td>
<td>COFFEE</td>
</tr>
<tr>
<td>14:30</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>14:30 - 15:00</td>
<td>READING / NAP</td>
</tr>
<tr>
<td>15:10</td>
<td>ELECTRODES ON</td>
</tr>
<tr>
<td>16:10 - 16:40</td>
<td>PVT</td>
</tr>
<tr>
<td>16:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>17:50</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>18:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>20:15</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>20:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>21:50</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>22:10 - 22:40</td>
<td>PVT</td>
</tr>
<tr>
<td>22:50</td>
<td>KSS (Desk)</td>
</tr>
<tr>
<td>23:30</td>
<td>KSS (Desk+5min)</td>
</tr>
<tr>
<td>23:35</td>
<td>LEAVE</td>
</tr>
</tbody>
</table>

**Figure 2.8:** Daily testing schedule: KSS measured throughout the day alternating between measurements made with the participant sitting at a desk only (Desk), and with the participant first sitting at a desk and then after having had a lie down for 5 minutes in the bedroom (Desk+5min).
2.4.1 Modified MSLT

The Modified MSLT commenced at 3.30pm with the last test session at 11pm, measuring objective sleepiness from the afternoon into late evening (as shown in Figure 2.8). For each MSLT session the participant removed their shoes, loosened any restrictive clothing and was asked to lie down in a comfortable position on a bed in a dimly lit (10lux), sound attenuated bedroom. They were instructed to "Lie quietly, relax, close their eyes, keep them closed, and try to go to sleep".

The EEG, EOG and EMG were viewed continuously on a computer monitor throughout the session in order to ascertain exactly when sleep onset occurred. Sleep onset was defined as the first 30s epoch of stage 1 sleep or of any other sleep stage (Rechtschaffen & Kales, 1968) and the Sleep Onset Latency (SOL) was defined as the time from lights out until sleep onset. If sleep did not occur in any given session the test was terminated after 20 minutes.

2.4.2 PVT

The PVT was carried out in the morning and early afternoon to avoid excessive use of the MSLT in the measurement of objective sleepiness. Each PVT session was 30 minutes rather than the more commonly used 10 minutes. This extension was made in order to increase the sensitivity of the task to any change in vigilance exhibited by the well rested participants (discussed previously in section 2.3.2).

2.4.3 KSS

The KSS was administered approximately every hour (whilst the participant sat at a desk) in order to gain information on the impact of each condition on subjective sleepiness over the course of the day. Approximately every two hours the KSS was carried out twice, firstly with the subject sitting at a desk and then after they had been lying down in a quiet, dark bedroom for 5 minutes. This was done to investigate the effect of varying situation on subjective sleepiness.

2.4.4 Ability to maintain wakefulness

In addition to the four conditions mentioned in section 2.4, a fifth condition was carried out. This was identical to condition 1 (with the same testing schedule as that shown in Figure 2.8) except that the Repeated Test of Sustained Wakefulness (RTSW) was used instead of the MSLT. Instead of the instruction to try to go to sleep, the participant was asked to "Lie quietly, relax, close your eyes, keep them closed, but try and stay awake".

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The RTSW condition was introduced to investigate the possibility that some of the participants would be able to fall asleep very quickly in the MSLT but be able to stay awake when required, as in the RTSW, exhibiting what has been termed by Harrison and Horne as "High sleepability without sleepiness" (1996a). This concept is discussed in more detail in Chapter 6. Unlike all other conditions, the order in which the RTSW condition was carried out was not counterbalanced and it was always carried out in the fifth week. Ideally, all five conditions would have been counterbalanced, but this was not possible due to restrictions imposed by the research proposal on which the present study was initially designed.
3 Study 1: Main effect of condition

3.1 Introduction

Previous studies have reported on the effects of nocturnal sleep extension (Roehrs et al., 1989; Carskadon & Dement, 1996b; Harrison & Horne, 1996b), daytime napping (Dinges et al., 1987; Gillberg et al., 1994; Hayashi et al., 1999) and the ingestion of caffeine (Zwyghuizen-Doorenbos et al., 1990) separately on various objective and subjective measures of daytime sleepiness. The aim of this experimental chapter is to directly compare the effect of extended nocturnal sleep with that of a short afternoon nap or the ingestion of caffeine on objective (as measured by the MSLT and PVT) and subjective (as measured by the KSS) daytime sleepiness in a group of healthy individuals with habitual sleep durations of 7-8h a night.

It is hypothesised that all three conditions (sleep extension, afternoon nap, caffeine) will increase sleep latency in the MSLT, reduce the mean reaction time and the number of lapses in the PVT and reduce subjective sleepiness as measured by the KSS compared to baseline.

Data from this chapter has been presented in poster format at the 19th Congress of the European Sleep Research Society, 9th-13th September, Glasgow, UK and is shown in Appendix 3.

Main themes covered in this section:

- Participant characteristics
- Night-time sleep: pre and post test days
- The effect of condition on:
  - MSLT scores and survival curves
  - Performance
  - Subjective sleepiness in two situations

3.2 Methods

This study comprised a repeated measures design, with all participants undergoing each of the four conditions [Sleep Extension (SE) vs. Nap (NAP) vs. Caffeine (CAFF) vs. Baseline (BL)] in a counterbalanced order. Participant characteristics are shown in
section 3.2.1 and a detailed description of the study design can be found in Chapter 2, sections 2.4.1 to 2.4.3.

### 3.2.1 Participant characteristics

The 20 participants comprised 11 females and 9 males with a mean age of 25.9y (s.d. 3.9). All had an ESS score of 10 or below and Trait anxiety scores below 50, within the normal range for these parameters (Johns, 1991; Spielberger et al., 1970). No participant was an extreme morning or evening type, with 13 (65% of sample) identified as 'neither morning nor evening' type (NT) [Morning-Evening (M/E) score=42-58] and 7 (35%) of the Morning Type (MT) category (M/E score=59-69) (Horne & Ostberg, 1976). Participant characteristics are detailed in Table 3.1.

#### Table 3.1: Participant characteristics for study 1.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age</th>
<th>ESS Score</th>
<th>Trait Score</th>
<th>M/E Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK01</td>
<td>M</td>
<td>26.0</td>
<td>3</td>
<td>41</td>
<td>56</td>
</tr>
<tr>
<td>YG02</td>
<td>M</td>
<td>24.0</td>
<td>0</td>
<td>24</td>
<td>53</td>
</tr>
<tr>
<td>HM03</td>
<td>F</td>
<td>23.0</td>
<td>6</td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td>DB04</td>
<td>M</td>
<td>32.4</td>
<td>4</td>
<td>28</td>
<td>59</td>
</tr>
<tr>
<td>KM05</td>
<td>F</td>
<td>25.0</td>
<td>9</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>BC06</td>
<td>F</td>
<td>32.8</td>
<td>9</td>
<td>33</td>
<td>58</td>
</tr>
<tr>
<td>CB07</td>
<td>F</td>
<td>22.3</td>
<td>6</td>
<td>32</td>
<td>68</td>
</tr>
<tr>
<td>AC08</td>
<td>F</td>
<td>22.0</td>
<td>5</td>
<td>24</td>
<td>61</td>
</tr>
<tr>
<td>JT09</td>
<td>F</td>
<td>27.9</td>
<td>10</td>
<td>39</td>
<td>57</td>
</tr>
<tr>
<td>EG10</td>
<td>F</td>
<td>25.4</td>
<td>10</td>
<td>27</td>
<td>63</td>
</tr>
<tr>
<td>GC11</td>
<td>M</td>
<td>29.6</td>
<td>10</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td>MO12</td>
<td>F</td>
<td>25.6</td>
<td>8</td>
<td>33</td>
<td>66</td>
</tr>
<tr>
<td>NB13</td>
<td>M</td>
<td>28.7</td>
<td>4</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>JL14</td>
<td>M</td>
<td>23.6</td>
<td>4</td>
<td>29</td>
<td>62</td>
</tr>
<tr>
<td>VS15</td>
<td>F</td>
<td>22.2</td>
<td>6</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td>RC16</td>
<td>M</td>
<td>22.2</td>
<td>1</td>
<td>31</td>
<td>56</td>
</tr>
<tr>
<td>CW17</td>
<td>F</td>
<td>23.7</td>
<td>4</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>RH18</td>
<td>M</td>
<td>21.5</td>
<td>2</td>
<td>26</td>
<td>49</td>
</tr>
<tr>
<td>PS19</td>
<td>F</td>
<td>26.0</td>
<td>8</td>
<td>32</td>
<td>43</td>
</tr>
<tr>
<td>LT20</td>
<td>M</td>
<td>34.3</td>
<td>6</td>
<td>31</td>
<td>64</td>
</tr>
</tbody>
</table>

Mean(s.e.) 25.9(0.86) 5.8(0.7) 32.7(1.33) 56.2(1.5)

#### 3.2.1.1 Habitual sleep duration

The sleep diary and actiwatch data were combined (Actiwatch activity and sleep analysis 5. Copyright Cambridge Neurotechnology Ltd. Version 5.27) and mean Sleep Period (SP, time from initial sleep onset until final awakening) was calculated for the three sleep screening days and the night before the Standard MSLT screening day...
(see Figure 3.1). Figure 3.1 shows the mean SP for each night to be within the required range of 7-8h and a MANOVA on this data showed there to be no significant effect of night, indicating consistency across the nights.

![Diagram showing mean sleep period for each condition](image)

**Figure 3.1:** Mean (s.e.) sleep period for night preceding the three screening days [Screen1 (n=19), Screen2 (n=20) and Screen3 (n=20)] and the Standard MSLT screening day (n=20).

### 3.2.1.2 Standard MSLT scores

Using the standard method of scoring for the MSLT (Carskadon et al., 1986a), any session in which the participant failed to fall asleep was allocated a score of 20 minutes and included in all calculations. The mean daily sleep latency for the 20 participants in the Standard MSLT was 11.5min (s.d. 0.8), with mean values for each test session shown in Figure 3.2.

---

1 The mean value presented for the Screen1 night is for 19 participants due to a failure of the actimeter to record the night’s sleep of one participant.
Figure 3.2: Mean (SE) sleep latency for each test session in the Standard screening MSLT.

A one factor repeated measures ANOVA showed a significant effect of time \[F(3,57)=4.70, \ p<0.01\] on sleep latency, which can be seen clearly in Figure 3.2. Post-hoc Bonferroni comparisons showed that participants took significantly longer to fall asleep in the 10am session compared to the 12pm (\(p<0.01\)) and 4pm (\(p<0.01\)) sessions.

3.2.1.3 PVT performance

All participants underwent a 30 minute PVT at 4.30pm on the screening day. Each participant's performance over the first 10 minutes of the test was examined to ensure that it was within normal boundaries, i.e. a mean Reaction Time (RT) of less than 350ms (after lapses have been removed) and no more than 10 lapses during that time. These normative values were based on those reported by Jewett et al. (1999), Drake et al. (2001) and Belenky et al. (2003). A lapse is defined as a reaction time of 500ms or longer. Mean RT (after removal of lapses) and total lapses over the first 10 minutes for each participant are shown in Table 3.2. All 20 participants exhibited normal levels of performance in the first 10 minutes of the screening PVT.
Table 3.2:  Mean reaction time (RT) (after removal of lapses, ms) and number of lapses (RT≥500ms) in the first 10 minutes of the screening PVT.

<table>
<thead>
<tr>
<th>Participant</th>
<th>RT (ms)</th>
<th>Lapses</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK01</td>
<td>267.27</td>
<td>0</td>
</tr>
<tr>
<td>YG02</td>
<td>279.01</td>
<td>0</td>
</tr>
<tr>
<td>HM03</td>
<td>297.39</td>
<td>2</td>
</tr>
<tr>
<td>DB04</td>
<td>252.59</td>
<td>2</td>
</tr>
<tr>
<td>KM05</td>
<td>243.53</td>
<td>0</td>
</tr>
<tr>
<td>BC06</td>
<td>293.81</td>
<td>0</td>
</tr>
<tr>
<td>CB07</td>
<td>313.97</td>
<td>2</td>
</tr>
<tr>
<td>AC08</td>
<td>294.68</td>
<td>1</td>
</tr>
<tr>
<td>JT09</td>
<td>331.49</td>
<td>9</td>
</tr>
<tr>
<td>EG10</td>
<td>280.43</td>
<td>0</td>
</tr>
<tr>
<td>GC11</td>
<td>302.51</td>
<td>3</td>
</tr>
<tr>
<td>MO12</td>
<td>273.45</td>
<td>1</td>
</tr>
<tr>
<td>NB13</td>
<td>305.32</td>
<td>4</td>
</tr>
<tr>
<td>JL14</td>
<td>227.55</td>
<td>0</td>
</tr>
<tr>
<td>VS15</td>
<td>310.22</td>
<td>4</td>
</tr>
<tr>
<td>RC16</td>
<td>259.76</td>
<td>1</td>
</tr>
<tr>
<td>CW17</td>
<td>306.17</td>
<td>0</td>
</tr>
<tr>
<td>RH18</td>
<td>281.84</td>
<td>0</td>
</tr>
<tr>
<td>PS19</td>
<td>299.38</td>
<td>1</td>
</tr>
<tr>
<td>LT20</td>
<td>279.88</td>
<td>1</td>
</tr>
<tr>
<td>Mean (s.e.)</td>
<td>285.01(5.75)</td>
<td>1.6(0.5)</td>
</tr>
</tbody>
</table>

3.2.1.4 Subjective sleepiness

As part of the screening process the 20 participants rated their subjective sleepiness hourly during waking hours for three consecutive days using the KSS. The mean KSS scores versus time of day for the 20 participants are shown in Figure 3.3.
Chapter 3: Study 1: Main effect of condition

Upon awakening KSS score steadily decreases with time indicating increasing subjective alertness, with maximal alertness between 10am and 12noon. The scores then increase to a peak in subjective sleepiness at around 2pm, coinciding with the "afternoon dip". After dropping again for a second period of increased alertness at around 6-7pm, the scores then increase to a maximum at the end of the waking day in preparation for a period of sleep. This pattern and magnitude of subjective sleepiness throughout the day is considered normal. As all of the participants experienced the "afternoon dip" in alertness, scope was left for an improvement in alertness with the application of daytime sleepiness countermeasures.

3.2.2 Data analysis

Where possible, parametric statistical tests were used to analyse the data. Box and whisker plots were created and each data distribution visually inspected to establish whether or not parametric statistics could be legitimately applied.

For parametric data (i.e., sleep latency in the Standard MSLT, PVT RT/lapses, KSS score), time and condition effects were investigated using the two factor repeated measures ANOVA. Where multiple comparisons of a single parameter were required (as in the sleep period/efficiency data), the MANOVA was used. Where significant effects were found, post-hoc Bonferroni pair-wise comparisons were carried out.

Figure 3.3: Mean KSS score (s.e.) over the waking day (from 8am to 10pm) over the three day screening period for the 20 main study participants.
For non-parametric data (i.e., sleep latency in the Modified MSLT), condition effects were investigated using the non-parametric equivalent of the one factor, repeated measures (within subjects) ANOVA, the Friedman test. A two factor repeated measures test investigating both time and condition could not be performed as there is no non-parametric equivalent of the two-factor repeated measures ANOVA. Where significant effects were found, pair-wise comparisons were carried out using the post-hoc Nemenyi test. Survival analysis was also performed on the sleep latency data, with the log rank Mantel-Cox test used to investigate condition effects.

3.3 Results

3.3.1 Sleep prior to test days

As for the screening nights, the sleep diary and actiwatch data were combined (Actiwatch activity and sleep analysis 5. Copyright Cambridge Neurotechnology Ltd. Version 5.27) and the mean sleep period calculated for the nights before each condition (see Figure 3.4).

![Graph showing mean sleep period for four conditions](image)

**Figure 3.4:** Mean (s.e.) sleep period for the four main conditions; baseline (BL, n=20), sleep extension (SE, n=20), nap (Nap, n=20) and caffeine (CAFF, n=19).

---

2 The mean value presented for the caffeine condition is for 19 participants due to a corruption of the software file for one participant.
As expected, the mean sleep period for the sleep extension condition (9.1h, s.d. 0.4) was significantly longer than that of baseline (7.6h, s.d. 0.4) \([t(19)=15.0, p<0.001, \text{ one-tailed}]\). For all other conditions it remained relatively constant at around 7.6h, demonstrating consistency across the testing days.

### 3.3.2 Modified MSLT scores

Mean daily sleep latencies for the Modified MSLT were calculated for each of the four conditions. The longest mean daily sleep latency was obtained for the nap condition (16.7min, s.d. 4.7), followed by caffeine (15.0min, s.d. 5.8), then sleep extension (13.5min, s.d. 6.1), with the baseline condition having the shortest mean daily sleep latency (12.6min, s.d. 6.4).

Mean sleep latencies for each test session are shown in Figure 3.5. Generally, sleep latency increased with time of day for all conditions. All conditions resulted in increased sleep latency compared to baseline except at 11pm. The nap condition increased sleep latency by the greatest amount, followed by caffeine and then the sleep extension condition.

![Figure 3.5: Mean (s.e.) sleep latencies for each test session for the BL, SE, NAP and CAFF conditions.* NAP significantly different to BL at 3.30pm (p<0.01); ** CAFF significantly different to BL at 5pm (p<0.05)](image)

For many of the MSLT sessions (especially at 7.45pm and 11pm) there were a large amount of 20min sleep latencies due to individuals remaining awake. Due to the data not fulfilling the requirements of the ANOVA, the non-parametric equivalent was used. Applying the one-factor, repeated measures Friedman test to investigate the effect of
condition in the 3.30pm test session, a significant effect of condition was found ($X^2 (3) = 26.9; p<0.01$). Post-hoc Nemenyi comparisons showed sleep latency in the nap condition to be significantly different to that at baseline in the 3.30pm test session (p<0.01).

In the 5pm test session there was also found to be a significant effect of condition using the Friedman test ($X^2 (3) = 7.7; p=0.051$). For this session, post-hoc Nemenyi comparisons showed the caffeine condition to be significantly different to baseline (p<0.05). There was found to be no significant effect of condition in the 7.45pm or 11pm test sessions.

Due to the nature of the sleep latency data, in addition to nonparametric statistical analyses, a suitable alternative method of analysis was sought. Survival curve analysis, first demonstrated by Kaplan & Meier (1958) and subsequently applied in the statistical analysis of MSLT data (Carskadon et al., 1980; Clodoré, Benoit, Foret & Bouard, 1990; Punjabi et al., 2003) was applied to the data. Creating a survival curve involves the calculation of the proportion of participants remaining awake after each minute interval from the start of the test and plotting this as a function of the time elapsed.
Figure 3.6: Survival curves showing the relationship between mean daily sleep latency and condition (1=BL, 2=SE, 3=NAP, 4=CAFF). The x-axis represents the time elapsed from the start of the MSLT session and the y-axis represents the proportion of participants remaining awake after time t (min) (value obtained by calculating the mean sleep latency over the four sessions for each participant).

From Figure 3.6 it can be seen that the estimated mean percentage of participants remaining awake for all four tests in each condition was as follows: BL= 0%, SE= 0%, NAP= 20% and CAFF= 5%. Mantel-Cox pairwise comparisons showed both the NAP [$X^2(3)=13.06$, $p<0.001$] and CAFF [$X^2(3)=4.86$, $p<0.05$] conditions to be significantly different to BL. Plots of each individual MSLT session are shown in Figure 3.7.
Figure 3.7a: Survival curves showing the relationship between sleep latency in the 3.30pm and 5pm MSLT sessions and condition (1=BL, 2=SE, 3=NAP, 4=CAFF). The x-axis represents the time elapsed from the start of the MSLT session and the y-axis represents the proportion of participants remaining awake after time, t (min).
Figure 3.7b: Survival curves showing the relationship between sleep latency in the 7.45pm and 11pm MSLT sessions and condition (1=BL, 2=SE, 3=NAP, 4=CAFF). The x-axis represents the time elapsed from the start of the MSLT session and the y-axis represents the proportion of participants remaining awake after time, t (min).
Chapter 3: Study 1: Main effect of condition

The mean survival for each session time is as shown in Table 3.3:

Table 3.3: Mean survival (%) in each MSLT session for each of the four conditions.

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th>SE</th>
<th>NAP</th>
<th>CAFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.30pm</td>
<td>5</td>
<td>0</td>
<td>65</td>
<td>25</td>
</tr>
<tr>
<td>5pm</td>
<td>15</td>
<td>15</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>7.45pm</td>
<td>45</td>
<td>55</td>
<td>75</td>
<td>55</td>
</tr>
<tr>
<td>11pm</td>
<td>80</td>
<td>70</td>
<td>55</td>
<td>70</td>
</tr>
</tbody>
</table>

Mantel-Cox pairwise comparisons showed the following conditions to be significantly different to baseline at the following test times:

- 3.30pm session: NAP [$X^2(3) = 27.92$, $p < 0.001$], CAFF [$X^2(3) = 3.70$, $p < 0.05$]
- 5pm session: NAP [$X^2(3) = 4.10$, $p < 0.05$]
- 7.45pm session: NAP [$X^2(3) = 4.97$, $p < 0.05$]

3.3.3 PVT performance

For each of the main conditions (BL, SE, NAP and CAFF) a 30 minute PVT session was carried out four times throughout the day. The daily mean RT and the square root of the total number of lapses for each condition are shown in Table 3.4. The mean RT is a simple parameter to calculate, giving a good overall indication of an individual’s performance. However, research has shown the total number of lapses in any session to be a more sensitive indicator of performance, more susceptible to changes in the levels of vigilance expressed by the individual completing the task (Dinges & Kribbs, 1991). Therefore, the total number of lapses was also considered here. In each case, the square root of the total number of lapses has been calculated, in order to reduce the spread (and therefore the number of outliers) of the data sets without distorting them.

