The effects of sleep loss on executive functioning

The Effects of Sleep Loss on Executive Functioning

By

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For My Family

Abstract

Most sleep loss research has concentrated on long duration, repeated measures performance of low-level, monotonous tasks, such as vigilance and reaction time, in support of the theory that sleep loss induces a decline in Non-Specific arousal while having no specific effects on functioning. Numerous studies have shown the beneficial effects of caffeine on this type of performance measure. Recent studies have been conducted on executive functioning tasks that are short, novel, and stimulating. These measures display a sensitivity to sleep loss after 36h that is not compensated by waking countermeasures such as motivation and caffeine. These findings suggest Specific effects of sleep loss, contrary to the Non-Specific theory, particularly on tasks associated with frontal lobe activation. Similarities between performance deficits following brain lesions and those observed in sleep loss subjects form the basis of a neuropsychological model of sleep function. This thesis was an endeavour to document the findings of executive functioning sensitivity following 27 and 36 hours of sleep loss, testing the effect of two common countermeasures, caffeine and a nap. It was established that the critical period of sleep loss for executive functioning performance is at 36 hours. Sleep deprivation effects for periods shorter than 36 hours can be countered by a waking countermeasure, caffeine. It was further established that a 2-hour prophylactic nap opportunity inhibited sleep deprivation effects at 36-hr performance testing for executive functions. The systematic analysis of the effects of sleep loss on language skill, a complex task which is possibly an executive functioning task associated with frontal lobe activation but largely neglected in the literature, detected an increase in variability in language skill, and a propensity towards production errors in speech, but not writing, at 36 hours without sleep. This effect was not observed at 27 hours. The findings are discussed in support of a hypothetical consolidated model of Specific and Non-Specific Effects of sleep loss.

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1.0 Sleep Loss and Cognitive Aspects of Executive Functioning

1.1 Introduction to Sleep Loss

Sleep is a biological process that humans engage in on a daily basis. It is needed to maximise optimum cognitive performance and to function well in daily activities. This need is often neglected due to societies increasing demands for 24- hour convenience. While most people sleep an average of 7.5 hours in a 24- hour period (Webb, 1992), changes to work schedules and leisure activities often restrict the amount of sleep people are taking. While sleep has been an object of study in the last century, the study of sleep loss is an area of increasing importance in the 24 -hour society.

The effects of sleep loss are wide-ranging and not fully defined. A large proportion of sleep loss studies have concentrated on long duration, monotonous tasks (cf. Pilcher & Hufcutt, 1996) while relatively few have addressed higher cognitive functioning underlying complex skills such as divergent thinking, decision making and communication. It has been widely reported (Dinges & Kribbs, 1991; Dinges, Kribbs, Steinberg, & Powell 1992; Dinges, Pack, Williams et al., 1997) that sleep deprivation and the resulting fatigue affect vigilant-type performance while novel, stimulating tasks are not affected. The sensitivity of the simple cognitive tasks is largely due to their dullness, monotony, and repetitive nature, in essence, to boredom effects (Williams, Lubin & Goodnow, 1959; Wilkinson, 1961; Wilkinson, 1992). In experiments utilising these 'sensitive' measures of sleep loss, advanced training to reduce practice effects and repeated testing, while commendable procedures for reducing error, likely contribute to the tedium of the testing session and overall decreased arousal and increasing sensitivity to sleep loss. In fact, it has been claimed that for a task to be sensitive to sleep loss, it must not be overly complex, interesting, variable, or short (Wilkinson, 1992).

In contrast, some recent evaluation of stimulating task performance during sleep deprivation has shown that various stimulating tasks are sensitive to sleep loss, particularly those associated with the prefrontal areas of the brain (Horne, 1988, 1993). More advanced sleep deprivation studies have begun to examine linguistic changes during sleep loss, including changes in phonology such as Harrison & Horne (1997).

While functions of sleep have been widely theorised (for review see Rechtschaffen, 1998) there as yet has not been any conclusive evidence (or widely accepted theories) about why we sleep. The large number of theories about sleep function include the following: sleep as a restorative process for the body's tissues; sleep as a behavioural adaptation; sleep as protection from predation; sleep for consolidation of learning; sleep to boost the immune response; sleep as a functional response to the demands of daily living on the body; and sleep as a restorative process for the brain. There is criticism for each of these popular theories (cf. Rechtschaffen, 1998) and the function of sleep continues to elude researchers. One of the possible theories for sleep function hypothesises that sleep is a restorative process for brain activity during the day. This theory proposes metabolic brain activity during the day produces heat and increases brain temperature, which is dissipated during slow wave sleep thus allowing neurons to regenerate to optimum state (McGinty & Szymusiak, 1990), although there is no evidence to support this claim. The thermo-regulatory theory attempts to explain correlational and stimulation data (Kattler, Dijk, & Borbely, 1994) observed during sleep-wake cycles and account for behavioural detriments in performance following sleep loss. While biological aspects are an important part of the study of sleep, focussing on behavioural performance during periods of sleep loss may give clues about the purpose of sleep.