Table 3.4: Mean daily RT (s.e.) and square root lapses (s.e.) for each condition.

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th>SE</th>
<th>NAP</th>
<th>CAFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (ms)</td>
<td>323.8(7.4)</td>
<td>322.3(7.6)</td>
<td>326.2(8.8)</td>
<td>324.9(8.5)</td>
</tr>
<tr>
<td>√Lapses</td>
<td>3.3(0.4)</td>
<td>3.1(0.4)</td>
<td>3.2(0.6)</td>
<td>3.2(0.5)</td>
</tr>
</tbody>
</table>

In order to investigate the effect of condition on daytime performance, the four PVT sessions were split into “morning” (11am and 1pm) and “evening” (4.10pm and 10.10pm) sessions.
3.3.3.1 Morning performance

The morning sessions (11am and 1pm) took place before the nap or caffeine had been administered for those conditions and so can be used to investigate consistency in performance over these and the baseline condition. As the sleep extension had already taken place at these times, performance in this condition can be compared to baseline to investigate any improvements as a result of the sleep extension. Table 3.5 shows mean RT and square root of the total number of lapses for each condition in the 11am and 1pm PVT sessions.

Table 3.5: Mean RT (s.e.) and square root of the total number of lapses (s.e.) for each condition in the 11am and 1pm PVT sessions.

<table>
<thead>
<tr>
<th></th>
<th>BL 11am</th>
<th>BL 1pm</th>
<th>SE 11am</th>
<th>SE 1pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (ms)</td>
<td>317.11 (6.4)</td>
<td>335.16 (7.4)</td>
<td>317.16 (6.9)</td>
<td>328.62 (7.7)</td>
</tr>
<tr>
<td>√Lapses</td>
<td>2.7 (0.4)</td>
<td>4.1 (0.4)</td>
<td>2.6 (0.4)</td>
<td>3.3 (0.5)</td>
</tr>
<tr>
<td></td>
<td>NAP 11am</td>
<td>NAP 1pm</td>
<td>CAFF 11am</td>
<td>CAFF 1pm</td>
</tr>
<tr>
<td>RT (ms)</td>
<td>324.22 (9.0)</td>
<td>333.44 (8.6)</td>
<td>319.08 (7.7)</td>
<td>337.23 (8.6)</td>
</tr>
<tr>
<td>√Lapses</td>
<td>3.3 (0.5)</td>
<td>3.6 (0.6)</td>
<td>3.0 (0.4)</td>
<td>3.7 (0.5)</td>
</tr>
</tbody>
</table>

Figure 3.8 shows mean reaction time (after removal of lapses) in the 11am and 1pm PVT sessions for each condition. A two factor repeated measures ANOVA showed a significant effect of time \([F(1,19)=26.72, p<0.001]\), with reaction times significantly slower at 1pm compared to 11am. There was no effect of condition or condition*time interaction indicating similar performance across conditions.

Figure 3.8: Mean RT (s.e.) for the PVT sessions at 11am and 1pm for all conditions: BL, SE, NAP and CAFF.
Figure 3.9 shows the square root of the total number of lapses in the 11am and 1pm PVT sessions for each condition. A two factor repeated measures ANOVA showed a significant effect of time \( [F(1,19)=20.00, \ p<0.001] \) and condition*time interaction \( [F(3,57)=4.28, \ p<0.01] \), with no effect of condition on the square root of the total number of lapses over the 30min PVT sessions.

The decreased level of performance in terms of lapses at 1pm compared to 11am is in agreement with the mean RT data. However, unlike the mean RT data, the lapses show a significant condition*time interaction. Lapses in the BL condition increase much more in the 1pm session compared to the 11am session than for any other condition. This could be explained for the SE condition, as the extra sleep obtained the night before testing may reduce the effect of the afternoon dip in alertness at 1pm, resulting in a smaller increase in lapses at this time. However, for the nap and caffeine conditions, the interventions have yet to be administered, and so the small increase in lapses from the 11am to 1pm sessions relative to BL can not explained by condition. Therefore, it is thought that this interaction may have arisen due to individual variation in performance, rather than as a true effect of condition.

3.3.3.2 Evening performance

The evening PVT sessions (4.10pm and 10.10pm) took place after all the active interventions in each condition had been administered and so can be used to investigate the effect of condition on performance at these times. Table 3.6 shows mean RT and square root of the total number of lapses for each condition in the 4.10pm and 10.10pm PVT sessions.
### Table 3.6: Mean RT (s.e.) and square root of the total number of lapses (s.e.) for each condition in the 4.10pm and 10.10pm PVT sessions.

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th>SE</th>
<th>NAP</th>
<th>CAFF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Session</strong></td>
<td><strong>4.10pm</strong></td>
<td><strong>10.10pm</strong></td>
<td><strong>4.10pm</strong></td>
<td><strong>10.10pm</strong></td>
</tr>
<tr>
<td><strong>RT (ms)</strong></td>
<td>317.33(8.2)</td>
<td>325.67(7.4)</td>
<td>317.83(8.1)</td>
<td>325.54(7.6)</td>
</tr>
<tr>
<td>√/Lapses</td>
<td>3.0(0.4)</td>
<td>3.4(0.5)</td>
<td>3.0(0.5)</td>
<td>3.4(0.4)</td>
</tr>
</tbody>
</table>

Figure 3.10 shows mean reaction time (after removal of lapses) in the 4.10pm and 10.10pm PVT sessions for each condition. A two factor repeated measures ANOVA showed a significant effect of time [F(1,19)=14.65, p<0.005] with no effect of condition or condition*time interaction on mean reaction time over the 30min PVT sessions. The increased mean RT in the 10.10pm session compared to the 4.10pm session could be due to a general decrease in alertness in the late evening as bedtime approaches. The lack of a significant effect of condition indicates that the SE, NAP, and CAFF conditions do not improve performance in the evening compared to BL.

![Mean reaction time (s.e.) for the 30min PVT sessions at 4.10pm and 10.10pm for all conditions: BL, SE, NAP and CAFF.](image)

Figure 3.11 shows the square root of the total number of lapses in the 4.10pm and 10.10pm PVT sessions for each condition. A two factor repeated measures ANOVA showed a significant effect of time [F(1,19)=9.09, p<0.01], with no effect of condition or condition*time interaction on the square root of the total number of lapses over the 30min PVT sessions. These results are in agreement with those for the mean RT at these times.
Chapter 3: Study 1: Main effect of condition

Figure 3.11: Square root of the total number of lapses (s.e.) for the 30min PVT sessions at 4.10pm and 10.10pm for all conditions: BL, SE, NAP and CAFF.

3.3.3.3 10-minute epochs

It is possible that by looking at the performance over the full 30 minutes of each session any subtle differences are masked or a ceiling effect is reached, hiding any changes that may occur earlier on in the test, after 10 minutes, for example. Therefore, the data was divided and analysed separately in 10 minute epochs: the first, second and third 10 minutes of each PVT session. Both mean RT and number of lapses were considered here. However, only evening sessions were analysed as all conditions were active at these session times, unlike in the morning sessions.

Analysis of the evening PVT sessions in 10min epochs showed no significant effect of condition or condition*time interaction for any epoch in any test session, providing no more information than that already obtained from examining the entire 30 minute test session.

3.3.4 Subjective sleepiness

The mean daily KSS scores for the SE, NAP and CAFF conditions, both with the participant sitting at a desk and after a 5 minute lie down, were lower than those for BL, indicating less subjective sleepiness for these conditions (see Table 3.7). The mean daily KSS score obtained after a 5 minute lie down was higher than that obtained at the desk for all conditions.
Table 3.7: Mean daily KSS scores (s.e.) for each condition, measured sitting at a desk (14 time points) and after a 5 minute lie down (7 time points).

<table>
<thead>
<tr>
<th>KSS Score</th>
<th>BL</th>
<th>SE</th>
<th>NAP</th>
<th>CAFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Desk</td>
<td>4.5(0.2)</td>
<td>4.3(0.1)</td>
<td>4.3(0.1)</td>
<td>4.2(0.1)</td>
</tr>
<tr>
<td>After 5min</td>
<td>4.9(0.2)</td>
<td>4.6(0.2)</td>
<td>4.8(0.3)</td>
<td>4.7(0.3)</td>
</tr>
</tbody>
</table>

KSS scores were obtained with the participant sat at a desk at 14 time points throughout the day: 10:50, 11:50, 12:50, 13:50, 14:30, 16:00, 16:50, 17:50, 18:50, 20:15, 20:50, 21:50, 22:50 and 23:30. Plotting mean KSS score (at desk) against time of day for each condition gives the distribution shown in Figure 3.12. A two factor ANOVA showed a significant effect of time [F(3,59)=15.20, p<0.001, G-G correction] and of condition [F(2,38)=3.37, p<0.05, G-G correction], with no significant condition*time interaction. Post-hoc Bonferroni comparisons showed CAFF to be significantly different from BL (p<0.005). Looking at Figure 3.12 it can be seen that the difference between the BL and CAFF conditions appears to occur mainly in the first four measurements, in which case this difference cannot be as a result of the caffeine as it was not consumed until 2.15pm. Therefore, the two factor ANOVA was repeated on the 9 time points (4pm-11.30pm) after the caffeine was administered to establish if this significant difference compared to BL persisted. It was found that by looking only at time points after the administration of the caffeine, there was no longer an effect of condition. This indicates that the significant difference between the BL and CAFF conditions when using all 14 time points was not as a result of the condition but due to other factors, such as individual day to day variation in subjective sleepiness, for example.
Figure 3.12: Mean KSS score (s.e.) for each condition against time of day with participants sitting at a desk (14 time points).

KSS scores were obtained immediately after the participant had been lying down for 5 minutes at 7 time points throughout the day: 11:50, 13:50, 16:00, 17:50, 20:15, 21:50 and 23:30. The reduced number of time points for this position was due to practical restrictions in terms of time and the amount of tests that could be performed during the day. KSS score (after 5min) versus time of day for each condition is shown in Figure 3.13. A two factor ANOVA showed a significant effect of time [F(3,43)=15.58, p<0.001, G-G correction] with no effect of condition or condition*time interaction. However, pairwise Bonferroni comparisons showed the sleep extension condition to be significantly different to baseline (p=0.03).
As can be seen in Figures 3.12 and 3.13, the distribution of subjective sleepiness over the course of the day for the two situations appears to differ. A three factor ANOVA for condition, time and situation (at desk, after 5min lie down) was performed on the 7 time measurement points common to both parameters to investigate this. There was found to be a significant effect of situation [F(1,19)=19.52, p<0.001], time [F(2,45)=16.25, p<0.001, G-G correction] and a situation*time interaction [F(6,114)=3.39, p<0.005], with no significant effect of condition. Figure 3.14 shows mean KSS score against time of day for the two situations. Upon visual inspection of this graph, the situation*time interaction appears to occur at 13:50. Here, the 5 minute lie down results in a greater increase in subjective sleepiness at this time compared to any other time of day.
3.3.5 Sleep the night after test days

For 12 of the 20 subjects, data was also obtained for each night following the main conditions and this is shown graphically in Figure 3.15\(^3\). A two factor repeated measures ANOVA showed a significant effect of condition [F(3,33)=18.06, p<0.001], of night [F(1,11)=17.52, p<0.005] and condition*night interaction [F(2,23)=11.37, p<0.001, G-G correction]. Post-hoc Bonferroni comparisons showed the sleep extension condition to be significantly different from all other conditions (p<0.005). The baseline, nap and caffeine conditions all showed similar sleep periods with no significant differences between them, indicating consistency across test days. As indicated by the significant effect of night and illustrated in Figure 3.15, the sleep period was consistently shorter the night after test days compared to the night before. The most likely cause of the significant condition*night interaction is the large difference in sleep period the night before and after testing in the sleep extension condition compared to all other conditions.

\(^3\) n = 8 missing due to a late change in the protocol to assess subsequent nocturnal sleep.
Figure 3.15: Mean (s.e.) sleep period for the nights before (pre) and after (post) the four main conditions; baseline (BL), sleep extension (SE), nap (NAP) and caffeine (CAFF) for 12 participants.* SE condition significantly different from all other conditions (p<0.01).

In addition to sleep period, the sleep efficiency for the night before and after each condition was calculated for the same 12 participants and is represented graphically in Figure 3.16.
Figure 3.16: Mean (s.e.) sleep efficiency for the nights before (pre) and after (post) the four main conditions; BL, SE, NAP and CAFF for 12 participants.

A two factor repeated measures ANOVA showed a significant effect of night \[F(1,11)=11.96, \ p<0.01\] on sleep efficiency, with no significant effect of condition or condition*night interaction.

### 3.4 Summary of findings

The main findings of this chapter are summarised below:

- Participants obtained regular habitual sleep periods within the range of 7-8h a night for all screening nights,
- Mean daily sleep latency in the Standard MSLT was 11.5min (s.d. 0.8), with the greatest sleep latency in the 10am session,
- During screening, participants had normal performance (PVT) and subjective sleepiness (KSS) levels,
- Participants obtained comparable and consistent sleep periods the night before all main test days,
  - Sleep period was significantly longer in the sleep extension condition compared to all others, as expected,
- Mean daily sleep latency was higher for the Modified compared to the Standard MSLT [12.6min (s.d. 1.4)],
Chapter 3: Study 1: Main effect of condition

- All conditions increased sleep latency compared to baseline at 3.30pm, 5pm and 7.45pm, but the only significant increase was for the nap condition at 3.30pm,
- Morning performance was comparable for all conditions, with better performance at 11am compared to 1pm,
- Evening performance was unaffected by condition, with performance worse at 10.10pm compared to at 4.10pm,
- KSS score at a desk was not affected by condition,
- There was no effect of condition on KSS score after the participant had been lying down for 5 minutes,
- Participants were subjectively more sleepy after the 5min lie down compared to when sitting at a desk and this increase in sleepiness was greatest at 1.50pm,
- Participants had shorter sleep periods and lower sleep efficiencies the nights after testing compared to the nights before.

3.5 Comment on findings

The 20 participants that took part in this study had a mean habitual sleep period of 7.6h (s.d. 0.6) a night and a mean daily sleep latency of 11.5min (s.d. 0.8) in the Standard MSLT, both of which are in agreement with other contemporary studies on normal, healthy, young adults without complaint of daytime sleepiness. Young adults (aged 18-29y) who took part in a study conducted by Levine et al. (1988) slept 8 hours the night before undergoing the Standard MSLT and obtained a daily MSLT score of 11.10 minutes. In a study conducted by Punjabi et al. (2003) the mean daily sleep latency was 10.1 minutes in a group of individuals with a mean sleep duration of 7.1h (s.e. 0.05) the night before testing.

All participants were able to extend their nocturnal sleep in the SE condition with a resultant reduction in daily sleep latency the next day of approximately 1 minute compared to BL. This is in agreement with previous studies on nocturnal sleep extension in that normal, healthy sleepers are, firstly, able to extended their nocturnal sleep length on demand, and secondly, in terms of the magnitude of improved objective sleepiness the next day (Roehrs et al., 1989; Carskadon & Dement, 1996b; Harrison & Horne, 1996b).

The extension of nocturnal sleep did not impact on subsequent performance, which agrees with the findings of other research (Belenky et al., 2003; Carskadon & Dement, 1986b). It could be that the PVT simply wasn't sensitive to individuals who were not
sleep deprived, but this seems unlikely, as other studies on sleep extension have shown both improvements (Van Dongen et al., 2003b) and decrements in performance after increasing nocturnal sleep up to 10h a night (Taub et al., 1971; Wright et al., 2000). This finding is of importance when assessing the practical benefits of extended sleep to the individual.

There was no significant impact of sleep extension on subjective sleepiness the next day as measured by the KSS. Other research has shown sleep extension to improve subjective sleepiness the following day (Wehr et al., 1993). However, a study by Totterdell et al. (1994) suggests that these improvements may be as a result of earlier bedtimes rather than the increase in sleep duration. This would agree with the findings of the present study (no change in subjective sleepiness with extended nocturnal sleep), in which the participants maintained similar bedtimes throughout.

Due to the novel nature of the present study, it was possible to directly compare the effects of nocturnal sleep extension with an afternoon nap or caffeine administered in the afternoon. Previous studies have shown afternoon napping (Dinges et al., 1987; Gillberg et al., 1994; Hayashi et al., 1999) and caffeine (Zwyghuizen-Doorenbos et al., 1990; Horne & Reyner, 1996) to be effective in reducing subsequent objective and subjective levels of sleepiness. The present study showed the afternoon nap and caffeine to be effective at increasing sleep latency, more so than nocturnal sleep extension, without impacting on sleep length or sleep efficiency the next night. Even though the nap and caffeine increased sleep latency, neither intervention had an effect on subsequent performance or subjective sleepiness levels. Positive effects of napping and caffeine on performance and subjective sleepiness levels have previously been reported by other researchers (Zwyghuizen-Doorenbos et al., 1990; Horne & Reyner, 1996). An explanation for this lack of agreement between previous and the current study may be that in the study carried out by Zwyghuizen-Doorenbos et al. (1990) the amount of caffeine the subjects received in the study was 500mg, more than three times the amount received by subjects in the present study. In addition, the performance measure used by Zwyghuizen-Doorenbos et al. (1990) was longer (40min), different (Auditory vigilance task) and carried out at a different time of day (2.30pm) to the present study. All of these differences in protocol could account for the difference in the findings between the two studies. Subjects in the study carried out Horne and Reyner (1996) received only 5h sleep the night prior to testing and so it is logical to expect the effects of a nap or caffeine in the afternoon to be more pronounced than if the subjects had obtained 7-8h sleep the night before. Also, Horne
and Reyner (1996) used a simulated motorway drive as their performance measure, with a one hour drive starting at 2pm, followed by a 30min break and then another 1h drive. This is a different performance measure to that used in the present study, and the duration of the task was much longer, both of which could account for the difference in the findings of Horne and Reyner (1996) and those of the present study.

The effect of the 5 minute lie down was to significantly increase KSS score, indicating increased subjective sleepiness. The effect of situation has been discussed by Johns (2002, p61), who found the level of “somnificity”, defined as “the general characteristic of a posture, activity and situation that reflects its capacity to facilitate sleep-onset in a majority of subjects” of “lying down to rest in the afternoon when circumstances permit” to be the highest of all the situations proposed in the ESS, a measure of sleep propensity. Eriksen et al. (2005) investigated the effect of different activities, such as reading, walking and social interaction, on subjective sleepiness as measured by the KSS and found that physical activity clearly reduced sleepiness compared to sedentary activities such as reading. The KSS scores obtained sitting at a desk for the present study are in agreement with those reported by Erikson et al. (2005).

In addition to the effect of situation, there was also a situation*time interaction, with a greater increase in subjective sleepiness after the 5 minute lie down at 1.50pm than at any other time. Due to circadian variations in alertness throughout the waking day [Process C, as described by Borbély (1994)], there is an increased propensity for sleep in the early afternoon, which explains the observed time*situation effect. This subjective increase in sleepiness in the afternoon has been discussed previously by Erikson et al. (2005).

3.5.1 Interpretation

As the 20 individuals studied were able to fall asleep during the day when given the opportunity to and were also able to extend their nocturnal sleep, this could be used as evidence to suggest that they are carrying an underlying sleep debt. However, as shown in this chapter, the improvements seen as a result of nocturnal sleep extension were minimal in terms of increased sleep latency, with either a short afternoon nap or caffeine proving more effective. It is also important to note that no condition had an effect on either performance or subjective feelings of sleepiness throughout the day. It is more likely that these individuals are achieving their nocturnal sleep requirement by obtaining 7-8h sleep a night, enabling them to perform adequately throughout the day, with the added benefit of being able to fall asleep during the day when circumstances permit.
In summary, following sleep extension of up to 90 minutes there was no significant improvement in daytime sleepiness. A short afternoon nap or a caffeinated drink was more effective, with neither intervention having a detrimental effect on subsequent sleep.
4 Study 2: Group differences

4.1 Introduction

Recent studies have reported a relatively high proportion of otherwise healthy individuals with short sleep latencies in the population (Levine et al., 1988; Roehrs et al., 1989; Manni et al., 1991; Roehrs et al., 1996a). It has been suggested that individuals with short latencies may be suffering from the effects of chronic sleep restriction, as studies have shown these individuals to have impaired performance during the day compared to those with longer latencies (Roehrs et al., 1990), and daytime sleep latency has been shown to increase with an increased nocturnal sleep duration (Bonnet & Arand, 1995).

The purpose of this chapter is to establish if differences in terms of sleep latency between two groups of individuals persist regardless of the test times used for the MSLT and also if these differences are confirmed by other measures of sleepiness, such as performance and subjective sleepiness.

It is hypothesised that those with short sleep latencies (as established using the screening Standard MSLT) will consistently have shorter sleep latencies in the main study than those with longer screening sleep latencies, but there will be no difference between the two groups in terms of performance, subjective sleepiness or how they are affected by the SE, NAP and CAFF conditions.

Data from this chapter has been presented in poster format at the 5th World Sleep Congress of the World Federation of Sleep Research & Sleep Medicine Societies (WFSRSMS), 2nd - 6th September, Cairns, Australia and is shown in Appendix 4.

Main themes covered in this section:

- Group characteristics
- Group differences in terms of:
  - Night-time sleep: pre and post test days
  - MSLT scores and survival curves
  - Performance
  - Subjective sleepiness in two situations
4.2 Methods

The study design was the same as that used for Chapter 3, except that the participants were split into two groups according to their level of sleepiness as measured by the Standard MSLT. As in Chapter 3, all participants underwent four conditions [Sleep Extension (SE) vs. Nap (NAP) vs. Caffeine (CAFF) vs. Baseline (BL)] in a counterbalanced order. Group characteristics are shown in section 4.2.1 and a detailed description of the study design can be found in Chapter 2, sections 2.4.1 to 2.4.3.