Which brings us to the question why do we study the effects of sleep loss? In one respect, we can examine this phenomenon to answer the theoretical question of why we sleep. It is common practice in neuropsychological literature to study the need for something by removing/preventing it and studying the subsequent changes in behaviour. This methodological practice can be extended to the study of sleep. One of the theories mentioned above is that sleep is necessary for cerebral recovery of function (Horne, 1988). This theory could encompass both Non-Specific cerebral recovery of function (general arousal), and also Specific recovery of function (specific effects). We will return to a discussion of non-specific and specific effects later on in this chapter. Firstly, it is necessary to point out this premise demonstrates it is logical practice to examine tasks sensitive to sleep loss and note the anatomical correlates and cognitive structures associated with those tasks in order to test theories of why we sleep.

A second application of the study of sleep loss is in applied research. In the 24-hour society in which we live, many people undergo periods of sleep loss for work and play. The behavioural measures studied in this thesis may make a direct contribution to the understanding of performance in various areas following a period of sleep loss. In this instance, it is the effects of sleep loss themselves that are of interest.

This thesis was intended to examine the effects of sleep loss and countermeasures on executive functioning tasks. Many tasks used in performance experiments rely on communication, that is, the comprehension and production of language between experimenter and subject, yet no research has been conducted on how communication may be effected by sleep loss. In fact, one would argue that many experiments conducted to date on the effects of sleep loss have not simply measured the specified variable, but rather have a serious confounding effect in the communication of the nature and understanding of the task between experimenter and subject. Therefore, it was a further intention of this thesis to conduct a systematic analysis of the effects of sleep loss on language and communication.

1.11 *Characteristics of Sleep Loss*

Historical sleep studies have shown sleep loss has numerous effects on simple cognitive performance, such as reaction time and vigilance, with relatively little effect on the functioning of human bodily processes including metabolism, digestion, cellular regeneration, and immune response (Horne, 1988). Performance studies have shown sleep deprivation has a detrimental effect on detection, monitoring, reaction time, and other lower functioning skills (Dinges & Kribbs, 1991). These performance deficits are observed more often when the task is familiar, monotonous, and occurs over a long duration.

Sleep deprivation experiments have been carried out in many different ways, involving both animal and human studies. Sleep loss can mean restricted sleep, partial sleep deprivation, total sleep deprivation, or sleep deprivation selective for a certain aspect of sleep, such as Rapid Eye Movement (REM) sleep. In addition to this, multiple factors can be manipulated including age, which is known to be a factor in quality of sleep. Regardless of the type of manipulation or sleep loss, similar anecdotal reports describe the observable effects of sleep loss. In an innovative experiment addressing the

question of age effects in sleep deprivation, Webb (1992) described the changes in behaviour observed from 20 year old and 50-60 year old volunteer:

> "The first night passed easily. If there was evidence of sleepiness, it was between two and six in the morning. During the second day, moods became a little grimmer and long tasks began to bring sighs of resignation. In the afternoon some subjects would nod off or have to put extra efforts out to maintain their performance. During the second night moods began to change markedly. Staying awake on longer tasks required considerable effort or occasional intervention by the experimenter. Tempers would flare and breaks were eagerly anticipated. By the early morning hours there was little cheerfulness. The mood was generally serious or even grim. Spontaneity was missing and subjects did what they were told apathetically" (Webb, 1992; p. 106).

This example is characteristic of the numerous anecdotal observations on mood in sleep loss experiments. Since early reports of sleep deprivation experiments, studies have reported motor performance deficits during sleep deprivation however, mood and subjective sleepiness are the factors most markedly affected (see Pilcher & Huffcutt, 1996 for a review). While it was long believed cognitive performance was only sensitive to sleep loss if it was of long duration and boring to the participant, Harrison & Horne (1997) reported contrary findings when they experimented with highly motivated subjects on short, novel, stimulating tasks. In this experiment, sleep loss appeared to be affecting performance on novel, stimulating, higher cognitive tasks thought to be immune to the effects of sleep loss, suggesting there are possible biological factors affected by sleep loss which cannot be overcome by psychological motivation.