Data discussed in this section is from the 20 participants who completed the study. They have been split into two groups according to their mean daily sleep latency in the screening Standard MSLT. Those with mean daily sleep latencies between 12-15 minutes were placed in one group (n=13) and those with means of 5-9 minutes were placed in the other group (n=7). According to the American Sleep Disorders Association (ASDA), those with a mean sleep latency of 12-15 minutes would fall into a category classed as 'mildly sleepy' and individuals with a mean sleep latency of 5-9 minutes would fall into a category classed as 'moderately sleepy' (Thorpy, 1992). Therefore, in this chapter the two groups will be referred to as the mild group (mean sleep latency 12-15min) and the mod group (mean sleep latency 5-9min).

4.2.1 Group characteristics

The characteristics of participants in the two groups are shown in Table 4.1. The number of participants in the mod group is less than that in the mild group due to the difficulty in recruiting participants with mean sleep latencies within the required range.
Table 4.1: Characteristics of participants in the mild (A, n=13) and mod (B, n=7) groups.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age</th>
<th>ESS Score</th>
<th>Trait</th>
<th>M/E Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK01</td>
<td>M</td>
<td>26.0</td>
<td>3</td>
<td>41</td>
<td>56</td>
</tr>
<tr>
<td>YG02</td>
<td>M</td>
<td>24.0</td>
<td>0</td>
<td>24</td>
<td>53</td>
</tr>
<tr>
<td>DB04</td>
<td>M</td>
<td>32.4</td>
<td>4</td>
<td>28</td>
<td>59</td>
</tr>
<tr>
<td>CB07</td>
<td>F</td>
<td>22.3</td>
<td>6</td>
<td>32</td>
<td>68</td>
</tr>
<tr>
<td>AC08</td>
<td>F</td>
<td>22.0</td>
<td>5</td>
<td>24</td>
<td>61</td>
</tr>
<tr>
<td>NB13</td>
<td>M</td>
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<td>4</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>JL14</td>
<td>M</td>
<td>23.6</td>
<td>4</td>
<td>29</td>
<td>62</td>
</tr>
<tr>
<td>VS15</td>
<td>F</td>
<td>22.2</td>
<td>6</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td>RC16</td>
<td>M</td>
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<td>1</td>
<td>31</td>
<td>56</td>
</tr>
<tr>
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<td>F</td>
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<td>4</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>RH18</td>
<td>M</td>
<td>21.5</td>
<td>2</td>
<td>26</td>
<td>49</td>
</tr>
<tr>
<td>PS19</td>
<td>F</td>
<td>26.0</td>
<td>8</td>
<td>32</td>
<td>43</td>
</tr>
<tr>
<td>LT20</td>
<td>M</td>
<td>34.3</td>
<td>6</td>
<td>31</td>
<td>64</td>
</tr>
<tr>
<td>Mean (s.e.)</td>
<td></td>
<td>25.3</td>
<td>4.1(0.6)</td>
<td>32.1(1.9)</td>
<td>56.0(1.9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age</th>
<th>ESS Score</th>
<th>Trait</th>
<th>M/E Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM03</td>
<td>F</td>
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<td>6</td>
<td>33</td>
<td>56</td>
</tr>
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<td>KM05</td>
<td>F</td>
<td>25.0</td>
<td>9</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>BC06</td>
<td>F</td>
<td>32.8</td>
<td>9</td>
<td>33</td>
<td>58</td>
</tr>
<tr>
<td>JT09</td>
<td>F</td>
<td>27.9</td>
<td>10</td>
<td>39</td>
<td>57</td>
</tr>
<tr>
<td>EG10</td>
<td>F</td>
<td>25.4</td>
<td>10</td>
<td>27</td>
<td>63</td>
</tr>
<tr>
<td>GC11</td>
<td>M</td>
<td>29.6</td>
<td>10</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td>MO12</td>
<td>F</td>
<td>25.6</td>
<td>8</td>
<td>33</td>
<td>66</td>
</tr>
<tr>
<td>Mean (s.e.)</td>
<td></td>
<td>27.0</td>
<td>8.9(0.5)</td>
<td>33.9(1.6)</td>
<td>56.4(2.7)</td>
</tr>
</tbody>
</table>

A MANOVA on the parameters shown in Table 4.1 showed the mod group to have a significantly higher ESS score \([F(1)=26.07, p<0.001]\) and significantly more females in it \([F(1)=4.65, p<0.05]\) than the mild group. There was no significant difference between the groups in terms of age, Trait anxiety score or morning/evening score.

4.2.1.1 Standard MSLT scores

The mean sleep latencies for each group per session of the screening Standard MSLT are shown in Figure 4.1. The mild group consistently has a longer sleep latency than the mod group, with their daily means 14.0min (s.e. 1.0) and 6.9min (s.e. 1.4) min respectively. A one factor ANOVA showed the mod group to have a significantly shorter sleep latency for all session times (10am, \(F(1)=66.67, p<0.001\); 12pm, \(F(1)=5.54, p<0.05\); 2pm, \(F(1)=6.07, p<0.05\); 4pm, \(F(1)=12.31, p<0.005\).
For both groups the longest sleep latency occurred at 10am, with the shortest sleep latency at 12pm for the mild group and at 4pm for the mod group.

![Graph showing sleep latency over time](image)

**Figure 4.1:** Mean sleep latency (s.e.) for the mild (blue line) and mod (grey line) group in the four sessions of the screening Standard MSLT. The crosses indicate the mean daily score for the mild (blue cross) and mod group (grey cross).

### 4.2.1.2 PVT performance

Mean Reaction Time (RT) and square root number of lapses for the two groups in the screening PVT are shown in Table 4.2. A MANOVA on this data showed there to be no significant difference between the groups for either measure of performance.

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Mod</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RT (ms)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10min</strong></td>
<td>282.9(7.1)</td>
<td>288.9(10.3)</td>
</tr>
<tr>
<td><strong>30min</strong></td>
<td>295.3(7.5)</td>
<td>306.0(12.9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Mod</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>√Lapses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10min</strong></td>
<td>0.8(0.2)</td>
<td>1.0(0.4)</td>
</tr>
<tr>
<td><strong>30min</strong></td>
<td>2.1(0.3)</td>
<td>2.9(0.7)</td>
</tr>
</tbody>
</table>

### 4.2.1.3 Subjective sleepiness

Figure 4.2 shows the mean KSS score for the two groups during their 3 day KSS screening. As the mod group had much shorter sleep latencies on the Standard MSLT one might expect them to have higher levels of subjective sleepiness throughout the day compared to the mild group if they were suffering from increased daytime sleepiness. A two factor ANOVA investigating the effect of time
of day (first time point was at 8am and last at 10pm as all 20 participants submitted data at these times) and group on KSS score showed a significant effect of time \([F(4,66)=7.17, p<0.001]\) with no significant effect of group or group*time interaction. This indicates that similar levels of subjective sleepiness were experienced by the two groups throughout the day.

![Figure 4.2](image)

**Figure 4.2:** *Mean KSS score (s.e.) over the waking day for the three day screening period for the 13 mild (blue line) and 7 mod (grey line) participants.*

4.2.2 Data analysis

As in Chapter 3, where possible, parametric statistical tests were used to analyse the data.

For parametric data (i.e., sleep latency in the Standard MSLT, sleep period/efficiency before test days, PVT RT/lapses and KSS score), time, condition, group and situation effects were investigated using the appropriate factor (one, two, three or four) repeated measures ANOVA. Where multiple comparisons of a single parameter were required (as in the participant characteristics and screening PVT data), the MANOVA was used. Where significant effects were found, post-hoc Bonferroni pair-wise comparisons were carried out.
For non-parametric data (i.e., sleep latency in the Modified MSLT and sleep period/efficiency after test days), group effects were investigated using the Mann-Whitney test. Survival analysis was also performed on the non-parametric sleep latency data, with the log rank Mantel-Cox test used to investigate group effects.

As the main effects of condition and time have already been investigated for the two groups combined as one in Chapter 3, only differences relating specifically to group will be referred to and discussed in this chapter.

4.3 Results

4.3.1 Sleep prior to test days

Recent research has suggested that there may be a link between night-time sleep duration and sleep latency in the MSLT for young healthy individuals, with those falling asleep faster in the MSLT having shorter habitual sleep durations than those with longer sleep latencies (Klerman & Dijk, 2005). As the two groups in the present study were separated according to their mean daily sleep latency in the Standard MSLT, their habitual sleep periods were compared, using the sleep diary and actimeter screening data, in order to ascertain whether or not they were in agreement with the data presented by these researchers.
Chapter 4: Study 2: Group differences

Figure 4.3: Mean (s.e.) sleep period for the three screening days [Screen1 (mild \(n=13\), mod \(n=6\)), Screen2 (mild \(n=13\), mod \(n=7\)) and Screen3 (mild \(n=13\), mod \(n=7\)], the Standard MSLT screening day (MSLT, mild \(n=13\), mod \(n=7\)) and the four main conditions; baseline (BL, mild \(n=13\), mod \(n=7\)), sleep extension (SE, mild \(n=13\), mod \(n=7\)), nap (NAP, mild \(n=13\), mod \(n=7\)) and caffeine (CAFF, mild \(n=13\), mod \(n=7\)).

To investigate any difference between the two groups the night before each of the four screening days (Screen1, Screen2, Screen3 and MSLT) a two factor repeated measures mixed ANOVA was performed. There was no significant effect of test day, group or test day*group interaction, indicating that the two groups achieved similar sleep periods the night before all screening days. This does not appear to confirm the suggested link between shorter sleep periods and short sleep latencies in the Standard MSLT. As can be seen in Figure 4.3, even though the difference between the groups is not statistically significant, there is a trend for those exhibiting shorter sleep latencies, i.e., the mod group, to have a longer sleep period before each screening day than those with longer sleep latencies (the mild group).
Sleep period the night before each of the main condition days was compared using a two factor repeated measures mixed ANOVA. As expected, a significant effect of condition was found \( F(3,51)=98.06, p<0.001 \), due to the increased sleep obtained for the sleep extension condition, with no effect of group or condition*group interaction. This indicates that the two groups obtained similar sleep periods the night before each of the main conditions, showing consistency between the groups across all test days.

As there is no difference between the two groups in terms of sleep period, there may be a difference in sleep efficiency that results in their differing sleep latencies for the Standard MSLT. A two factor repeated measures mixed ANOVA on sleep efficiency over the four screening days (Screen1, Screen2, Screen3 and MSLT) showed a significant effect of test day \( F(3,51)=4.84, p<0.01 \). Sleep efficiency was significantly higher the night before the MSLT test day compared to Screen2 \( (p<0.01) \) and Screen3 \( (p<0.05) \). There was no significant effect of group or test day*group interaction, indicating that the two groups exhibited similar sleep efficiencies the night before each screening test day.

Sleep efficiency the night before each of the main conditions for each group was investigated by way of a two factor repeated measures mixed ANOVA. There was no significant effect of condition, group or condition*group interaction, indicating consistency across condition and group in terms of sleep efficiency before each test day.

### 4.3.2 MSLT scores

#### 4.3.2.1 Standard versus Modified MSLT scores

As previously stated, the 20 participants were allocated to the mild or mod group according to their mean daily sleep latency in the Standard MSLT (four sessions at 10am, 12pm, 2pm and 4pm). The mild group had a mean daily sleep latency of 14.0min (s.d. 1.0) and the mod group had a mean daily sleep latency of 6.9min (s.d. 1.4). A two factor repeated measures mixed ANOVA on sleep latency in the Standard MSLT showed a significant effect of time (previously discussed in Section 3.2.1.2) and group \( F(1,18)=122.96, p<0.001 \), with no time*group interaction.

To investigate the effect of testing later on in the day, the main study MSLT sessions were carried out at 3.30pm, 5pm, 7.45pm and 11pm. It was hypothesised
that the difference between the two groups in terms of mean daily sleep latency would remain unchanged with the later test times.

For the baseline condition (BL) the mean daily sleep latency for the mild and mod groups were 13.3min (s.d. 1.4) and 11.2min (s.d. 1.9) respectively, which is longer for both groups than the sleep latencies obtained for the Standard MSLT. Applying the Mann-Whitney Test to the sleep latencies obtained for the BL condition, there was no significant difference between the two groups for any test session. This demonstrates that the differences found between the two groups in the Standard MSLT do not persist when the test times are shifted to later on in the day.
4.3.2.2 Effect of condition

Sleep latencies for each condition are plotted separately for the two groups in Figure 4.4.

Figure 4.4: Mean (s.e.) sleep latencies in each test session for the BL, SE, NAP and CAFF conditions. Graph A represents the data from the mild group (n=13) and graph B represents the data from the mod group (n=7).
It can be seen in Figure 4.4 that the sleep latencies obtained for the two groups appear to differ, particularly in the CAFF condition sessions and at 7.45pm in the SE condition. As in Chapter 3, due to the nature of the sleep latency data for the main conditions, a nonparametric method of statistical analysis was required to establish whether or not these differences were significant. The Mann-Whitney test was performed to investigate the difference between the two groups for each of the conditions at each of the session times and failed to show significance for any MSLT session in any of the conditions.

Survival analysis was also used to investigate any difference between the groups and survival curves for each session are shown below in Figure 4.5.
Chapter 4: Study 2: Group differences

The graphs show the proportion of time awake for two groups, labeled as "mild" and "mod," over different BL and SE periods. The x-axis represents the time in increments of 2.0, starting from 6.0 to 20.0. The y-axis represents the proportion awake, ranging from 0.0 to 1.0. The graphs illustrate the differences in the time spent awake between the two groups.
Figure 4.5: Relationship between mean daily sleep latency with condition and group. Participants have been grouped according to condition (BL, SE, NAP and CAFF) and group (mild, mod). The x-axis represents the time elapsed from the start of the MSLT session and the y-axis represents the proportion of participants remaining awake after time, t (min).
Although not significantly different (as calculated using the Mantel-Cox test for each condition), the survival curves in Figure 4.5 show the mild group to have a trend for better survival than the mod group in each condition, with the greatest difference observed in the nap condition.
Chapter 4: Study 2: Group differences

Figure 4.6: Mean sleep latency across the MSLT test sessions. Participants are grouped according to session (3.30pm, 5pm, 7.45pm and 11pm) and group (mild, mod). The x-axis represents the time elapsed from the start of the MSLT session and the y-axis represents the proportion of participants remaining awake after time, t (min).
As shown in Figure 4.6 the mild group also show a trend for better survival than the mod group for all session times, although this was found not to be statistically significant using the Mantel-Cox test.

4.3.3 PVT performance

The mean daily RT and square root of the number of lapses for each group are shown for each condition in Table 4.3.

Table 4.3: Mean daily RT (s.e.) and square root of the total number of lapses (s.e.) in each condition for the mild (n=13) and mod (n=7) groups.

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th></th>
<th>SE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT (ms)</td>
<td>√Lapses</td>
<td>RT (ms)</td>
<td>√Lapses</td>
</tr>
<tr>
<td>mild</td>
<td>320.9(7.2)</td>
<td>3.1(0.4)</td>
<td>314.4(6.6)</td>
<td>2.7(0.4)</td>
</tr>
<tr>
<td>mod</td>
<td>329.2(15.7)</td>
<td>3.7(0.8)</td>
<td>337.0(16.1)</td>
<td>3.8(0.9)</td>
</tr>
<tr>
<td>NAP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RT (ms)</td>
<td>√Lapses</td>
<td>RT (ms)</td>
<td>√Lapses</td>
</tr>
<tr>
<td>mild</td>
<td>317.4(8.7)</td>
<td>2.9(0.6)</td>
<td>318.8(7.2)</td>
<td>2.9(0.4)</td>
</tr>
<tr>
<td>mod</td>
<td>342.6(17.3)</td>
<td>3.9(1.1)</td>
<td>336.3(17.9)</td>
<td>3.7(1.0)</td>
</tr>
</tbody>
</table>

As can be seen in Table 4.3, although not significantly different (two factor ANOVA for condition and group, firstly on RT data, then on lapse data), in all conditions the moderate group has a slower RT than the mild group, with a greater number of lapses. In Chapter 3 the four PVT sessions were split into “morning” (11am and 1pm) and “evening” (4.10pm and 10.10pm) sessions and the same has been done in this chapter.

4.3.3.1 Morning performance

Figure 4.7 shows the performance of the two groups in terms of mean RT and square root of the number lapses in the morning (11am and 1pm) PVT sessions.
Figure 4.7: Mean (s.e.) RT (Figure 4.7A) and square root of the total number of lapses (Figure 4.7B) in the PVT sessions at 11am and 1pm for all conditions: BL, SE, NAP and CAFF.

A three factor repeated measures ANOVA was performed to investigate the effect of group, firstly on RT and then on the square root of the number of lapses. The effects of condition and time have already been considered in Section 3.2.2.1 and so will not be discussed here. Only effects relating to group will be considered in this section. There was no significant effect of group (or interactions involving
group) on the mean RT or the square root of the number of lapses, indicating that both groups exhibited similar levels of performance in the morning PVT sessions.

4.3.3.2 Evening performance

Figure 4.8 shows the performance of the two groups in terms of mean RT and square root of the number of lapses in the evening (4.10pm and 10.10pm) PVT sessions.

![Figure 4.8](image_url)

**Figure 4.8**: Mean (s.e.) RT (Figure 4.8A) and square root of the total number of lapses (Figure 4.8B) for the PVT sessions at 4.10pm and 10.10pm for all conditions: BL, SE, NAP and CAFF.
As for the morning PVT sessions, a three factor repeated measures ANOVA was performed on mean RT and square root of the number of lapses to investigate any effect of group on performance. There was no significant effect of group (or interactions involving group) on the mean RT or the square root of the number of lapses, indicating that both groups exhibited similar levels of performance in the evening sessions.

4.3.3.3 10-minute epochs

As in Section 3.3.2.3 it was thought that more information may be gleaned from the PVT data by splitting the 30 minute sessions into three epochs, representing the first, second and third 10 minutes of the test. The performance of two groups was compared after each epoch in all four of the PVT sessions (morning and evening) and no significant difference was found between the groups in any epoch of any session in terms of mean RT or the square root of the number of lapses.

4.3.4 Subjective sleepiness

As can be seen in Table 4.4 the mean KSS score for both groups in all conditions is higher after lying down for 5 minutes than when sitting at a desk. This effect of situation was shown to be significant in Section 3.5.2.

<table>
<thead>
<tr>
<th></th>
<th>BL</th>
<th></th>
<th>SE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mild</td>
<td>Mod</td>
<td>Mild</td>
<td>Mod</td>
</tr>
<tr>
<td>At Desk</td>
<td>4.6(0.2)</td>
<td>4.4(0.2)</td>
<td>4.3(0.2)</td>
<td>4.3(0.2)</td>
</tr>
<tr>
<td>After 5min</td>
<td>5.0(0.3)</td>
<td>4.7(0.3)</td>
<td>4.8(0.3)</td>
<td>4.3(0.4)</td>
</tr>
<tr>
<td>NAP</td>
<td></td>
<td></td>
<td>CAFF</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mild</td>
<td>Mod</td>
<td>Mild</td>
<td>Mod</td>
</tr>
<tr>
<td>At Desk</td>
<td>4.4(0.2)</td>
<td>4.1(0.2)</td>
<td>4.3(0.2)</td>
<td>4.1(0.3)</td>
</tr>
<tr>
<td>After 5min</td>
<td>5.0(0.3)</td>
<td>4.2(0.4)</td>
<td>5.0(0.3)</td>
<td>4.2(0.5)</td>
</tr>
</tbody>
</table>

The mod group has a consistently lower KSS score both at a desk and after lying down compared to the mild group and the increase in score after lying down is consistently smaller for the mod group compared to the mild group. In order to investigate the effect of group on KSS score (at desk) a three factor ANOVA was performed. In addition to the findings stated in Section 3.3.4 for condition and time, there was no effect of group or condition*group interaction, but there was a significant time*group interaction [F(3,63)=3.66, p<0.001, G-G correction]. Plotting
mean KSS score versus time of day for the two groups, as in Figure 4.9, this interaction appears to first take place at 2.30pm, where the mod group experience a much larger increase in sleepiness than the mild group at this time. A second point of interaction appears to occur at 4.50pm, where, from this point on, instead of rating themselves the same as or more sleepy than the mild group, the mod group consistently rate themselves as less sleepy than the mild group.

![Figure 4.9: Mean KSS score (s.e.) sitting at a desk against time of day for the mild (blue line) and moderate (grey line) groups.](image)

Examining the data for the KSS scores after a 5 minute lie down, a three factor ANOVA confirmed the results stated in Section 3.3.3 and additionally found no significant effect of group or any interactions involving group.

In order to investigate the effect of group when comparing the two situations, a four factor ANOVA was performed on situation (at desk, after 5min lie down), condition, time and group. Again, the results involving situation, time and condition were the same as those stated in Section 3.3.3, with the addition of a significant situation*group interaction [F(1,18)=4.42, p=0.05], shown in Figure 4.10. There was no significant effect of group, group*time or group*condition interaction.
Figure 4.10: Mean KSS score (s.e.) sitting at a desk and after a 5min lie down for the mild (blue line) and moderate (grey line) groups.

As can be seen in Figure 4.10 the mild group have a greater increase in subjective sleepiness as a result of the lie down than the mod group.

4.3.5 Sleep the night after test days

Using data from the 12 participants (7mild, 5mod) who provided sleep information for the night after each main study day, group differences were investigated and are shown in Figures 4.11 and 4.12.

Figure 4.11: Mean (s.e.) sleep period for the nights post each condition (BL, SE, NAP CAFF) for the mild (n=7, blue lines) and mod (n=5, grey lines) groups.
Due to the small number of subjects providing this data (7mild, 5mod), the non-parametric Mann-Whitney test was used to investigate differences between the two groups in terms of sleep period the nights after testing. The mild group had a significantly shorter sleep period than the mod group after the nap condition \([U=6.0; \text{exact } p=0.037 \text{ (one-tailed)}]\), with no difference between the two groups for any other condition.

The sleep efficiency in the nights after each condition for the same 12 participants is shown in Figure 4.12. Using the Mann-Whitney test once more to look at group differences, there was no significant difference between the two groups in terms of sleep efficiency the nights after testing.

![Figure 4.12: Mean (s.e.) sleep efficiency for the nights post each condition (BL, SE, NAP CAFF) for the mild (n=7, blue lines) and mod (n=5, grey lines) groups.](image)

### 4.4 Summary of findings

The basic findings in this chapter are summarised below:

- Groups were similar for age, Trait anxiety and M/E scores,
- The mod group had significantly higher ESS scores and a greater number of females in it than mild group,
- Groups had similar KSS scores in screening,
- Sleep period before screening days was similar for the two groups, with a trend for the mod group to sleep slightly longer than the mild group,
• The groups obtained similar SP and SE_{SP} before each main study day,
• Group differences seen in the Standard MSLT did not persist when testing was moved to later in the day, as in the BL condition,
• There was no effect of group on sleep latency in the four conditions,
• The mild group had better survival than the mod group in the nap condition and at 5pm, 7.45pm and 11pm overall, but this was not significant,
• There were no significant group differences in terms of mean daily RT or lapses for each condition. However, the mod group did consistently have a slower mean RT and more lapses than the mild group,
• There were no significant group differences for am or pm performance, even when split into 10 minute epochs,
• Daily mean KSS score was higher (although not significantly) for the mild group than the mod group for all conditions,
• There was no effect of group on KSS at a desk, but there was a time*group interaction – the mod group had a much higher score at 2.30pm,
• Although not significantly different, the mild group improved similarly for all interventions, whereas the mod group improved more in the nap and caffeine conditions compared to the sleep extension condition,
• KSS scores after lying down for 5min showed no effect of group,
• There was a situation*group interaction – the mild group had a greater increase in subjective sleepiness after a 5min lie down than the mod group,
• SP was significantly shorter for the mild group the night after the nap condition,
• There was no effect of group on SE_{SP} the nights after testing.

4.5 Comment on findings

In terms of group characteristics, the mod group had a higher mean ESS score and a greater number of females in it than the mild group and there was no significant difference between the groups in terms of age, Trait anxiety or M/E score. There was no significant difference between the two groups in terms of sleep length and sleep efficiency obtained the nights before test days. This indicates that the shorter sleep latency exhibited by the mod group in the Standard MSLT cannot simply be attributed to a shorter habitual sleep length compared to the mild group, or poorer sleep quality, as these two parameters were comparable for both groups.
Previous studies have investigated the difference between long, i.e. >9h a night or so, and short, i.e. <6h a night sleepers and attributed differences in sleep latency to sleep debt or a higher sleep propensity/pressure in the short sleepers (Aeschbach et al., 1996). The present study investigated two groups of individuals who regularly sleep within the narrow bandwidth of 7 and 8 hours a night and yet still exhibit very different sleep latencies in the Standard MSLT. It seems likely that this difference is due to interindividual variation in the ability to fall asleep during the day rather than as a result of one group suffering from a greater level of daytime sleepiness than the other. This explanation is further strengthened by the finding that when MSLT testing is moved to later on in the day, as in the baseline condition, the significant differences between the two groups no longer remain.

When considering how the two groups may react to sleep extension, an afternoon nap or caffeine, it is reasonable to expect that the mod group would benefit more from these interventions if they are suffering a greater magnitude of sleep debt than the mild group. Although there was no significant difference between the two groups in terms of sleep latency, the mod group experienced a greater increase in sleep latency at 3.30pm for the sleep extension and caffeine conditions, and at both 5pm and 7.45pm for sleep extension, nap and caffeine. This suggests that the mod group may have benefited to a greater extent from the interventions than the mild group. This could be an indication of a larger sleep deficit being addressed in the mod group compared to the mild group, but as there was no significant difference found between the groups, the difference between the two in terms of deficit appears small. Alternatively, due to the small sample sizes here, the power size may have been too small to significantly detect changes and so further study with more subjects may be warranted.

The PVT has been shown to be a sensitive test of vigilance, able to detect changes as a result of extended or restricted sleep as well as subtle changes in alertness throughout the day due to circadian variation, discussed in Chapter 3. However, here, there was no significant effect of group on performance throughout the day, with the mod group performing equally well as the mild group.

In terms of subjective sleepiness, there was no difference between the groups in KSS score measured at a desk. However, there was a time*group interaction, with the mod group experiencing a much greater increase in sleepiness at 2.30pm than the mild group. It appears that the mod group are affected to a larger extent by the
circadian dip in alertness experienced by many in the mid-afternoon than the mild group. It was also observed that up until 4.50pm, the mod group had a higher KSS score than the mild group, but after this time the two groups switched, with the mod group feeling less sleepy than the mild group at all subsequent test times.

The time*condition interaction in terms of subjective sleepiness may go some way to explaining the difference between the groups in terms of sleep latency in the Standard MSLT and the lack of difference between the two in the Modified MSLT. The Standard MSLT commences at 10am with the last session at 4pm, during which time the mod group feel subjectively sleepier than the mild group. After 4.50pm the mod group no longer rate themselves as sleepier than the mild group, which could explain why the two groups are not significantly different in terms of sleep latency in the Modified MSLT. The data suggest that the mod group are more susceptible to the effects of the afternoon dip in alertness, feeling sleepier at this time, resulting in shorter sleep latencies than the mild group when undergoing the Standard MSLT.

KSS scores after a 5min lie down did not differ between the two groups, but the mild group did experience a greater increase in subjective sleepiness as a result of lying down compared to sitting at a desk than the mod group.

4.5.1 Interpretation

The two groups were classified according to their differing MSLT scores in the Standard MSLT, which, in accordance with ASDA would categorise individuals as suffering from either mild or moderate levels of sleepiness (mean sleep latency 12-15min or 5-9min, respectively) (Thorpy, 1992). The purpose of this chapter was to establish if these differences in terms of sleep latency persist regardless of the test times used for the MSLT and also if these differences are confirmed by other measures of sleepiness, such as performance and subjective sleepiness.

The difference between the groups in terms of sleep latency does not persist when testing is carried out later on in the day, and is not supported by other measures of sleepiness such as the PVT and KSS. The Standard MSLT is a well established sensitive measure of daytime sleepiness, able to distinguish normal from pathological populations (Engleman et al., 1994; Alloway et al., 1999) and measure the effect of various interventions or drugs on daytime sleepiness (Thorpy, 1992; Arand et al., 2005). However, when dealing with otherwise healthy, young adults, with no sleep disorders, excessive daytime sleepiness or evidence of impaired
daytime performance; it seems unwise to use the MSLT alone to distinguish one healthy individual from another. These results indicate that there is little difference between the two groups, except that the mod group appears to have an exacerbated post-lunch dip.
5 EEG activity during sleep and wakefulness

5.1 Introduction

The overall purpose of this experimental chapter is to assess EEG spectral components of the nap, Modified MSLT sessions and overnight EEG's with a view to addressing several aims:

The first aim of this chapter is to investigate whether specific components of the nap led to the increased sleep latency observed in the subsequent MSLT following the nap condition. The nap length of 20 minutes was chosen as it has been shown to provide measurable benefits in terms of increased feelings of alertness and performance, without any negative effects (Naitoh, 1992; Gillberg et al., 1994; Horne & Reyner, 1996; Hayashi et al., 1999). With a longer nap time it is more likely that increasing amounts of slow wave sleep may be obtained, resulting the build up of sleep inertia. Increased sleep inertia has been shown to produce feelings of grogginess and impaired performance on awakening, both of which are undesirable (Naitoh, 1992, p206-207).

Standard sleep staging was performed to establish the sleep composition within the nap and EEG analysis on the delta (0.5-3.5Hz) and alpha (8-11Hz) bands was investigated over the course of the nap to establish more detailed information on the depth of sleep obtained (delta) along with the degree of sleep disturbance (alpha).

The waking EEG in the MSLT sessions during the baseline and sleep extension conditions was also investigated. EEG analysis on the period from 'lights out' to sleep onset in the MSLT sessions provides information on change in the microstructure during this transition, which cannot be obtained from visual scoring alone. Alpha (8-11Hz) and theta (4-7.5Hz) frequency bands were investigated as, once the eyes are closed, there has previously been shown to be a sharp decline in the alpha activity of relaxed wakefulness and an increase in theta activity common to stage 1 sleep as the transition from wakefulness to sleep progresses (Alloway, Ogilvie & Shapiro, 1999; De Gennaro, Ferrara & Bertini, 2001).

Finally, the overnight EEG recordings were analysed in order to establish if there was any group difference in terms of sleep architecture during a typical night at home. Individuals undergoing partial sleep deprivation have been shown to exhibit reduced sleep onset latencies, higher sleep efficiencies and a gradual increase in stage 4 with each night of restricted sleep (Elmenhorst et al., 2007). If the mod group are suffering from the build up of a chronic sleep debt, it is hypothesised that they will exhibit these
characteristics to a greater extent than the mild group. The amount of delta (0.5-3.5Hz) activity in the first 5 hours of the night will also be investigated. Increased delta activity indicates a higher homeostatic sleep drive in accordance with process S, defined by Borbély (1994). If the mod group reside under a higher homeostatic sleep pressure (possibly due to the existence of a sleep debt) it is reasonable to expect that they will exhibit a greater amount of delta activity than the mild group.

Hypotheses for this experimental chapter are as follows:

i) sleep latency in subsequent MSLT sessions will be unaffected by nap composition in terms of sleep stage, delta or alpha activity,

ii) sleep extension will result in increased alpha and decreased theta activity during the sleep onset period of MSLT sessions compared to baseline,

iii) there will be no difference between the two participant groups in terms of nocturnal sleep composition and delta activity in the first 5h of sleep.

Main themes covered in this section:

- Nap composition and subsequent daytime objective sleep tendency
- Waking EEG after normal and extended sleep
- Overnight sleep architecture and EEG content

5.2 Methods

The study design was the same as that used in Chapters 3 and 4, whereby all participants underwent four conditions [Sleep Extension (SE) vs. Nap (NAP) vs. Caffeine (CAFF) vs. Baseline (BL)] in a counterbalanced order. Group characteristics are shown in section 4.2.1 and a detailed description of the study design can be found in Chapter 2, sections 2.4.1 to 2.4.3.

In this chapter, data obtained from the screening overnight EEG recording (see section 2.2.3) will be analysed and discussed along with data from the baseline, sleep extension and nap conditions.

5.2.1 Analysis of spectral EEG data

Before extraction, each EEG recording was visually scrutinised for artefacts such as EMG activity and movement and, where present, data containing artefacts were excluded from analysis. Power data for the required frequency bandwidths were extracted at a sampling rate of 100Hz and Fast Fourier Transformed (FFT) at a rate of
128Hz. The raw data files were exported into Excel for analysis and initially, the raw power data for each frequency band was investigated. A large inter-individual variation in raw power values was found with many outliers and so it was decided to calculate the relative change in power for each individual in order to reveal any difference between the groups in terms of EEG activity.

Recordings were standardised by calculating Fisher's Z-Scores (the relative change in power at time, t). This was done by referencing the raw power data to the mean of the first 60 seconds of clean EEG signal after lights out (A) and dividing by the standard deviation of the power values from lights out to the end of the recording (B).

The following equation was used:

\[
\text{Fisher's Z-Score}_t = \frac{\text{power value}_t - A}{\text{StDev}_B}
\]

A = mean power of the first 60s of clean EEG signal after lights out
B = all power values from lights out to the end of the recording

5.2.1.1 Nap and MSLT recordings

For the nap recordings, once standardised, due to the variation in nap length across individuals, each recording was divided equally into four quartiles from lights out to final sleep offset in order to maintain the chronology of the nap.

For the participants who fell asleep in the MSLT sessions, the time from lights out until sleep onset was divided into four equal quartiles in order to maintain the chronology of the sleep/wake transition and enable comparison between individuals. This method has been used previously by Alloway et al. (1999) to investigate differences in the transition from wakefulness to sleep in narcoleptics and normal sleepers.

5.2.1.2 Overnight EEG recordings

In a slight modification of the equation in section 5.2.1, instead of referencing the recording to 60s of wake, each overnight recording was referenced to 5min of REM sleep, as it contained minimal delta activity and, as the individual was asleep at this time with REM-related muscle atonia, it was also relatively free from artefacts.
5.2.2 Data analysis

For parametric data (i.e., spectral content of the nap and waking EEG content), quartile, group and condition effects were investigated using the appropriate factor (two or three) repeated measures ANOVA. Where multiple comparisons of a single parameter were required (as in the nap composition, sleep in the MSLT compared to % sleep stage in the nap, nocturnal EEG characteristics), the MANOVA was used. Where significant effects were found, post-hoc Bonferroni pair-wise comparisons were carried out. Group differences in terms of delta activity in the first 5h of sleep in the nocturnal sleep recording were investigated using a one-tailed t-test. Correlations [i.e., nap composition versus subsequent performance/KSS score and MSLT score (where n=11)] were investigated using the one-tailed Pearson correlation.

For non-parametric data [i.e., nap composition versus subsequent MSLT score, (where n=9], correlations were investigated using the one-tailed Spearman rank coefficient.

5.3 Results

5.3.1 Nap composition: Sleep staging

The composition of the nap in terms of standard sleep stages (Rechtschaffen & Kales, 1968) and spectral EEG content was examined to ascertain whether there was a specific aspect of the nap that makes it so effective at increasing sleep latency in the subsequent MSLT sessions at 3.30pm and 5pm. How the two groups (mild and mod) responded to the nap in terms of nap composition and subsequent objective sleepiness was also investigated.

Table 5.1 shows the composition of the nap in terms of Sleep Onset Latency (SOL, time to first 60s of sleep), Sleep Period (SP), Total Sleep Time [TST=SP-Wake After Sleep Onset (WASO)] and Sleep Efficiency relative to SP (SE\textsubscript{SP}). It can be seen that the average TST obtained by the 20 participants was 18.9min (s.d. 3.4), with only one participant achieving considerably less than the attempted 20 minutes (RC16, TST=8.5min).
Table 5.1: Nap composition: Sleep onset Latency (SOL), Sleep Period (SP = S1+S2+S3+S4+WASO), Total Sleep Time (TST = S1+S2+S3+S4) and Sleep Efficiency relative to sleep period (SE_{sp}). Mean (s.e.) values are shown at the bottom of the table.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SOL</th>
<th>SP</th>
<th>TST</th>
<th>SE_{sp}</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK01</td>
<td>10.3</td>
<td>22.7</td>
<td>18.7</td>
<td>82.4%</td>
</tr>
<tr>
<td>YG02</td>
<td>10.8</td>
<td>20.2</td>
<td>15.2</td>
<td>75.2%</td>
</tr>
<tr>
<td>HM03</td>
<td>7.3</td>
<td>23.3</td>
<td>19.8</td>
<td>85.0%</td>
</tr>
<tr>
<td>DB04</td>
<td>2.9</td>
<td>19.8</td>
<td>19.8</td>
<td>100.0%</td>
</tr>
<tr>
<td>KM05</td>
<td>3.2</td>
<td>25.8</td>
<td>21.3</td>
<td>82.6%</td>
</tr>
<tr>
<td>BC06</td>
<td>6.2</td>
<td>21.3</td>
<td>19.3</td>
<td>90.6%</td>
</tr>
<tr>
<td>CB07</td>
<td>7.5</td>
<td>22.5</td>
<td>14.5</td>
<td>64.4%</td>
</tr>
<tr>
<td>AC08</td>
<td>7.2</td>
<td>20.7</td>
<td>20.2</td>
<td>97.6%</td>
</tr>
<tr>
<td>JT09</td>
<td>2.5</td>
<td>23.2</td>
<td>18.2</td>
<td>78.4%</td>
</tr>
<tr>
<td>EG10</td>
<td>8.1</td>
<td>20.5</td>
<td>17.5</td>
<td>85.4%</td>
</tr>
<tr>
<td>GC11</td>
<td>2.6</td>
<td>26.5</td>
<td>21.5</td>
<td>81.1%</td>
</tr>
<tr>
<td>MO12</td>
<td>5.6</td>
<td>21.8</td>
<td>18.8</td>
<td>86.3%</td>
</tr>
<tr>
<td>NB13</td>
<td>8.2</td>
<td>19.8</td>
<td>17.3</td>
<td>87.4%</td>
</tr>
<tr>
<td>JL14</td>
<td>3.6</td>
<td>21.0</td>
<td>21.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>VS15</td>
<td>5.0</td>
<td>20.2</td>
<td>20.2</td>
<td>100.0%</td>
</tr>
<tr>
<td>RC16</td>
<td>3.6</td>
<td>8.5</td>
<td>8.5</td>
<td>100.0%</td>
</tr>
<tr>
<td>CW17</td>
<td>8.9</td>
<td>22.0</td>
<td>17.5</td>
<td>79.5%</td>
</tr>
<tr>
<td>RH18</td>
<td>1.3</td>
<td>26.5</td>
<td>23.5</td>
<td>88.7%</td>
</tr>
<tr>
<td>PS19</td>
<td>7.3</td>
<td>21.5</td>
<td>21.5</td>
<td>100.0%</td>
</tr>
<tr>
<td>LT20</td>
<td>7.0</td>
<td>27.5</td>
<td>24.0</td>
<td>87.3%</td>
</tr>
<tr>
<td>All</td>
<td>5.9(0.6)</td>
<td>21.8(0.9)</td>
<td>18.9(0.8)</td>
<td>87.6%(2.2)</td>
</tr>
<tr>
<td>Mild</td>
<td>6.4(0.8)</td>
<td>21.0(1.2)</td>
<td>18.6(1.2)</td>
<td>89.4%(3.2)</td>
</tr>
<tr>
<td>Mod</td>
<td>5.0(0.9)</td>
<td>23.2(0.9)</td>
<td>19.5(0.6)</td>
<td>84.2%(1.5)</td>
</tr>
</tbody>
</table>

Chapter 5: EEG activity during sleep and wakefulness
5.3.1.1 Effect of group

Figure 5.1 shows the time spent in each sleep stage (including WASO) for each participant.

![Figure 5.1: Time spent in S1, S2, S3, S4 and WASO for each of the 20 participants.](image)

A MANOVA on the data shown in Table 5.1 and Figure 5.1 indicated no significant effect of group on TST, time spent in each sleep stage (S1, S2, S3, S4 and WASO), SOL or SE\textsubscript{SP} in the nap.

In terms of percentage of time spent in each sleep stage as a function of the sleep period, a MANOVA showed there to be no significant effect of group, although the moderate group did obtain a greater percentage of S1 and WASO, with a lower percentage of S3 and S4 compared to the mild group, as shown in Figure 5.2.
Figure 5.2: Percentage (s.e.) of time spent in each sleep stage relative to Sleep Period (SP = S1+S2+S3+S4+WASO) for the mild (n=13) and mod (n=7) groups.

5.3.1.2 Effect of nap on subsequent objective sleepiness

In order to investigate the effect of nap content on sleep latency in the 3.30pm and 5pm MSLT sessions, correlations between sleep stages in the nap and subsequent MSLT sleep latency were examined. Less WASO and more deep sleep result in a higher sleep efficiency, which will in turn decrease objective sleepiness in any subsequent sleep opportunity. Therefore, it was hypothesised that deep sleep (stages 3 and 4) would be positively correlated with increased sleep latency, and light sleep (stages 1 and 2 and WASO) would be negatively correlated with increased sleep latency in subsequent MSLT sessions.

In the 3.30pm MSLT session less than half of the participants (n=9) fell asleep within the 20 minute window, a clear indicator of low levels of objective sleepiness. The high number of 20 minute scores resulted in a skewed distribution, preventing the accurate use of parametric analyses and so the non-parametric Spearman rank coefficient was used to investigate connections between sleep stage and subsequent sleep latency. No significant correlation between any sleep stage and subsequent sleep latency was found.

In the 5pm MSLT session 11 participants fell asleep and the distribution of scores was such that parametric analyses could be legitimately applied. A Pearson correlation on
all 20 participants showed WASO to be significantly negatively correlated with sleep latency at this time (r=-0.43; n=20; p=0.03; one-tailed. $r^2=0.18$). This correlation is strengthened when only those that fell asleep in the MSLT session (n=11, 7 mild and 4 mod) are considered (r=-0.61; n=11; p=0.02; one-tailed. $r^2=0.38$) and is shown in Figure 5.3.

![Figure 5.3](image)

**Figure 5.3:** Relationship between percentage of WASO obtained in the nap and subsequent sleep latency for those who fell asleep in the 5pm MSLT session (n=11).

Examining the mild and mod groups separately, for the mild group, WASO was significantly negatively correlated with sleep latency (r=-0.55; n=13; p=0.03. $r^2=0.30$), as shown in Figure 5.4. This was not the case for the mod group, where there was no correlation between any sleep stage and subsequent sleep latency. This may have been due to the small sample size for the mod group (n=4).