The profound effects of sleep loss on mood and subjective sleepiness has been reported in various studies (for review see Webb, 1992) in which subjects have displayed psychological changes, such as suspiciousness or delusions about the experiment, during the period of deprivation (no less than 60 hours), although it is possible these changes in behaviour were in response to lengthy lab confinement. Some individuals become withdrawn, respond to experimenters in an apathetic manner, and have to be frequently reminded to continue their tasks (Webb, 1992). Others display anti-social behaviour, becoming less inhibited, suspicious of the experiment or experimenters, and report visual hallucinations and a reduced desire to co-operate. While these findings were used to support the theory that sleep deprivation mimics psychotic symptoms, it has more recently been shown that some of these effects can be overcome with compensatory effort suggesting non-specific, generalised effects of sleepiness. Other

symptoms may be classified as specific behavioural effects attributed to impairments in frontal lobe functioning (Horne, 1993).

1.12 *Psychomotor Performance and Sleep Loss*

Most sleep deprivation experiments have studied a number of cognitive and motor performance skills and subjective responses of sleepiness, fatigue, and mood. While some experiments have dealt with higher cognitive functioning associated with decision making, divergent thinking and communication (Schein, 1957; Harrison & Horne, 1997, 1998a,b; Bard et al., 1996), most studies have concentrated on vigilance-type tasks (cf. Pilcher & Huffcutt, 1996).

A large portion of the sleep loss literature comprises extensive studies of performance on reaction times to intermittent stimuli and monitoring in various sensory modalities, often referred to as vigilance (e.g. Donnell, 1969; Dinges & Kribbs, 1991; Dinges et al., 1997). While these studies have been an important step in sleep deprivation research it is difficult to extrapolate from this low-level cognitive functioning to the highly complex, multivariate, interactive scenarios approximating real world situations of total sleep loss or reduced sleep. It has been shown that these vigilance type tasks are highly sensitive to sleep loss, unless motivation is sufficient to overcome their performance (Dinges et al., 1992).

Other psychomotor performance measures, such as detection rates, accuracy, and more complex activities, such as driving, are also sensitive to sleep loss (cf. Pilcher & Huffcutt, 1996). Very few studies of discrete testing with the use of standardised psychological measures have addressed higher-order cognitive processes such as working memory, communication, language ability and group interaction. Instead, most of the focus has rested on sustained performance over long periods of time. The rate of performance decline generally represents an interaction between the task complexity and the subject's experience, including familiarity with the task, motivation to do well, and boredom/interest factor. Since the subject's experience has a large impact on performance ratings and most of the tasks are repeated frequently over a long period, various countermeasures have been tested to assess their value at reversing the effects of sleep loss in these conditions.

1.13 *Countermeasures*

Obviously, the best countermeasure for sleepiness is a normal duration sleep but in many situations where sleep is impossible other countermeasures must be employed. Below is a brief account of countermeasures previously used to combat non-specific effects of sleep loss, also known as a general decline in arousal.

1.131 Motivation

A popular view of performance associated with sleep loss claims that for a task to be sensitive to sleep loss, it must be longer than 10 minutes, dull, monotonous, and boring to the individual. Novel, stimulating tasks are rarely shown to be sensitive to the effects of sleep loss. Contrary to this popular view, it has been reported that sleep deprived (SD) individuals can perform equal to non-SD controls if they are properly motivated to do so (Dinges et al., 1992). Horne & Pettitt (1985) reported subjects can maintain their performance capacity up to 40 hours of sleep deprivation if properly motivated to do so, e.g. by monetary incentive, or emotional interest in outcome. Motivation works equally well as an incentive to fall asleep faster (Harrison, Bright & Horne, 1996).

This beneficial effect of motivation does not appear to extend to complex, frontal-type tasks, such as word fluency and response inhibition (Harrison & Horne, 1997, 1998a,1999a), innovative thinking and flexible decision making (Harrison & Horne, 1999a), and temporal memory (Harrison & Horne, 1999b). The differential effects of motivation as a countermeasure suggest both specific and non-specific effects of sleep loss.

1.132 Naps

In a reduced sleep scenario one of the possible countermeasures to declining performance is the use of a nap to combat sleepiness. Sleep studies have yet to report the effects of a nap on higher-order complex cognitive performance but naps have been studied as possible countermeasures to sleepiness and sustained performance in other situations involving lower-level functioning and sleep loss.