![Figure 5.4](image)

**Figure 5.4:** Relationship between percentage of WASO obtained in the nap and subsequent sleep latency for the mild participants in the 5pm MSLT session (n=13).
In order to investigate the effect of nap composition on objective sleepiness in terms of the success of a subsequent MSLT session (whether an individual fell asleep or not), the mean percentage of the sleep period spent in each sleep stage was calculated for those who fell asleep in the 3.30pm and 5pm MSLT sessions (labelled ‘Yes’) and compared to the mean for those who did not fall asleep (labelled ‘No’). Mean values are shown in Table 5.2.

**Table 5.2:** Percentage (s.e.) of time spent in each sleep stage for those who fell asleep in the 3.30pm and 5pm MSLT sessions (Yes) and those who didn’t (No).

<table>
<thead>
<tr>
<th></th>
<th>3.30pm</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>WASO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>20.5%(4.4)</td>
<td>56.2%(6.3)</td>
<td>5.0%(2.1)</td>
<td>3.9%(2.3)</td>
<td>14.3%(4.6)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>18.5%(2.6)</td>
<td>57.3%(3.2)</td>
<td>4.9%(1.7)</td>
<td>7.9%(4.1)</td>
<td>11.4%(2.4)</td>
<td></td>
</tr>
<tr>
<td>5pm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>17.9%(3.1)</td>
<td>53.7%(4.5)</td>
<td>5.6%(1.5)</td>
<td>8.1%(4.6)</td>
<td>14.7%(3.3)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>20.7%(3.6)</td>
<td>60.9%(3.4)</td>
<td>4.2%(2.2)</td>
<td>4.6%(3.0)</td>
<td>9.6%(2.7)</td>
<td></td>
</tr>
</tbody>
</table>

A MANOVA was performed to establish whether there was any difference between the percentage of time spent in each sleep stage and whether or not sleep was obtained in the 3.30pm MSLT session; no significant difference was found between the two groups. However, those who slept at 3.30pm obtained less S4 and more WASO in the nap than those that didn’t fall asleep at 3.30pm. For the 5pm MSLT, no significant effect of group was found.

The data suggest that there does not appear to be a particular nap composition that determines whether or not an individual will obtain sleep in subsequent MSLT sessions.

5.3.1.3 Effect of nap on subsequent subjective sleepiness & performance

Looking at nap composition and subsequent KSS score using a Pearson correlation, the percentage of S4 was found to be significantly correlated with KSS score after the nap (mean value for the six KSS scores from 4pm to 11.30pm) ($r=0.38; p=0.05, n=20$; one-tailed. $r^2=0.14$). However, as can be seen in Figure 5.5, an outlier (S4=50.4%, KSS score=6.4) appears to be greatly influencing the distribution. Indeed, once this outlier is removed, the correlation no longer remains.
Figure 5.5: Relationship between the percentage of S4 obtained in the nap and subsequent subjective sleepiness.

Performance (in terms of number of lapses) in the afternoon (4.10pm) and evening (10.10pm) PVT sessions was also investigated and found not to be correlated with any individual sleep stage in the nap.

5.3.2 Nap composition: Spectral content

In section 5.3.1.1 it was shown that, even though not statistically significant, the mod group appeared to obtain a lower percentage of slow wave sleep and a higher percentage of WASO than the mild group in the nap. Therefore, the amount of delta activity (0.5-3.5Hz) and alpha activity (8-11Hz) obtained in the nap were investigated, as they are spectral components of slow wave sleep and WASO respectively.

A two factor ANOVA showed there to be a significant effect of quartile on delta power \(F(2,38)=13.66, \ p<0.001, \ G-G \ correction\) with no significant effect of group or quartile*group interaction. Post hoc Bonferroni comparisons showed the fourth quartile to be significantly different to the first \(p<0.005\), second \(p<0.005\) and third quartiles \(p<0.001\). Although the difference was not significant, the mod group consistently achieved less delta than the mild group throughout the nap, as shown in Figure 5.6.
A two factor ANOVA indicated a significant effect of quartile on alpha power \( F(3,54)=6.84, p<0.05 \) with no significant effect of group or quartile*group interaction. Post hoc Bonferroni comparisons showed the fourth quartile to have significantly higher alpha activity than the first \((p<0.05)\), second \((p<0.001)\) and third quartiles \((p<0.01)\) and the second quartile to have significantly less alpha activity than the third quartile \((p<0.05)\).

### 5.3.3 Waking EEG activity

In Chapter 3.3.1 the issue of participants failing to fall asleep within the given time frame for some MSLT sessions was discussed. The frequency of sleep onset in the MSLT sessions was used to decide which conditions and MSLT sessions would be investigated in terms of EEG activity. Figure 5.7 shows the frequency of sleep onset at each session time for each condition.
Chapter 5: EEG activity during sleep and wakefulness

Figure 5.7: Number of participants who fell asleep in each MSLT session (3.30pm, 5pm, 7.45pm, 11pm) for each condition (BL, SE, NAP, CAFF). 80% frequency of sleep onset indicated by the red line.

As shown in Chapter 3.3.1, there was no significant effect of condition or group on the 7.45pm and 11pm MSLT sessions and so they are not considered here. In addition, few participants fell asleep in the nap and caffeine conditions at 3.30pm and 5pm (less than 80%), indicating that they were clearly not sleepy and so these too were not investigated further in this Chapter. Therefore, the 3.30pm and 5pm MSLT sessions for the baseline and sleep extension conditions were investigated.

It was hypothesised that extension of nocturnal sleep would result in increased alertness in the MSLT sessions the next day. This has been demonstrated by an increase in sleep latency, discussed previously in Chapter 3. In terms of EEG activity, an increase in daytime alertness commonly results in increased alpha activity and reduced theta activity when the individual is relaxed with their eyes closed trying to fall asleep (Alloway et al., 1999; Åkerstedt & Gillberg, 1990). Therefore, theta (4-7.5Hz) and alpha (8-11Hz) activity were analysed for the 3.30pm and 5pm MSLT sessions to investigate whether or not the sleep extension had an impact on them at these times.

5.3.3.1 Theta (4-7.5Hz)

In the 3.30pm MSLT session a three factor ANOVA showed a significant effect of quartile [n=19, F(2,28)=22.62, p<0.001, G-G correction] with no effect of condition or group or any interactions on theta activity. The same was carried out for the 5pm MSLT session and showed similar results, a significant effect of quartile [n=15,
F(3,39)=20.70, p<0.001] with no effect of condition or group or any interactions. Theta activity in the 3.30pm and 5pm MSLT sessions is shown graphically in Figure 5.8.

![Graph A](image1)

**Figure 5.8:** Mean relative Theta power (s.e.) over the four quartiles of the 3.30pm (A) and 5pm (B) MSLT sessions for those who fell asleep.

5.3.3.2 Alpha (8-11Hz)

A three factor ANOVA showed a significant effect of quartile [n=19, F(2,27)=18.44, p<0.001, G-G correction] with no effect of condition or group on alpha activity in the 3.30pm MSLT session. There was a significant condition*quartile*group interaction [n=19, F(3,51)=5.20, p<0.005] with no other significant interactions. It can be seen in Figure 5.9 that the effect of sleep extension is to increase alpha power for the mild
group relative to baseline over all four quartiles, but decrease alpha power in the mod
group over the first two quartiles, with no change in quartiles three and four.

![Graph showing relative alpha power over four quartiles](image)

**Figure 5.9:** Relative Alpha power (s.e.) over the four quartiles of the 3.30pm MSLT for those who fell asleep (BL, n=19, SE, n=20).

For the 5pm MSLT session a three factor ANOVA showed a significant effect of quartile [n=15, F(2,27)=30.43, p<0.001, G-G correction] with no effect of condition or group or any interactions (see Figure 5.10).

![Graph showing relative alpha power over four quartiles](image)

**Figure 5.10:** Relative Alpha power (s.e.) over the four quartiles of the 5pm MSLT for those who fell asleep (BL, n=17, SE, n=17).
Overall, in Figures 5.8 to 5.10 it can be seen that at both 3.30pm and 5pm relative theta power increases and relative alpha power decreases with each quartile, indicating the transition from wakefulness to sleep.

### 5.3.4 Nocturnal EEG activity

The purpose of this section is to determine whether the two groups exhibit different sleep architecture, which may go some way to explaining their difference in sleep latency in the Standard MSLT. Figure 5.11 shows the sleep structure for the 20 participants. The sleep period for GC11 is much reduced relative to the other participants due to technical difficulties resulting in the recording ceasing at 4.30am. Therefore, GC11 will not be included in any calculations involving the time spent in sleep stages as the recording is not a true reflection of the individual’s entire night’s sleep.

![Sleep composition for each participant](image)

**Figure 5.11:** *Sleep composition for each participant.*
Table 5.3: Overnight Sleep onset Latency (SOL, time to first 60s of sleep), Sleep Period (SP = S1+S2+S3+S4+WASO), Total Sleep Time (TST = S1+S2+S3+S4) and Sleep Efficiency relative to sleep period (SE_SP). Mean (s.e.) values are shown at the bottom of the table. GC11 not included in calculations of the mean values.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SOL (min)</th>
<th>SP</th>
<th>TST (min)</th>
<th>SE_SP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK01</td>
<td>11.2</td>
<td>452.6</td>
<td>440.0</td>
<td>97.2%</td>
</tr>
<tr>
<td>YG02</td>
<td>6.5</td>
<td>546.4</td>
<td>508.5</td>
<td>93.1%</td>
</tr>
<tr>
<td>HM03</td>
<td>3.0</td>
<td>505.9</td>
<td>483.4</td>
<td>95.6%</td>
</tr>
<tr>
<td>DB04</td>
<td>1.8</td>
<td>454.0</td>
<td>416.5</td>
<td>91.7%</td>
</tr>
<tr>
<td>KM05</td>
<td>6.9</td>
<td>423.9</td>
<td>412.4</td>
<td>97.3%</td>
</tr>
<tr>
<td>BC06</td>
<td>12.0</td>
<td>492.6</td>
<td>469.5</td>
<td>95.3%</td>
</tr>
<tr>
<td>CB07</td>
<td>1.5</td>
<td>529.3</td>
<td>488.5</td>
<td>92.3%</td>
</tr>
<tr>
<td>AC08</td>
<td>8.5</td>
<td>422.8</td>
<td>414.3</td>
<td>98.0%</td>
</tr>
<tr>
<td>JT09</td>
<td>3.5</td>
<td>464.1</td>
<td>462.0</td>
<td>99.5%</td>
</tr>
<tr>
<td>EG10</td>
<td>4.0</td>
<td>479.1</td>
<td>458.5</td>
<td>95.7%</td>
</tr>
<tr>
<td>GC11</td>
<td>1.7</td>
<td>346.7</td>
<td>335.7</td>
<td>96.8%</td>
</tr>
<tr>
<td>MO12</td>
<td>7.7</td>
<td>606.8</td>
<td>577.0</td>
<td>95.1%</td>
</tr>
<tr>
<td>NB13</td>
<td>7.1</td>
<td>437.5</td>
<td>405.0</td>
<td>92.6%</td>
</tr>
<tr>
<td>JL14</td>
<td>10.4</td>
<td>414.2</td>
<td>397.0</td>
<td>95.8%</td>
</tr>
<tr>
<td>VS15</td>
<td>3.6</td>
<td>469.4</td>
<td>460.4</td>
<td>98.1%</td>
</tr>
<tr>
<td>RC16</td>
<td>3.0</td>
<td>467.2</td>
<td>453.0</td>
<td>97.0%</td>
</tr>
<tr>
<td>CW17</td>
<td>4.6</td>
<td>417.9</td>
<td>415.4</td>
<td>99.9%</td>
</tr>
<tr>
<td>RH18</td>
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<td>481.4</td>
<td>473.5</td>
<td>98.4%</td>
</tr>
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<td>482.3</td>
<td>474.0</td>
<td>98.3%</td>
</tr>
<tr>
<td>LT20</td>
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<td>479.6</td>
<td>471.5</td>
<td>98.3%</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td><strong>5.3(0.8)</strong></td>
<td><strong>475.1(10.8)</strong></td>
<td><strong>456.9(9.6)</strong></td>
<td><strong>96.3%(0.5)</strong></td>
</tr>
<tr>
<td><strong>Mild</strong></td>
<td><strong>4.9(1.0)</strong></td>
<td><strong>465.7(11.1)</strong></td>
<td><strong>447.5(9.8)</strong></td>
<td><strong>96.2%(0.8)</strong></td>
</tr>
<tr>
<td><strong>Mod</strong></td>
<td><strong>6.2(1.4)</strong></td>
<td><strong>495.4(25.1)</strong></td>
<td><strong>477.1(22.2)</strong></td>
<td><strong>96.4%(0.7)</strong></td>
</tr>
</tbody>
</table>

A MANOVA was performed on the data in Table 5.3 and showed there to be no significant effect of group on SOL, SP, TST or SE_SP. In addition, a MANOVA confirmed that there was also no effect of group on percentage of time spent in each stage relative to SP. This data is represented graphically in Figure 5.12.
Chapter 5: EEG activity during sleep and wakefulness

5.3.4.1 Delta (0.5-3.5Hz)

In section 5.3.3 it was shown that there is little difference between the mild and mod groups in terms of EEG composition during the transition from wakefulness into sleep. Therefore, the wake-sleep transition for the overnight EEG recordings was not examined. In the same way that theta activity is an indicator of increased sleepiness during the day, delta activity during the night is a good indicator of sleep need in accordance with process S in the two-process model proposed by Borbély (1994). A greater amount of delta activity during sleep indicates a higher homeostatic sleep pressure and could provide an explanation to the different sleep latencies exhibited by the mild and mod groups in the Standard MSLT. It may be that the 'moderately' sleepy group are under a slightly higher sleep pressure than the mild group, resulting in their short sleep latencies at the times when the Standard MSLT is carried out (10am-4pm), with no accompanying performance decrements or increased subjective sleepiness.

Delta activity over the first 5 hours of sleep was analysed, as this is where the greatest amount of delta activity occurs and sleep is most likely to continue uninterrupted by episodes of wakefulness. The recording for GC11 was complete for the first 5 hours and so was included in the analysis with the data for the other 19 participants.

Figure 5.12: Sleep composition (s.e.) for the mild (n=13) and mod (n=6) groups. GC11 not included.
Figure 5.13: Relative Delta power for the mild (n=13) and mod (n=7) groups in the first 5 hours of sleep.

Figure 5.13 shows the relative delta power across the first 5 hours of the overnight EEG recording for the mild and mod groups. A t-test on this data (600 data points) showed the mod group to have significantly more relative delta activity (mean=0.84) than the mild group (mean=0.75) [t(1198)=-2.91, p<0.005, one-tailed].

5.4 Summary of findings

- There was no significant difference in the percentage of each sleep stage obtained by the two groups in the 20min nap,
- WASO was negatively correlated with sleep latency in the 5pm MSLT session,
  - Looking at the two groups separately, this correlation remains for the mild group but does not for the mod group,
- There was no significant difference between the groups in terms of whether or not sleep onset was achieved in the MSLT sessions,
- There was a trend for those obtaining more WASO in the nap to be more likely to fall asleep in both the 3.30pm and 5pm MSLT sessions,
- There was no relationship between nap composition and subsequent subjective sleepiness or performance,
- In terms of delta activity throughout the nap there was no significant difference between the two groups
- There was no effect of sleep extension or group on EEG theta activity in the MSLT sessions,
• There was no effect of sleep extension or group on EEG alpha activity in the 5pm MSLT session, however, there was a significant condition*quartile*group interaction in alpha activity at 3.30pm,
• Nocturnal sleep was similar for the two groups in terms of sleep stage composition and sleep efficiency,
• The mod group had significantly more delta activity in the first 5h of nocturnal sleep than the mild group.

5.5 Comment on findings
All participants were able to sleep in the nap condition, although RC16 did wake after about 8.5 minutes, unable to re-initiate sleep after this time. Sleep Onset Latency, time spent in sleep stage 1 and time spent in sleep stage 2 were all within one standard deviation of the mean values obtained in another study involving a 20 minute afternoon nap carried out by Hayashi et al. (1999). There was no significant difference between the two groups in terms of sleep composition in the nap, indicating similar levels of daytime sleep tendency. The individuals taking part in the study by Hayashi et al. (1999) did not obtain any slow wave sleep and 3 out of the 7 individuals obtained REM sleep. In the present study, no participant obtained any REM sleep, 11 obtained stage 3 sleep and out of that 11, 8 also obtained some stage 4 sleep. Previous studies have suggested that naps less than 30 minutes in length are advantageous as they only allow the individual time to obtain the lighter stages of sleep (stage 1 and stage 2), reducing the negative impact of sleep inertia (performance decrements and increased feelings of sleepiness) on awakening (Naitoh, 1992, p206; Horne & Reyner, 1996). In the present study, over half of the participants obtained some slow wave sleep during the course of the nap, however, the mean length of time spent in stages 3 and 4 combined was short (less than three minutes). There was found to be no relationship between sleep stage composition in the nap and subsequent KSS scores or PVT performance, suggesting that the deeper stages of sleep did not result in increased sleep inertia and its associated negative effects after the nap.

Although the afternoon nap did not have a negative impact on subsequent subjective sleepiness or performance, it did not have a significant positive impact on these parameters either, which disagrees with the findings of other nap studies (Gillberg et al., 1994; Horne & Reyner, 1996; Hayashi et al., 1999). The difference between the findings of the present study and those of other studies may be explained by differences in protocol, such as nocturnal sleep duration obtained the night prior to testing and the experimental methods used. The study carried out by Gillberg et al.
(1994) investigated the effect of a 30min nap after sleep was restricted to 4h the night before, measuring the effects of the nap on subsequent KSS scores and performance in a 28min visual vigilance task. Although the tasks were similar to those used in the present study, the restricted sleep the night before and the longer nap duration are likely to be the cause of the increased impact of the nap on subsequent performance and sleepiness. Horne and Reyner (1996) also carried out tests following a night of restricted sleep (5h), giving a 15min nap in the afternoon and measuring performance on a 2h simulated motorway drive in a car simulator. Here, the restricted sleep, in addition to the different, longer duration performance measure may account for the greater impact of the nap in Horne and Reyner’s (1996) study compared to that observed in the present study.

The study carried out by Hayashi et al. (1999) was on the effect of a 20min nap following 8h sleep the night before testing, i.e., a similar prior sleep length to the present study, and the same nap duration. Hayashi et al. (1999) measured several subjective parameters on a 100mm visual analogue scale, including subjective sleepiness and found subjective sleepiness to be significantly lower following the afternoon nap. Discrete sleepiness scales such as the KSS may not be as sensitive to changes in sleepiness as the visual analogue scales and so this may explain the non-significant effect of the nap on KSS score in the present study. In the study carried out by Hayashi et al. (1996), participants also underwent a battery of performance measures (logical reasoning, addition, alphanumeric detection and auditory vigilance). They found that the nap significantly improved performance in the logical reasoning and auditory vigilance tasks in terms of percentage correct values, however, there was no effect of the nap on reaction time in any of the tasks. So, although the authors found a significant effect of the nap on performance, reaction time in a task similar to the PVT, the auditory vigilance task, was unaffected by the nap, and therefore is in agreement with the findings of the present study.

In the 5pm MSLT session, sleep latency was found to be negatively correlated to the amount of WASO obtained in the nap. This seems logical when considering the restorative properties of sleep and that the more sleep an individual is able to obtain within a given time, the less sleepy they will be subsequently. When considering the groups separately, this correlation holds for the mild group but does not remain for the mod group, which may be explained by the small sample size in the mod group. Additionally, although not statistically significant, there was a trend for those obtaining
more WASO in the nap to fall asleep more often in the 3.30pm and 5pm MSLT sessions.

Delta activity increased steadily over the course of the nap as the deeper stages of sleep were obtained in agreement with the nap study carried out by Morikawa, Hayashi & Hori (1997). Alpha activity in the nap decreased over the first two quartiles and then slowly increased to a maximum in the forth quartile. The reduction of alpha activity during the transition from wakefulness to sleep is well documented (Alloway et al., 1999; De Gennaro, et al., 2001). The subsequent increase in alpha power after an initial reduction has been observed by De Gennaro et al. (2001) and is thought to correspond to the existence of a different kind of alpha activity, which is associated with processes involved in the maintenance of sleep (Pivik & Harman, 1995). In terms of both delta and alpha activity during the nap there was no significant difference between the two groups, indicating that they were experiencing similar levels of sleep pressure.

In accordance with other studies exploring the sleep onset process, during the transition from wakefulness to sleep in the MSLT sessions there was a gradual increase in theta activity and a decrease in alpha activity (De Gennaro et al., 2001; Alloway et al., 1999). There was no significant effect of condition in either frequency band in either of the MSLT sessions (3.30pm and 5pm), suggesting that sleep extension did not impact significantly on objective sleepiness as measured by waking EEG. In terms of group differences, there was no effect of group on theta activity in the 3.30pm or 5pm MSLT sessions or on alpha activity at 5pm. In the 3.30pm MSLT session there was a significant condition*quartile*group interaction (p<0.005), with sleep extension increasing alpha power relative to baseline by roughly the same amount over all four quartiles for the mild group, but decreasing alpha power in the mod group over the first two quartiles, with no impact on alpha power in quartiles 3 and 4 relative to baseline. An explanation for this difference may be that the alpha activity recorded in the mild group was dominated by the type of alpha activity that originates from the occipital region of the brain and is an indicator of increased sleep disturbance. In this group, sleep extension resulted in a slight increase in alpha activity over the sleep onset period, indicating increased alertness compared to baseline. Conversely, the alpha activity recorded in the mod group may consist to a larger extent of 'sleep maintaining' alpha, which originates from the frontal-central area of the brain, as discussed by Pivik and Harman (1995). This would account for the initial reduction in alpha activity observed in the sleep extension condition compared to baseline. However, as only central channels were recorded in this study, it is not possible to
determine whether this is the case. As the significant interaction was only observed in the 3.30pm MSLT session and there was found to be no significant effect of condition overall, the interaction appears small and may simply be explained by inter-individual differences in alpha activity.

In the overnight recording, the percentage of time spent in each sleep stage (relative to sleep period) was in agreement with the normal values quoted by Williams, Karacan & Hursch (1974, p51) with stages 1, 4, REM and WASO within one standard deviation and stages 2 and 3 just outside one standard deviation of those specified by Williams et al. (1974). There was no significant difference between the two groups in terms of their overnight sleep composition, sleep onset latency, total sleep time or sleep efficiency. In terms of EEG activity, the mod group exhibited more delta activity in the first 5 hours of sleep than the mild group. This increased delta activity could indicate that these individuals are under a higher homeostatic sleep pressure as described by Borbély (1994), which could be caused by the existence of a sleep debt. However, it is reasonable to assume that if the mod group do have a degree of sleep debt, then its magnitude is relatively small, as it can only be detected on the microscopic level of EEG analysis, and not macroscopically in terms of performance, sleep stage composition or sleep efficiency, for example.

5.5.1 Interpretation

The increased delta activity overnight, coupled with short sleep latencies during the day may indicate that the mod group exist under a higher sleep homeostatic pressure than the mild group. However, in terms of daytime sleepiness, as determined by alpha and theta activity in the waking EEG of the MSLT sessions, there was no significant difference between the two groups. In addition, overnight sleep onset latency was no shorter and sleep efficiency was no higher in the mod group compared to the mild group. Therefore, it is suggested that the mod group may simply reside at one end of the normal range in terms of daytime sleep tendency and nocturnal sleep EEG composition.
Chapter 6: Maintaining wakefulness

6 Maintaining wakefulness

6.1 Introduction

The purpose of this section is to investigate the effect of instruction on sleep latency in order to attempt to distinguish the ability to fall asleep from the ability to remain awake. Previous studies have shown sleep latency to increase when the instruction given to participants at the beginning of each test session is changed from 'try to go to sleep' to 'try to stay awake' (Hartse et al., 1982; Mitler et al., 1982). Therefore, a fifth condition (in addition to the main protocol) was carried out whereby each participant was instructed to try to remain awake instead of trying to fall asleep in each test session. This test is identical to the MSLT in every way except for the instruction and is therefore known as the Repeated Test of Sustained Wakefulness (RTSW) (Hartse et al., 1982). By measuring the ability to stay awake under soporific conditions identical to those used in the MSLT it is hoped that information will be provided on whether the participants are truly sleepy, unable to stay awake in the MSLT or the RTSW, or simply possess the ability to fall asleep when circumstances permit, indicated by an increased sleep latency in the RTSW compared to the MSLT.

It is hypothesised that sleep latencies will be longer and fewer participants will fall asleep in the RTSW condition compared to the Modified MSLT condition, with no change in PVT performance or subjective sleepiness as measured by the KSS.

The concept of high sleepability without sleepiness, first introduced by Harrison and Horne (1996a) will be explored, with any participants suspected of possessing such a trait investigated and discussed.

Main themes covered in this section:

- The effect of instruction on
  o Sleep latency
  o EEG activity during the transition from wakefulness to sleep
  o Performance
  o Subjective sleepiness
- The concept of sleepability along with identification of individuals thought to possess this trait
Data from this chapter has been presented in poster format at the 19th Congress of the European Sleep Research Society, 9th-13th September, Glasgow, UK and is shown in Appendix 5.

6.2 Methods

All participants underwent two conditions [baseline (Modified MSLT) versus RTSW (RTSW)]. The testing schedule for the baseline condition (Modified MSLT) is shown in Figure 2.8. The schedule for the RTSW condition was identical to that of the Modified MSLT condition, except that MSLT sessions were replaced with RTSW sessions. Due to the addition of the RTSW condition initially as an adjunct to the main study conditions reported in Chapters 3-5, the order in which the Modified MSLT and RTSW conditions were carried out was not counterbalanced. Participant characteristics are shown in section 3.2.1 and group characteristics are shown in 4.2.1.

The two conditions are defined below:

**Condition 1: Baseline condition (Modified MSLT)**

A standard control comprising a normal night's sleep without any extra sleep, followed by daytime testing using the Modified MSLT the next day.

Condition 1 will be referred to throughout this section as the Modified MSLT condition

**Condition 2: RTSW condition (RTSW)**

Identical to Condition 1 except Modified MSLT sessions are replaced with RTSW sessions, where the instruction to remain awake is given instead of the instruction to try to fall asleep.

Condition 2 will be referred to throughout this section as the RTSW condition

The RTSW condition was carried out second and the Modified MLST condition first by every participant. It is possible that this lack of compensation for order effects may impact on the results, for example, performance may be worse in the RTSW condition as the participants have carried out the PVT many times previously and so may have suffered from a lack of motivation or boredom in this condition.
Conversely, performance may be better in the RTSW condition as a result of practice effects. However, as all participants underwent practice PVT sessions prior to taking part in the study, this should not be a cause of differing performance levels between the two conditions. Additionally, sleep latency may be affected by order effects. It is possible that participants will fall asleep faster as they become accustomed to the study routine and the experimenters week by week, and so any observed increase in the RTSW condition will be in addition to that required to overcome the effect of familiarity. Therefore, as the lack of counterbalancing may reduce sleep latency, any measured increase in sleep latency in the RTSW condition relative to the Modified MSLT could be considered to be as a result of the change in instruction, i.e., an affect of condition.

### 6.2.1 Data analysis

As for all other experimental chapters, where possible, parametric statistical tests were used to analyse the data.

For parametric data (i.e., sleep period/efficiency before test days, PVT RT/lapses, KSS score and waking EEG data), time, condition, group, situation and quartile effects were investigated using the appropriate factor (one, two, three or four) repeated measures ANOVA. Where significant effects were found, post-hoc Bonferroni pair-wise comparisons were carried out.

For non-parametric data (i.e., sleep period/efficiency after test days and sleep latency), group effects were investigated using the Mann-Whitney test and condition effects were investigated using the Wilcoxon signed ranks test. Survival analysis was also performed on the sleep latency data, with the log rank Mantel-Cox test used to investigate condition and group effects.

### 6.3 Results

#### 6.3.1 Sleep the night prior to testing

In order to ensure that the sleep obtained the night before each condition was consistent, actimeters were worn the night before each test day and the participant was instructed to sleep their usual amount. The mean value for the Sleep Period (SP) and Sleep Efficiency (relative to SP) before each condition are shown in Table 6.1.
Table 6.1: Mean (s.e.) Sleep Period (SP) and sleep efficiency (relative to SP) obtained the night before the Modified MSLT and RTSW conditions.

<table>
<thead>
<tr>
<th></th>
<th>Sleep Period, SP (h)</th>
<th>Sleep Efficiency SP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified MSLT</td>
<td>7.6(0.1)</td>
<td>87.1(1.2)</td>
</tr>
<tr>
<td>RTSW</td>
<td>7.7(0.1)</td>
<td>86.4(1.2)</td>
</tr>
</tbody>
</table>

SP the night before the Modified MSLT and RTSW conditions was compared using a two factor ANOVA. There was no significant effect of condition, group, or condition*group interaction, indicating that SP between test days and groups was consistent. The same was performed for sleep efficiency, which also showed no significant difference for group, condition or condition*group interaction.

6.3.2 MSLT/RTSW scores

Mean daily sleep latencies were 12.6min (s.d. 3.5) and 14.5min (s.d. 3.9) for the Modified MSLT and RTSW conditions respectively. Mean sleep latencies at each session time for the two conditions are shown in Figure 6.1. As in Chapters 3 and 4, due to the nature of the sleep latency data for the two conditions, nonparametric statistical analyses were used to establish the significance of any differences in sleep latency.

![Figure 6.1: Mean (s.e.) sleep latencies in each test session for the Modified MSLT and RTSW (n=20) * p<0.01.](image)

The Wilcoxon matched-pairs signed ranks test showed a significant difference between the median sleep latency for the Modified MSLT (14.6 min, s.d. 5.3) and the RTSW (17.9min, s.d. 4.2) conditions at 7.45pm (W=8, p<0.01, one-tailed).
There was no significant difference between the two conditions for any other session, although sleep latency was increased in both the 3.30pm and 5pm session for RTSW relative to Modified MSLT.

Mean sleep latencies at each session time for the two conditions and the two groups are shown in Figure 6.2.

Figure 6.2: Mean (s.e.) sleep latency for each test session in the Modified MSLT (blue lines) and RTSW (red lines) conditions for the mild (solid lines) and mod (dotted lines) groups.

Looking at Figure 6.2 it can be seen that the sleep latencies obtained for the mod group in the Modified MSLT are generally shorter than those for the mild group. For the mild group there is an increase in sleep latency at 3.30pm and 7.45pm relative to the Modified MSLT condition, with no effect at any other time. The moderate group show increased sleep latency in all sessions for the RTSW condition relative to the Modified MSLT, particularly at 5pm. The Mann-Whitney test was performed to investigate the effect of group on sleep latency and showed there to be no significant difference between the two groups for either condition at any of the session times.

6.3.2.1 Survival analysis

Due to the limited window of 20 minutes to fall asleep in each test session, survival analysis was used to view differences over the testing period between the two conditions and groups.
Survival curves for each condition are shown in Figure 6.3. It can be seen that the mild group appear to take longer to fall asleep in the Modified MSLT condition than the mod group and sleep latency is increased for both groups in the RTSW, exceeding the 20 minute limit for the mild group. The Mantel-Cox test showed mean survival to be significantly better in the RTSW condition compared to the Modified MSLT condition \( [X^2(1)=4.22, \ p<0.05] \), with no significant difference between the two groups.

![Figure 6.3: Relationship between mean daily sleep latency, condition and group. Participants have been grouped according to condition (Modified MSLT and RTSW) and group (mild, mod). The x-axis represents the time elapsed from the start of the MSLT/RTSW session and the y-axis represents the proportion of participants remaining awake after time t (min).](image)

6.3.2.2 Frequency of sleep onset

In addition to investigating sleep latency and survival rate in the test sessions, it was thought that whether or not an individual fell asleep in any given session would give some insight into the benefit of the RTSW condition in terms of assessing ability to remain awake. Figure 6.4 shows the number of participants who fell asleep either 0, 1, 2, 3 or 4 times during the day and which group they were a member of.
Figure 6.4: Frequency of sleep onset for the two groups in the Modified MSLT and RTSW conditions.

It can be seen that for both groups the RTSW condition results in the distribution shifting towards fewer sleep onsets during the day compared with the Modified MSLT. However, the shift for the mod group appears to be slightly more substantial than that for the mild group, indicating a greater impact of instruction.

To investigate group differences the Mann-Whitney test was performed and no significant difference was found between the groups for either condition. The Wilcoxon matched-pairs signed ranks test showed the RTSW condition to have significantly fewer sleep onsets than the Modified MSLT condition ($W=26$, $p<0.05$, one-tailed).

6.3.3 Performance

Mean daily Reaction Time (RT) and the square root of the number of lapses over the four PVT sessions for each group in each condition is shown in Table 6.2.
Table 6.2:  *Mean (s.e.) daily Reaction Time (RT) and square root of the number of lapses for both groups in the Modified MSLT and RTSW conditions.*

<table>
<thead>
<tr>
<th></th>
<th>MSLT</th>
<th>RTSW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT (ms)</td>
<td>√Lapses</td>
</tr>
<tr>
<td>Mild</td>
<td>320.9(7.2)</td>
<td>3.1(0.4)</td>
</tr>
<tr>
<td>Mod</td>
<td>329.2(15.7)</td>
<td>3.7(0.8)</td>
</tr>
</tbody>
</table>

It can be seen from the data in Table 6.2 that mean RT and number of lapses are increased for both groups in the RTSW compared to the Modified MSLT condition and for the mod group compared to the mild group in both conditions.

A three factor ANOVA on the mean RT for each PVT session showed a significant effect of condition \([F(1,18)=10.40, p<0.01]\) and time \([F(3,40)=7.62, p<0.005, G-G correction]\) with no effect of group or any interaction between any parameters. Post hoc Bonferroni comparisons showed the 1pm PVT session to have a significantly higher mean RT than the 11am \((p<0.001)\) and 4.10pm sessions \((p<0.005)\).

This analysis was repeated on the square root of the number of lapses in each PVT session and the same results found, a significant effect of condition \([F(1,18)=4.60, p<0.05]\) and time \([F(3,54)=9.22, p<0.001]\) with no effect of group or any interaction between any parameters. Post hoc Bonferroni comparisons showed the 1pm PVT session to have a significantly higher number of lapses than the 11am \((p<0.001)\) and 4.10pm sessions \((p<0.005)\). The lapse data over the four PVT sessions is shown in Figure 6.5.
Figure 6.5: Mean (s.e.) square root of the number of lapses for each test session in the Modified MSLT (blue lines) and RTSW (red lines) conditions for the mild (solid lines) and mod (dotted lines) groups.

6.3.4 Subjective sleepiness

Addressing subjective sleepiness, it is hypothesised that any variation in KSS score between the two conditions would be due to intra-individual variation only.

6.3.4.1 Effect of condition on KSS score sitting at a desk

Taking the KSS scores measured with the participants sitting at a desk, a three factor ANOVA on condition, time and group gave a significant effect of condition [F(1,18)=5.13, p<0.05], time [F(13,75)=10.84, p<0.001, G-G correction] and time*group interaction [F(4,75)=5.06, p<0.001, G-G correction] with no effect of group. Figure 6.6 displays mean KSS scores at a desk for the Modified MSLT and RTSW conditions. It can be seen that subjective sleepiness is slightly lower for the RTSW condition over most of the day, particularly between 10.50am and 1.50pm.
Figure 6.6: Mean KSS score (s.e.) sitting at a desk against time of day (14 time points) for the Modified MSLT and RTSW conditions (n=20).

6.3.4.2 Effect of condition on KSS score after a 5 minute lie down

A three factor ANOVA on KSS score after a 5min lie down showed a significant effect of time \( [F(6,108)=12.72, p<0.001] \), condition*group interaction \( [F(1,18)=5.15, p<0.04] \); indicating that the mod group had a larger overall decrease in KSS score in the RTSW condition compared to the Modified MSLT condition than the mild group], time*group interaction \( [F(6,108)=3.70, p<0.005] \); with the mod group exhibiting lower KSS scores than the mild group from 4pm onwards] and condition*time interaction \( [F(6,108)=2.22, p<0.05] \); indicating participants had lower KSS scores in the RTSW condition than in the Modified MSLT condition up until 4pm] (see Figure 6.7). There was no significant effect of condition or group on KSS after a 5min lie down.
6.3.4.3 Subjective sleepiness before and after a 5 minute lie down

A four factor ANOVA on KSS score before and after a 5min lie down showed a significant effect of situation [F(1,18)=13.00, p=0.005], time [F(3,58)=13.35, p<0.001, G-G correction], condition*group [F(1,18)=4.42, p<0.05; indicating the mod group had a larger reduction in KSS scores in the RTSW condition compared to the Modified MSLT condition than the mild group], time*group [F(3,58)=4.26, p<0.01 G-G correction; with the mod group exhibiting lower KSS scores than the mild group from 4pm onwards] and situation*time interaction [F(6,108)=3.00, p<0.05; indicating a greater increase in KSS score after the 5min lie down compared to sitting at a desk at 11.50am and 1.50pm than at any other time]. There was no significant effect of condition or group. Figure 6.8 shows the KSS score before and after a 5 minute lie down for the two conditions.
Chapter 6: Maintaining wakefulness

6.3.5 Waking EEG

In order to investigate the effect of instruction on EEG determined sleepiness in the Modified MSLT/RTSW sessions, theta activity (4-7.5Hz) was examined for the two conditions and groups during the 3.30pm Modified MSLT/RTSW session. Quartiles were calculated for the Modified MSLT condition based on the time from lights out to sleep onset as used in Chapter 5. The quartiles for the RTSW condition were then calculated using the same epoch lengths as those for the Modified MSLT condition enabling comparison of relative theta power in the two conditions.

Figure 6.9 shows relative theta power for the two groups (only participants that fell asleep in the sessions) in the Modified MSLT and RTSW conditions.

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4 Participant BC06 was found to be an outlier, with extremely low theta activity relative to the other participants and so was excluded from all EEG analyses.
A three factor ANOVA on theta activity in those individuals that fell asleep in the 3.30pm Modified MSLT and RTSW sessions (mild, n=8 and mod, n=6) showed there to be a significant effect of quartile \( [F(3,23)=40.10, p<0.001, G-G \text{ correction}] \). There was no significant effect of condition or group or any interactions. Post hoc Bonferroni comparisons showed all four quartiles to be significantly different to one another \( (p<0.05) \), indicating the build up of theta approaching sleep onset (as shown in Figure 6.9).

**6.3.6 Sleep the night after test days**

For 12 of the 20 subjects, data was also obtained for each night following the conditions and this is shown graphically in Figure 6.10\(^5\). The effect of condition and night on SP was investigated using a two factor ANOVA. No significant effect of condition, night, or any interactions were found, indicating that the SP was comparable across both conditions and nights.

Due to the small number of subjects providing this data (7mild, 5mod), the non-parametric Mann-Whitney test was used to investigate differences between the two groups in terms of sleep period the nights after testing, and no significant difference between the groups was found after either condition.

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\(^5\) n = 8 missing due to a late change in the protocol to assess subsequent nocturnal sleep.
Figure 6.10: Mean (s.e.) Sleep Period (SP) for the nights pre and post the Modified MSLT (blue lines) and RTSW (red lines) conditions for the mild (solid lines) and mod (dotted lines) groups.

Sleep efficiencies (SE_{SP}) the nights before and after test days are shown in Figure 6.11. The effect of condition and night on SE_{SP} was investigated using a two factor ANOVA. No significant effect of condition, night, or any interactions were found, indicating that the SE_{SP} was comparable across both conditions and nights.

Using the Mann-Whitney test to investigate group differences in terms of sleep efficiency the nights after test days, there was found to be no significant difference between the two groups the nights after either condition.

Figure 6.11: Mean (s.e.) sleep efficiency (relative to SP) for the nights pre and post the Modified MSLT (blue lines) and RTSW (red lines) conditions for the mild (solid lines) and mod (dotted lines) groups.
6.4 High sleepability without sleepiness

Harrison and Horne (1996a) have previously discussed the possibility of certain individuals being able to fall asleep quickly during the day having slept adequately the night before and seemingly without detriment to their daytime functioning (in terms of both performance and subjective sleepiness). In the present study, as the mod group comprise individuals who fall asleep rapidly in the Standard MSLT, there is the possibility that some of these individuals may possess the trait of "High Sleepability with No other evidence of Sleepiness" (HSNS) (1996a, p16).

Harrison and Horne define the key features of HSNS as "(i) rapid sleep onset during MSLT trials, despite normal or ad libitum nocturnal sleep, (ii) no evidence of daytime napping or subjective complaints of daytime sleepiness, and (iii) normal scores at a psychological task highly sensitive to sleepiness" (1996a, p17).

Mean daily Standard MSLT scores (sessions at 10am, 12pm, 2pm and 4pm) for the mod group after a normal night's sleep (mean SP=7.8h, s.d. 0.2) are shown in Table 6.3.

Table 6.3: Mean (s.e.) Standard MSLT score and number of lapses in the 30min screening PVT for all individuals in the mod group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Mean Standard MSLT Score (min)</th>
<th>No. Lapses</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM03</td>
<td>6.4(1.0)</td>
<td>11</td>
</tr>
<tr>
<td>KM05</td>
<td>7.3(0.7)</td>
<td>1</td>
</tr>
<tr>
<td>BC06</td>
<td>8.9(3.8)</td>
<td>5</td>
</tr>
<tr>
<td>JT09</td>
<td>9.1(2.5)</td>
<td>42</td>
</tr>
<tr>
<td>EG10</td>
<td>4.8(1.0)</td>
<td>3</td>
</tr>
<tr>
<td>GC11</td>
<td>6.3(2.4)</td>
<td>15</td>
</tr>
<tr>
<td>MO12</td>
<td>5.7(1.0)</td>
<td>3</td>
</tr>
</tbody>
</table>

As can be seen from the data in Table 6.3, the mean scores for all members of the mod group are under 10 minutes after a normal night's sleep, satisfying criteria number (i) for HSNS. Figure 6.12 shows mean daily Standard MSLT scores for all 20 participants.
As part of the screening process for the main study, only those with an Epworth Sleepiness Scale (ESS) score of 10 or below, who napped less than once a week and had normal levels of subjective sleepiness as measured by the Karolinska Sleepiness Scale (KSS) were included in the study. This screening process has ensured that all participants in Table 6.3 satisfy criteria number (ii) for HSNS.

Criteria number (iii) specified by Harrison and Horne (1996a, p17) refers to the Wilkinson Auditory Vigilance Task (WAVT, Wilkinson, 1968), which was carried out for 60 minutes commencing at 2pm. In the present study, the Psychomotor Vigilance Task (PVT) was used, which, due to its dull and monotonous nature, also has a high sensitivity to changes in sleepiness (Dinges & Kribbs, 1991). PVT performance in terms of number of lapses (Reaction Time, RT ≥500ms) in the 4pm, 30 minute session carried out on the same day as the Standard MSLT is shown for each mod group participant in Table 6.3 and for all participants in Figure 6.13. The mean number of lapses for the mild group was 5.3 (s.d. 4.7) and for the mod group was 11.4 (s.d. 14.4). In order for an individual to be considered as having HSNS, their performance must be comparable to their "less sleepy" (as defined by the Standard MSLT) counterparts, i.e. the mild group. It is proposed that those in the mod group with total number of lapses greater than 1 standard deviation from the mean of the mild group should not be considered as possessing HSNS, as their performance, although not significantly different, is indeed worse than their "less sleepy" counterparts. Therefore, those in the mod group with number of lapses

Figure 6.12: Mean (s.e.) daily Standard MSLT score for participants in the mild (blue bars) and mod group (grey bars).
exceeding 10 (mean=5.3, s.d.=4.7), i.e., HM03, JT09 and GC11 are eliminated from being considered as possessing HSNS.

Figure 6.13: Number of lapses (RT≥500ms) for all participants in the 30min screening PVT. HM03, JT09, GC11 – lapses >10 so not considered HSNS.

Harrison and Horne’s study (1996a, p17) found that long term extension to nocturnal sleep had little or no effect on the daytime sleep latency of individuals possessing HSNS. In the current study nocturnal sleep was only extended for one night, with subsequent MSLT sessions later on in the day than the Standard MSLT. Therefore, in order to investigate the effect of sleep extension on potential HSNS candidates in terms of sleep latency, the values obtained for the sleep extension (SE) condition were compared to those obtained for the baseline condition (BL).

Table 6.4: Mean (s.e.) daily Modified MSLT/RTSW scores in the baseline (BL, Modified MSLT), sleep extension (SE) and Repeated Test of Sustained Wakefulness (RTSW) conditions for those potentially considered as possessing HSNS (KM05, BC06, EG10 and MO12).

<table>
<thead>
<tr>
<th>Participant</th>
<th>BL</th>
<th>SE</th>
<th>RTSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>KM05</td>
<td>11.6(3.6)</td>
<td>14.7(3.1)</td>
<td>14.9(3.9)</td>
</tr>
<tr>
<td>BC06</td>
<td>12.1(4.6)</td>
<td>16.5(3.1)</td>
<td>12.9(4.1)</td>
</tr>
<tr>
<td>EG10</td>
<td>5.6(1.5)</td>
<td>12.5(2.7)</td>
<td>16.5(3.5)</td>
</tr>
<tr>
<td>MO12</td>
<td>14.6(3.0)</td>
<td>10.7(3.3)</td>
<td>20.0(2.6)</td>
</tr>
</tbody>
</table>
It can be seen that nocturnal sleep extension increased subsequent sleep latency in three out of the four of the participants in Table 6.4. This could indicate that these individuals are in need of greater nocturnal sleep and therefore are not exhibiting HSNS. However, all participants also carried out the RTSW condition whereby volition to stay awake in each daytime session was explored. It is proposed that those possessing HSNS will just as easily be able to maintain wakefulness in the test sessions of the RTSW as they are able to fall asleep in the Modified MSLT sessions. A substantial increase in sleep latency in the RTSW condition is a powerful indicator that an individual has sufficient levels of alertness to function adequately during the day. It can be seen from the data in Table 6.4 that KM05, EG10 and MO12 were all able to increase their sleep latency in the RTSW condition substantially relative to BL. This increase was significant for EG10 (t=-2.8, p=0.02) and MO12 (t=-1.9, p=0.05).

Therefore it is suggested that individuals EG10 and MO12 possess HSNS as they:

1. fall asleep rapidly in all sessions of the Standard MSLT (see Figure 6.14)
2. do not nap during the day and do not complain of daytime sleepiness
3. have levels of vigilance in the PVT comparable to their "less sleepy" counterparts (as shown in Figure 6.13)
4. are able to significantly increase their sleep latency when instructed to stay awake.
Figure 6.14: Sleep latency in each session of the Standard MSLT. Participants EG10 and MO12, defined as having HSNS, partly due to their short sleep latencies, are shown in black.

6.5 Summary of findings

- Participants obtained comparable and consistent nocturnal sleep the night before test days,
- The effect of changing the instruction to try to stay awake was to increase sleep latency in the 3.30pm, 5pm and significantly at 7.45pm ($p<0.001$) sessions compared to the Modified MSLT,
- There was no significant difference between the groups in terms of sleep latency for either condition at any of the session times,
- In terms of survival in the Modified MSLT/RTSW sessions, the mild group had better survival in both conditions than the mod group and both groups had better survival in the RTSW condition compared to the Modified MSLT condition, although this was not statistically significant,
- The frequency of sleep onsets was significantly reduced in the RTSW condition compared to the Modified MSLT condition,
  - Although not significant, the mod group showed a trend for a greater improvement in the RTSW compared to the Modified MSLT than the mild group in terms of frequency of sleep onset,
• Performance in terms of mean RT and number of lapses in the PVT sessions was significantly worse for the RTSW condition. The mod group consistently performed less well than the mild group, although the difference was not significant,

• There was a significant effect of condition on KSS score measured at a desk but not for KSS score measured after a 5 min lie down,

• There were condition*group and condition*time interactions for KSS after a 5min lie down,

• Comparing KSS at desk with after a 5min lie down, there was a significant condition*group interaction,

• There was no effect of condition or group or any interactions on relative theta activity in the 3.30pm Modified MSLT session,

• There was no effect of group or condition on nocturnal sleep the night’s following test days,

• Two participants in the study, EG10 and MO12 were identified as having HSNS as defined by Harrison and Horne (1996a) and using the additional criteria of ease of staying awake compared to ease of falling asleep.

6.6 Comment on findings

The effect of changing the instruction from ‘try to go to sleep’ to ‘try to stay awake’ was to increase the daily sleep latency in 17 out of 20 participants, with a mean increase in daily sleep latency of 2.9min (± 2.9). Sleep latency was increased at 3.30pm and 5pm (but not reaching significance), and significantly at 7.45pm (p<0.01). This increase in sleep latency with instruction agrees with Hartse et al. (1982), who found a significant increase in daily sleep latency of 4.5min in the RTSW compared to the MSLT after a normal night’s sleep. The larger difference found by Hartse et al. (1982) compared to the present study may be in part due to the timing of the test sessions. Hartse et al. (1982) carried out their MSLT/RTSW test sessions at 10am, 12pm, 2pm and 4pm, covering the afternoon dip in alertness. In the present study the test sessions did not commence until 3.30pm and continued until 11pm, with many participants unable to fall asleep in the MSLT sessions, particularly in the evening (7.45pm and 11pm). This left no room for improvement in sleep latency at these times when the instruction was changed to ‘stay awake’ (RTSW), creating a ceiling effect that limited the impact of this change in instruction. Another study carried out by Mitler et al. (1982) involved five test sessions at 10am, 12pm, 2pm, 4pm and 6pm. Here, the authors found an increase
of approximately 2.5min with the change of instruction to 'try to stay awake'; a value closer to that found in the present study. In terms of frequency of daily sleep onset there were significantly fewer sleep onsets in the RTSW condition, which is in agreement with the findings of Clodoré et al. (1980), who directly compared the MSLT with the RTSW in a group of 11 young, healthy adults using a six session (10am, 12pm, 2pm, 4pm, 6pm and 8pm) protocol.

It is important to consider the significance of these findings in real terms. An increase in daily sleep latency in the RTSW compared to Modified MSLT of just less than 3 minutes may be of statistical significance, but perhaps its impact in a practical sense may be rather limited. However, the only difference between the RTSW and the Modified MSLT in the present study was the instruction to stay awake or to go to sleep. The environment that the individual was placed under was still extremely soporific; the room was dark, they were lying down and they had their eyes closed. Bonnet and Arand (1999) have shown that prior activity can affect ability to remain awake, with physical activity, such as knee bends and standing, increasing sleep latency dramatically. They have also subsequently reported (2001) that simply a change of position from lying down to sitting up can increase mean sleep latency by approximately 7 minutes. In a real world situation where it is important for an individual to remain awake, the environment is likely to be much less soporific than that of the RTSW test in the present study, with the individual sitting or moving around, with their eyes open under conditions of much higher light intensity. Therefore, the present study has measured ability to remain awake under the most difficult circumstances, and so any increased wakefulness would be further enhanced in a more practical, less soporific setting.

When considering the relatively small increase in sleep latency in the RTSW condition compared to the Modified MSLT, the issue of motivation should be addressed. Individuals were given the instruction to remain awake instead of go to sleep, but there was no incentive to try particularly hard to achieve this, other than a willingness to obey the instructions given. Harrison et al. (1996) have shown that incentives can have a marked impact on sleep latency, with participants showing an ability to fall asleep faster when offered monetary rewards for doing so. The participants of the present study may have tried harder if there was increased incentive to do so, however, as the only incentive to fall asleep in the Modified MSLT was the instruction to do so, for consistency, instruction alone was also used for the RTSW test.
In addition to the issue of motivation, test duration should also be considered. Both the Modified MSLT and the RTSW tests offered a maximum time of 20 minutes within which the participant was required to fall asleep or to stay awake. As many individuals did not fall asleep in the Modified MSLT sessions, particularly at 7.45pm and 11pm, there was no scope for improvement in the RTSW condition. This ceiling effect may have limited the increase in sleep latency in the RTSW condition, underestimating the effect of instruction on these individuals. Previous studies have used maximum test durations of 30 to 50 minutes (Hartse et al., 1982; Doghramji et al., 1997; Bonnet & Arand, 1999; Bonnet & Arand, 2001) in order to account for the extra time that individuals may be able to stay awake. However, extended test durations were not an option in the present study as they would have encroached on the time slots required for other tests in the study protocol.

As the sleep obtained the night before each condition was comparable (in terms of duration and efficiency), it cannot be considered responsible for the observed difference in sleep latencies for the two conditions. In addition, the environment and protocol used for both conditions was maintained as consistent as possible, enabling confidence that the increase in sleep latency in the RTSW condition was as a direct result of the change in instruction. As discussed previously in section 6.2, the lack of counterbalancing of the two conditions may also have affected the sleep latencies. However, it is thought that this would result in shorter sleep latencies in the RTSW condition (as it was always carried out second) as participants become accustomed to the protocol, environment and the experimenters conducting the tests. Therefore, any increase in sleep latency in the RTSW condition compared to the Modified MLST condition can be considered an effect of condition.

There was no significant difference found between the two groups in terms of daytime sleep latency, although the mod group exhibited consistently shorter sleep latencies in both tests compared to the mild group. This finding is in agreement with that of Hartse et al. (1982), who found that individuals with long sleep latencies in the MSLT also had long sleep latencies in the RTSW and vice versa. This finding suggests that, although the effect of instruction was to alter sleep tendency, the size of the effect appears to be relative to the individual and not so large that participants remained awake for long periods of time in the RTSW, but fell asleep immediately after being instructed to do so.
There was a significant increase in both mean reaction time and the number of lapses on the PVT in the RTSW condition compared to the Modified MSLT condition. Rather than an effect of condition, it is thought that this reduction in performance occurred due to the lack of counterbalancing of the order in which the two conditions were carried out; the RTSW condition was carried out second by all participants. As the PVT is a dull, monotonous task and in the present study was carried out for an extended duration of 30min, four times a day, it is likely that even the most diligent individual may suffer from a loss of motivation and increased boredom after carrying the test out so many times. This would explain the increased mean RT and increased number of lapses in the PVT observed for the RTSW condition. In addition, the decrease in performance in the RTSW condition compared to the Modified MSLT, although statistically significant, was relatively small (<25ms mean RT and <9 lapses) and therefore, unlikely to be indicative of any substantial performance impairment.

In their sleep restriction study involving various Time in Bed (TIB) conditions, Van Dongen, Rogers and Dinges (2003a) also found marginal, although statistically significant reductions in PVT performance after 14 nights of 8h sleep a night and assigned boredom as a possible explanation for this. If the present study was repeated, the two conditions would be order-counterbalanced to avoid the problem of familiarity and possible boredom effects on the tests carried out. In terms of group effects, there was no effect of group for either condition, indicating similar performance between individuals in the mild and mod groups.

In terms of subjective sleepiness measured sitting at a desk, participants were significantly more alert in the RTSW condition compared to the Modified MSLT condition. There was no significant effect of condition for the measurements taken after a 5min lie down. However, after a 5min lie down there was a significant interaction between group and condition, with the mod group reporting a greater increase in alertness in the RTSW condition compared to the mild group, along with a condition*time interaction, with participants more alert in the RTSW condition than the Modified MSLT condition at 11.50am and 1.50pm, but showing similar alertness for subsequent measurement times. Harrison et al. (1996) found that participants given an incentive and asked to try to fall asleep faster in MSLT trials reported higher levels of subjective sleepiness as measured by the KSS than a control group. The authors interpreted this finding as an indication that subjective sleepiness was modified by external factors and that the increase in subjective
sleepiness of incentive participants "might reflect actual success in their attempts to reduce their arousal levels and fall asleep" (p684). In the same way, it may be that the participants undergoing the RTSW condition in the present study may have felt more alert whilst sitting at a desk because they were repeatedly trying to remain awake throughout the day, their alertness reflecting their attempt to keep their arousal levels high. After a 5min lie down, the effect of this modification of sleepiness appears reduced and is reflected by the non-significant effect of condition for this measurement. The significant group*condition interaction and the condition*time interaction both appear to be caused by the mod groups increased alertness in at 11.50am and 1.50pm, which may suggest that the sleepiness experienced by the mod group is modified by external factors to a greater extent than the mild group. Or, the difference in KSS score in the morning and early afternoon may simply be a reflection of day to day individual variation in subjective sleepiness.

Two participants in the present study were found to possess HSNS according to the criteria set out by Harrison and Horne (1996a). In addition to satisfying these criteria, these individuals were also able to remain awake when requested to, demonstrating an ability to fall asleep quickly in soporific conditions at will, along with an equal ability to maintain alertness when required.

6.6.1 Interpretation

In their study comparing the MSLT with the Maintenance of Wakefulness Test (MWT), Bonnet and Arand (2001) state that "The argument that some people are more skilful at falling asleep has also been used to explain why some non-sleep-deprived individuals characteristically fall asleep more quickly on the MSLT than others. However, there is little data to support these hypotheses" (p441). However, studies conducted by Harrison and Horne (1996b) and Roehrs et al. (1996a) both revealed individuals who appear to be more skilled at falling asleep rapidly, with their short sleep latencies remaining unchanged even when nocturnal sleep duration was increased for a number of nights. In addition, Engleman et al. (1994) found, despite large increases in subjective sleepiness in OSA patients following treatment, that the increase in sleep latency (from 6.1 to 7.2min) was relatively small. These studies appear to indicate that some individuals have an ability to fall asleep quickly, however, their ability to remain awake in soporific conditions was not tested. In the present study both ability to fall asleep and ability to remain awake were investigated, with two individuals from the mod group identified as being able to fall asleep quickly when asked, but to remain awake
equally as well when required. This demonstrates that in these two individuals their short sleep latency is not indicative of an increased need for sleep, as they are able to resist sleep and maintain wakefulness in soporific conditions when required, and maintain normal levels of performance throughout the day, but more that they have an ability to fall asleep quickly. The relevance of this finding is discussed in more detail in Chapter 7, section 7.3.

One might argue that the five mod group participants found not to have HSNS could be exhibiting signs of increased daytime sleepiness caused by insufficient night-time sleep, failing to meet their requirements. If they were suffering from elevated levels of daytime sleepiness they would show impaired performance compared to the individuals in the less objectively sleepy (mild) group. In the present study there was consistently found to be no significant difference between the two groups in terms of PVT performance, suggesting a similar ability to maintain vigilance in the two groups.

Lavie and Zvuluni (1992) found that when sleep was restricted by the same amount, some people had shorter MSLT scores than others and the range of MSLT scores followed a normal distribution. It seems reasonable to assume that in any population there will be a normal distribution of sleep durations, and therefore, for any one sleep duration there will be a normal distribution of daytime sleep latencies and performance levels. Combining the findings of previous studies (Engleman et al., 1994; Harrison & Horne, 1996b, Roehrs et al., 1996a) with those of the present study, it appears that many normal, healthy individuals who regularly sleep between 7-8h a night and who fall asleep rapidly during the day may reside at one end of a normal distribution in terms of sleep latency. At the extreme end of this normal distribution there may be a small subgroup of individuals possessing HSNS, who exhibit particularly short sleep latencies, good performance levels and report normal levels of subjective sleepiness during the day.
7 Discussion

Through examination of the literature, several areas requiring investigation were highlighted and a set of research questions proposed (see Chapter 1). Whether or not the present study has answered each of the research questions will now be addressed, along with the implications of these findings.

7.1 Research questions

All of the following research questions relate to a sample of young, healthy individuals who habitually sleep 7-8h a night and do not complain of daytime sleepiness, exhibit normal levels of daytime performance, but have some level of daytime sleepiness as measured objectively by the Standard MSLT.

7.1.1 The effect of session times on MSLT scores

How do MSLT scores alter when testing commences in the afternoon (3.30pm) and carries on until the late evening (11pm)?

As part of the screening for the present study, all twenty subjects underwent the Standard MSLT (four test sessions carried out two-hourly, starting at 10am), obtaining a mean daily MSLT score of 11.5min (s.d. 0.8). This value is consistent with those found in other studies on healthy, young adults after a normal night’s sleep (Carskadon & Dement, 1982; Carskadon & Dement, 1987; Levine et al., 1988; Manni et al., 1991; Bonnet & Arand, 1998). In order to investigate how delaying the test times until later on in the day affected MSLT scores, participants also underwent the Modified MSLT, which consisted of four test sessions, commencing at 3.30pm and finishing at 11pm. The mean daily MSLT score in the Modified MSLT was 12.6min (s.d. 6.4), approximately 1min longer than that achieved in the Standard MSLT. If the two groups within the sample of twenty participants (mild group, n=13; mod group, n=7) are examined separately, they do not appear to be affected equally by the change in the timing of the test sessions. The mean daily score for the mild group was 14.0min (s.d. 1.0) in the Standard MSLT and 13.3min (s.d. 1.4) in the Modified MSLT, i.e., similar for both MSLT protocols. The mean daily score for the mod group increased by more than 4 minutes in the Modified MSLT [11.2min (s.d. 1.9)] compared to the Standard MSLT [6.9min (s.d. 1.4)]. The significant difference in daily sleep latency between the groups for the Standard MSLT was not significant for the Modified MSLT. In other words,
individuals classed as having a higher level of sleepiness in the Standard MSLT became indistinguishable from those classed as having lower levels of sleepiness when the test times are moved to later on in the day. This finding raises the question of whether the test times used by the Standard MSLT, i.e. 10am-4pm, cover a large enough proportion of the waking day to be representative of an individual's daytime sleepiness. It appears that the Standard MSLT may overestimate sleep tendency in some cases, and if used alone to measure daytime sleepiness, could result in an individual being diagnosed with a condition that they do not have. To avoid this problem, it is suggested that MSLT testing covers a greater proportion of the waking day. In addition, the MSLT should always be used in conjunction with other objective sleepiness measures and the individual's medical history in order to obtain an accurate assessment their daytime functioning.

7.1.2 Sleep extension versus afternoon nap or caffeine

Are healthy 7-8h sleepers able to extend their nocturnal sleep by up to 90mins on demand?

All participants in the study were able to extend their nocturnal sleep, increasing their mean sleep period of 7.6h (s.d. 0.4) at baseline to 9.1h (s.d. 0.4) in the sleep extension condition. Sleep efficiency did not differ significantly during these two nights (BL 86.3% s.d. 5.6; SE 86.4% s.d. 5.8). This does not agree with the findings of other studies, which have shown a reduction in sleep efficiency with increased sleep duration (Taub et al., 1971; Carskadon & Dement, 1979; Harrison & Horne, 1996b; Roehrs et al., 1996b). In many sleep extension studies the bedtime is advanced with the risetime held constant and often, increased sleep latency at bedtime is found to be the main contributor to the reduction in sleep efficiency across the night, as reported by Taub et al. (1971). As the bedtime was held constant in the present study, this may go some way to explaining the similar sleep efficiencies the nights before the baseline and sleep extension conditions.

Does one night of sleep extension of up to 90mins extra sleep improve objective and subjective sleepiness in normal, healthy individuals that normally sleep 7-8h a night?

As reported in Chapter 3, the effect of one night of extended sleep was a small improvement in objective sleepiness as measured by the MSLT; an increase in daily MSLT score of approximately 1min when nocturnal sleep duration was increased by up to 90min the previous night. The PVT, another sensitive objective test of daytime
alertness, and the KSS (a measure of subjective sleepiness) did not show any improvement with extended sleep duration. In addition, EEG markers of objective sleepiness (alpha and theta activity), during the transition from wakefulness to sleep in the afternoon MSLT sessions (3.30pm and 5pm), showed no change with extended nocturnal sleep the night before.

**How does the impact of sleep extension on objective and subjective daytime sleepiness compare to that of a 20min afternoon nap or 150mg caffeine?**

Relative to baseline, sleep extension increased daily sleep latency by approx. 1min, compared to 4min for the nap and 2.5min for the caffeine. This suggests that the afternoon nap was the most effective intervention, followed by caffeine, with extended sleep the least effective at reducing objective daytime sleep tendency.

As found with the sleep extension condition, the afternoon nap and caffeine conditions had no effect on subsequent performance (PVT) or subjective sleepiness (KSS).

### 7.1.3 Effect of physical position and test duration on subjective sleepiness

**Does a change in situation from sitting at a desk to lying down in a dimly lit room for 5mins have a measurable impact on daytime subjective sleepiness?**

Lying down in a dimly lit room for 5 minutes significantly increased subjective sleepiness as measured by the KSS compared to sitting at a desk. The magnitude of this increase was modified by time of day, with a greater increase in KSS scores at 1.50pm after the lie down than at any other time. As previously discussed in Chapter 3.2, the observed increased impact of a lie down at 1.50pm (in terms of increased sleepiness) may be due to circadian factors and an increased vulnerability to subjective sleepiness experienced by many individuals at this time.

On average, there was found to be a greater increase in subjective sleepiness in the mild group after a 5min lie down than in the mod group. As the mod group appear to experience a greater dip in subjective alertness in the afternoon than the mild group when sitting at a desk, it seems logical to assume that they would be affected to a greater extent by the change in situation, however, the opposite has been observed. It may be that the mod group, although particularly susceptible to circadian variations in
alertness are either less affected by, or less aware of, changes in their environment (such as light level and body position) than the mild group.

7.1.4 Differences in the mild and mod groups

Do otherwise healthy individuals with shorter daily MSLT scores (5-9min) exhibit increased subjective sleepiness and decreased performance compared to those with longer (12-15min) daily MSLT scores?

The mod group (mean Standard MSLT score, 5-9min) did not have significantly longer mean reaction times or a greater number of lapses in the PVT sessions compared to the mild group (mean Standard MSLT score, 12-15min), indicating similar levels of performance between the two groups.

The mod group consistently exhibited mean daily KSS scores equal to or lower than the mild group, indicating lower levels of subjective sleepiness. Over the course of the day, subjective sleepiness in the mod group was initially equal to or greater than the mild group, with a more pronounced dip in alertness at 2.30pm, followed by lower levels of subjective sleepiness than the mild group from about 5pm onwards.

Do the two groups exhibit similar sleep architecture (in terms of sleep stages and EEG frequency content) during a normal night’s sleep?

During a night of sleep at home, there was no significant difference between the two groups in terms of Sleep Onset Latency (SOL), Sleep Period (SP), Total Sleep Time (TST), Sleep Efficiency relative to sleep period (SE_{SP}) or percentage of time spent in each sleep stage (S1, S2, S3, S4, REM and WASO) throughout the night. In the first 5h of sleep, the mod group had a significantly higher amount of delta activity than the mild group.

In their study carried out on sleepy (mean SL ≤6min) and alert (mean SL ≥16min) normal participants, Roehrs et al. (1990) found that the percentage of sleep stages obtained during the night did not vary significantly between the two groups, and the findings of the present study are in agreement with this. However, in their study, the sleepy group had higher sleep efficiencies than the alert group and from this the authors concluded that the sleepy participants were under a higher sleep pressure due to the build up of a chronic sleep debt. In the present study, no significant difference was found between the two groups in terms of sleep efficiency over the course of the
night, and so the explanation of inter-individual variation in sleep EEG composition may be more appropriate in this case.

Do the two groups react differently to extending their sleep, napping or caffeine in terms of objective and subjective sleepiness?

There was no significant difference between the groups in terms of the effect of sleep extension, nap or caffeine on MSLT sleep latency. However, although not significant, the mod group showed a trend for benefiting more from the sleep extension condition at 7.45pm and the caffeine condition at 3.30pm, than the mild group. There was no differential effect of condition on the performance or subjective sleepiness of the two groups.

The above findings have important implications when deciding whether to advocate extended nocturnal sleep in habitual 7-8h sleepers with no reported daytime sleepiness or performance decrements. Rather than suggest extended nocturnal sleep as an aid to increase daytime functioning, an afternoon nap or approximately two cups of standard caffeinated coffee may be more convenient and effective alternatives. However, as there was found to be no significant effect on performance or subjective sleepiness in the sample of individuals examined, it may be difficult to convince similar individuals to incorporate these countermeasures into their daily routines for such a limited return.

Are the two groups of individuals able to increase their daytime sleep latency simply by trying to remain awake instead of trying to fall asleep?

Both the mild and the mod group were able to increase their sleep latency and reduce the number of times that they fell asleep in the RTSW condition compared to the MSLT condition. There was no significant difference between the groups in terms of how their sleep latency or their frequency of sleep onset was affected by the conditions. However, although not significant, the mod group showed a greater increase in daily score in the RTSW condition relative to the MSLT condition (~2.5min) than the mild group (~1.5min). This shows that the individuals with short mean sleep latencies in the Standard MSLT (5-9min) were able to resist sleep and increase their sleep latency, just as well, if not marginally better than those with longer mean sleep latencies in the Standard MSLT (12-15min) when testing was carried out in the afternoon and evening.
Is there a subset of individuals within the group with daily MSLT scores between 5-9min that possess High Sleepability, No Sleepiness, as defined by Harrison and Horne (1996a)?

Chapter 6.3 examined the mod group in detail and identified two individuals as potentially possessing High Sleepability, No Sleepiness (HSNS). These individuals met the criteria set out by Harrison and Horne (1996a), along with an additional criteria; the ability to increase sleep latency substantially when requested to remain awake instead of trying to go to sleep. The importance of this finding is discussed in detail in section 7.3.

7.2 Study limitations and future work

The present study, like any other, has a number of limitations, which must be acknowledged in order for the findings to be put into context. Firstly, the study was carried out on a sample of university students, who may not necessarily be representative of the working population in general. In order to make the sample as representative as possible of healthy young adults in the general population, the minimum inclusion age was 21y, which excluded the majority of undergraduate students, who often have irregular work routines and sleep/wake patterns.

A sample size of 20 participants may be considered by some to be relatively small. Initially, it was hoped for a sample size of 24, 12 participants in each of the two groups. However, due to the difficulty in recruiting participants who regularly slept 7-8h a night in addition to the required daily MSLT scores, 13 participants were obtained for the mild group and 7 participants for the mod group. The repeated measures study design, with each participant undergoing five complete days in the laboratory, helped to counteract any detrimental effects of a relatively small sample size.

The present study was carried out in the controlled environment of a laboratory. This is not a study limitation in itself, however, when attempting to ascertain the real-world impact of findings from this type of study, care must be taken not to assume that statistical significance in the laboratory is equal to practical significance in the real-world setting, as, due to various uncontrollable factors in the real-world environment, sometimes the two are very different.

Only individuals who regularly slept 7-8h a night were included in the present study. Many individuals regularly sleep less than 7h or more than 8h a night and so only a
proportion of the population has been represented by this study. However, the UK population average has consistently been shown to be between 7-7.5h a night (McGhie & Russell, 1962; Tune, 1969; Reyner & Horne, 1995; Groeger, Zilstra & Dijk, 2004) and in recent times this group in particular has been suggested to be failing to meet their sleep needs (Bonnet & Arand, 1995; Spiegel et al., 1999; Wright, Hughes, Hull & Czeisler, 2000). Further investigation is required to establish the effect of the various daytime sleepiness countermeasures used in the present study on those who habitually sleep more or less than 7-8h a night.

7.3 Conclusions

The present study demonstrates that young, healthy adults, who regularly sleep 7-8h a night without complaint of daytime sleepiness, are able to extend their nocturnal sleep by approximately 90 minutes simply by remaining in bed for that extra time. The effect of this extra sleep is to nominally increase their MSLT sleep latency the next day, without any change to daytime performance or subjective feelings of sleepiness. By directly comparing extended nocturnal sleep with a short afternoon nap or caffeine, nocturnal sleep extension was found to be the least effective at increasing daytime sleep tendency the next day, with the afternoon nap having the greatest impact, followed second by caffeine. None of the interventions altered subsequent night-time sleep. The above findings have important implications when deciding whether to advocate extended nocturnal sleep in habitual 7-8h sleepers with no reported daytime sleepiness or performance decrements. Rather than suggest extended nocturnal sleep as a remedy for moderate daytime sleepiness, a short afternoon nap or caffeine may be more convenient and effective alternatives.

In terms of group differences, although the two groups within the sample exhibited markedly different daily sleep latencies in the Standard MSLT, these differences were not maintained when test times commenced in the afternoon and continued up until the late evening. The mod group showed a trend for a higher level of subjective sleepiness in the early afternoon compared to the mild group. This could be due to an increased sensitivity to circadian variations in alertness, causing the mod group to be particularly susceptible to the 'afternoon dip'. This may account for the group differences observed in the Standard MSLT (as testing times cover the period when the afternoon dip in alertness is most likely to occur) and the lack of group differences when MSLT testing was carried out later on in the day.
The finding that the mod group were particularly sensitive to the 'afternoon dip', reporting increased sleepiness and demonstrating an ability to fall asleep quickly at this time suggests that they may have an elevated level of daytime sleepiness compared to the mild group. However, the performance of the mod group on the PVT in the afternoon was as good as those in the mild group, indicating that both groups were able to sustain adequate levels of alertness when required.

In terms of waking EEG composition, the two groups exhibited similar levels of alertness during the MSLT sessions and additionally their sleep EEG showed no difference in terms of sleep stage composition or sleep efficiency during a night of habitual sleep. The mod group had a greater amount of delta activity in the first 5h of sleep than the mild group, which could be an indicator of increased sleep pressure in this group. As other indicators of sleep pressure (nocturnal sleep onset latency, percentage of sleep stages 3 and 4, sleep efficiency) failed to show a difference between the two groups, it is thought that the difference in delta activity is probably more likely to be an expression of inter-individual variability, rather than an indicator of increased sleep need in the mod group.

It is reasonable to assume that in any population there will be a normal distribution of any particular parameter that is measured, be it sleep duration, sleep latency or performance, for example. It is suggested that the mod group reside at one end of the normal distribution in terms of objective daytime sleepiness as measured by the Standard MSLT, and the mild group reside at a position further along the scale. If the mod group do exist under an elevated sleep pressure, there appears to be no detrimental effect of its presence other than a more pronounced dip in alertness in the afternoon, which can itself be considered a normal phenomenon.

When attempting to establish how these findings relate to adults in the general population, it is important to note that those displaying sleep latencies short enough to be included in the mod group were relatively difficult to recruit. Out of the 61 participants who underwent the Standard MSLT, 32 were excluded as their daily MSLT scores were outside the ranges required for the study and of these, no individual had a daily MSLT score that was too short to be included in the study, i.e., <5min. All 32 excluded participants had daily MSLT scores greater than 9min (either falling in between the two group ranges, or greater than that required to be allocated to the mild group). Therefore, of the 61 participants screened, approximately 11% exhibited mean
daily scores between 5-9min (with 3% potentially possessing HSNS), 0% had a mean score of <5min and the remaining 89% had mean scores of >9min.

In terms of the prevalence of individuals with HSNS (approximately 29% of the mod group), the present study shows similar results to those reported by Roehrs et al. (1996b), Harrison and Horne (1996b) and Kamdar et al. (2004). In their study of 11 sleepy (mean SL ≤6min) normal participants with mean MSLT scores of ≤6min, Roehrs et al. (1996b) found that during a two week sleep extension protocol to 10h a night, 36% of the participants failed to show any improvement in the daily sleep latency and experienced an immediate reduction with extended sleep leading the authors to conclude that “Their short average daily sleep latency was a result of causes other than chronic insufficient sleep” (p576). The higher prevalence of potential HSNS individuals in this study may be explained by the shorter mean sleep latencies in the group investigated compared to those in the mod group of the present study.

In their sleep extension study, Harrison and Horne (1996b) reported that 18% (2 out of 11) of participants found the extended sleep protocol hard to adapt to and in their subsequent paper, defined them as possessing HSNS (1996a). Kamdar et al. (2004) found similar results, reporting that 2 of their 15 (13%) participants were unable to extend their sleep and exhibited little MSLT improvement in their maximal sleep extension study. Unlike the study carried out by Roehrs et al. (1996b), the lower prevalence of potential HSNS individuals in the studies conducted by Harrison and Horne (1996b) and Kamdar et al. (2004) may be due to the longer mean sleep latencies of the groups investigated.

The low percentage of HSNS participants in the studies mentioned above and the present sample suggest that this trait may not have a high prevalence in any given population. It seems that generally, those with shorter sleep latencies do perform slightly worse on performance tests such as the PVT, but these differences are not large enough to be of statistical or practical significance. However, very occasionally there will be an individual who is able to fall asleep extremely quickly and yet show performance levels similar to another individual with a much longer sleep latency, exhibiting the characteristics of HSNS.
In summary, the present study shows that some individuals who regularly sleep 7-8h and exhibit signs of sleepiness during the day in situations conducive to sleep are able to extend their nocturnal sleep, and this may be indicative of a sleep debt in these individuals. However, the benefits of sleep extension are limited and inefficient when compared to an afternoon nap or caffeine. For many otherwise healthy adults, there is a modest level of daytime sleepiness that can only be detected with sensitive laboratory measures, in addition to the innate ability of all humans to obtain sleep in excess of their physiological needs. It is possible that this reflects a need for more sleep, or it may simply be within the bounds of what is considered 'normal' and therefore acceptable in modern society.


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Appendix 1: Actiwatch instruction sheet

Loughborough Sleep Research Centre

Participant Instructions

For three days you will be asked to keep a sleep diary and to wear an Actiwatch. An Actiwatch is a harmless, battery-powered device that measures movement during sleep and tells us when you fell asleep / awoke. This device also gives us an indication of the quality and quantity of sleep you had.

Please start wearing the Actiwatch as soon as it is issued to you and continue to wear it for seven days and seven nights.

Here are some notes for you to follow with regards to care of the Actiwatch. It is worn on the wrist like a watch. It does not matter on which wrist you wear it. It is a very delicate instrument that should not be banged, dropped etc., nor allowed to get wet.

Please remove the Actiwatch when washing, showering, swimming or playing sports (if you do remove the Actiwatch please record at what times this is done so that I can account for any gaps in data).

Please remember to press the button on the Actiwatch once when you intend on going to sleep and once when you wake up in the morning.
Appendix 2: Consent Form

Loughborough Sleep Research Centre

Consent Form: Confidential

Consent of Subject to be included in Research Trial:

I, ..........................................................................................................................

Consent to taking part in an experiment within the Sleep Research Centre, for daytime testing. An explanation of the nature and purpose of the procedure has been given to me by Charlotte Platten.

I understand that I may feel sleepy during some parts of the experiment and consent to abide by the instructions given to me by the experimenter during the testing period for reasons relating to safety.

I understand that I may withdraw from the experiment at any time and that I am under no obligation to give reasons for such withdrawal. Upon withdrawal, I understand that I may request any data already collected to be discarded from the study.

I understand that any information about me that I have given will be treated as confidential by the experimenter.

Signed: .................................................................
Date: .................................................................
Signature of Experimenter: ..................................................
Appendix 3: Poster presentation

Poster presented at the 19th Congress of the European Sleep Research Society, 9th-13th September, Glasgow, UK.
Is an afternoon nap or a cup of coffee as good as morning sleep extension at reducing afternoon and evening sleepiness?

Charlotte Platten, Clare Anderson, Kate Jordan, Jim Horne
Sleep Research Centre, Loughborough University, Loughborough, UK.

INTRODUCTION
Sleep extension should alleviate daytime sleepiness as measured by the MSLT. Recent research suggests that 7.5h a night is not enough and we should be aiming for up to 90min more than this to ensure against the build up of a sleep debt and increased sleepiness levels during the day.

As the standard MSLT gives little information on evening sleepiness, we compared the effect of extending nocturnal sleep with an afternoon nap or a caffeinated drink on MSLTs administered late afternoon until late evening, in a group of healthy young adults who habitually slept between 7.5h a night.

METHODS
Twenty healthy young adults aged 25.9±3.9y (Av.TST 7.5h), selected following standard research MSLTs (setup shown in Figure 1), were classed as having mild to moderate levels of daytime sleepiness [MSL Sleep onset Latency (SoL) 5-15min].

In the main study, MSLT sessions were later: 15:30h, 17:00h, 19:45h, 23:00h, with 30min PVT sessions at 16:00h, 22:00h and KSS (hourly). Tests were given under 4 counterbalanced conditions: nil intervention (baseline), extended prior nocturnal sleep (up to 90min), afternoon nap (20min) and caffeinated drink (150mg at 14:15h).

RESULTS
19 participants were able to extend their nocturnal sleep (84±30min) and all were able to sleep in the nap condition (Total Sleep Time 18.9±0.8min).

Main study MSLTs showed all active treatments reduced the 'afternoon dip', with nap most effective until mid-evening; next effective was caffeine, then sleep extension, as shown in Figure 2.

Figure 3: PVT performance at 1600 and 2200h

Figure 4: KSS score measured hourly throughout the day. Interventions: Nap at 14:30h, caffeine at 14:15h

Late evening MSLT (i.e. 11pm), PVT performance (Figure 3) and subjective sleepiness (Figure 4) did not differ between conditions.

CONCLUSION
A 20min nap in the afternoon is more effective at reducing objective sleepiness as measured by the MSLT than extending nocturnal sleep by 90min. In addition, none of the interventions impacted on performance or subjective sleepiness.

REFERENCES

Author Contact Details: C.R.Platten@lb.ac.uk
Study supported by the ESRC
Appendix 4: Poster presentation

Poster presented at the 5th World Sleep Congress of the World Federation of Sleep Research & Sleep Medicine Societies (WFSRSMS), 2nd - 6th September, Cairns, Australia.
Comparison Of Sleep Extension, Nap And Caffeine On Afternoon And Evening Sleepiness In Mildly And Moderately Sleepy Healthy Young Adults

Charlotte Platten, Clare Anderson, Kate Jordan and Jim Horne
Sleep Research Centre, Department of Human Sciences, Loughborough University, Loughborough, UK
Email: c.r.platten@lboro.ac.uk

Introduction
Increased nocturnal sleep should alleviate daytime sleepiness as measured by the Multiple Sleep Latency Test (MSLT). However, little is known about evening sleepiness, as MSLTs usually cease at 16:00 or 18:00.

We compared extending nocturnal sleep with an afternoon nap, caffinated drink or nil treatment (baseline) on MSLTs given late afternoon until late evening, on healthy, young adults defined as mildly (MILD) or moderately (MODERATE) sleepy by the Standard MSLT.

We investigated i) whether MODERATE participants exhibited decreased vigilance in the Psychomotor Vigilance Task (PVT) and higher Karolinska Sleepiness Scale (KSS) ratings, compared with MILD participants at baseline, and ii) how each group responded to the active interventions.

Method
Two groups of seven adults (28.2±3.6y), av. Total Sleep Time (TST) = 7.7±0.5h, were selected following standard screening MSLTs, according to whether they were mildly (MILD = Av. MSLT Sleep Onset Latency (SOL) of 12-15min) or moderately (MODERATE = Av. SOL of 6-8min) sleepy.

Figure 1 shows the typical setup for an MSLT session: a sound attenuated, dimly lit room (<10ux); participant instructed to "Lie quietly, relax, close your eyes, and try to go to sleep".

In the main study, MSLTs were later, at: 15:30h, 17:00h, 19:45h and 23:00h, with 30min PVT sessions at 16:10h, 22:10h, and KSS hourly, as shown in Figure 2.

Tests were given under four conditions: nil intervention (baseline), extended prior nocturnal sleep (90min), afternoon nap (20min) and caffinated drink (150mg at 14:15h).

Results
Given that the groups differed in baseline MSLTs, there was no difference between them for baseline PVT and KSS.

Excluding a significant beneficial nap effect on the 15:30h MSLT session (p<0.05), all active interventions produced similar increased SOLs for both groups, although MODERATE showed somewhat greater MSLT evening improvement with all interventions (see Figure 3). There was no effect on PVT between active interventions for either group. PVT lapses for each group are shown in Figure 4.

Conclusions
MSLT-defined moderately and mildly sleepy adults exhibit the same levels of performance and subjective sleepiness and show no differential benefit from extended sleep. Both groups show greater MSLT improvement following an afternoon nap or caffinated drink in comparison to extended sleep.

References
Appendix 5: Poster presentation

Poster presented at the 19th Congress of the European Sleep Research Society, 9th-13th September, Glasgow, UK.
Inconsistencies in daytime sleepiness: Standard MSLT vs. delayed MSLT vs. MWT

Charlotte Platten, Clare Anderson, Jim Horne
Sleep Research Centre, Loughborough University, Loughborough, UK.

INTRODUCTION

The Multiple Sleep Latency Test (MSLT) distinguishes different levels of sleepiness in healthy adults who are subjectively good sleepers without any symptoms of daytime sleepiness. However, this test usually only covers 30% of the waking day (2-hourly sessions, 10:00-16:00h).

We used the Standard research MSLT to subdivide adults into two groups with different levels of MSLT-defined sleepiness and re-tested them under two conditions (on different days):

1. Modified MSLT utilising later testing times - four sessions, 15:30h-23:00h
2. Modified Maintenance of Wakefulness Test (MWT) - same times as condition 1.

We assessed the consistency of Standard MSLT findings when the usual testing times were shifted to cover mid-afternoon to late evening for both MSLT protocol (condition 1) and when participants were encouraged to remain awake (MWT protocol - condition 2).

METHODS

Twenty healthy young adults (25.9±3.9y) (Av.TST 7.8h) were selected following Standard research MSLTs and classed as either 'mildly' (Mild group) [Sleep onset Latency (SoL) 12-15min, n=13] or 'moderately' (Mod group) (SoL 5-9min, n=7) sleepy.

Only individuals with adequate performance on the PVT and normal subjective sleepiness levels as measured by the ESS and KSS took part in the study.

In the main study, MSLT and MWT sessions were later: 15:30h, 17:00h, 19:45h, 23:00h.

RESULTS

Although the two groups differed significantly in the initial Standard MSLT (Figure 1), there was no significant difference in SoL between the groups for conditions 1 and 2 (Figure 2). There was a significant increase in SoL in the MWT versus the Modified MSLT (p<0.01).

Individuals in the 'Mod' group were able to increase their SoL just as easily as the 'Mild' group simply by trying to stay awake instead of trying to go to sleep.

CONCLUSION

Differences in healthy individuals in terms of objective sleepiness, as measured by the Standard morning-until-afternoon MSLT, do not persist until late evening as measured by the Modified MSLT and MWT.

When assessing apparent levels of daytime sleepiness in otherwise healthy individuals, testing should continue beyond 16.00h to cover the whole of the waking day.

REFERENCES