Timing and duration of naps are the most important considerations in their application to combat sleepiness. Dinges et al. (1987) defined a "nap" as any sleep period <50% of a person's average nocturnal sleep length. While this is a possible definition, it seems that 25-50% of a person's average sleep length is longer and potentially more restorative

than a typical "nap". For the purposes of this paper, a "nap" is defined as a period of sleep less than or equal to the length of one sleep cycle, i.e. 90 minutes. Timing of a nap in a 24h period would be expected to interact with circadian rhythms. Caldwell (1997) suggested naps have a restorative value if placed in the circadian troughs (between 0200h and 0500h or 1400h – 1700h) because it is easier to maintain sleep during these periods of circadian rhythm fatigue however, previous reports suggested poor post-nap performance in naps occurring during the first 1-2 hours in the trough phase (Akerstedt & Gillberg,1979; Rosa et al., 1983). Dinges et al. (1987) reported a nap improved visual reaction time performance regardless of where it was placed in a 54h-sleep deprivation period. Caldwell further suggested prophylactic napping, or napping before performance, was the best way to prevent performance decline. However, it is more likely that restorative napping, napping taken during a break in performance, would be a more suitable countermeasure to decrements in complex cognitive performance. Weeks & MacLean (1998) reported a restorative nap has differential effects on psychomotor performance, suggesting timing of a nap before or following sleep loss needs to be further examined. Naps can have a positive effect on sleepiness and mood, suggesting naps as a countermeasure may have the same effects as caffeine in that mood and subjective sleepiness are enhanced but benefits to performance are questionable.

Angus, Pigeau, & Heslegrave (1992) reported the effects of sleep loss can be reversed with a 2h nap however, the effects described were categorised as psychomotor tasks, those involving visual/auditory monitoring and a physical reaction such as pressing a button, rather than complex cognitive performance. Horne (1993) suggested duration of the nap is extremely important in reversing the effects of sleep loss, with 20 minutes being the optimum duration for maximising performance on continuous tasks, such as driving. Naps of greater length risk causing sleep inertia. Sleep inertia refers to high levels of sleepiness and desire to go back to sleep immediately upon waking. While sleep inertia lasts for a short period of time after a short nap, generally less than 5 minutes (Naitoh, Kelly & Babkoff, 1993), it can last up to 30 minutes if waking coincides with a circadian trough (Gillberg, Kecklund, Axelsson et al., 1996). This period of disorientation is associated with large performance decrements and high subjective sleepiness ratings. Typically, once the period of sleep inertia has passed, beneficial effects of a nap are observed between 0.5 - 24 hours post nap. A short nap was addressed during the course of this research as a possible countermeasure to

reported declines in complex, higher cognitive functioning during sleep loss (See Chapter 2).

1.133 Caffeine

Increasingly, researchers are attempting to find appropriate means of enhancing the performance of sleep deprived individuals through drug therapy. A popular method is the use of caffeine, which is commonly used to increase subjective wakefulness at times when alertness is required, e.g. when driving or studying for exams. Some studies of caffeine report increased anxiety, jitteriness, and nervousness, and other studies report no effects (McKim, 1996). When positive effects are reported they are typically mood enhancing, such as increases in feelings of well-being, self-confidence, alertness, concentration, motivation, and energy. Griffiths & Mumford (1995) reported positive effects were more likely to be observed in a restricted set of conditions such as with subjects who abstained from caffeine intake or were deprived of caffeine overnight. In addition, positive effects are more likely observed at low doses (e.g. 20 - 200 mg) while the higher the dose, the higher chance that unpleasant effects will be observed. Changes in cognitive effects are typically evident within 30 minutes and remain higher than placebo levels for at least eight hours (McKim, 1996).

Robelin & Rogers (1998) reported that caffeine improved mood and psychomotor performance relative to placebo in alert individuals. They found that three different levels of caffeine affected mood and performance to the same extent, which is consistent with previous reports indicating a low ceiling effect for psychoactive effects of caffeine. Durlach (1998) reported a 60mg dose of caffeine improved reaction time on pattern recognition, delayed match to sample, and match to sample visual search within minutes of consumption. This evidence suggests caffeine may improve low level cognitive performance in alert individuals. Loke (1988) reported caffeine tended to increase 'tenseness' and 'nervousness' but had non-specific effects on cognitive performance. Revelle et al. (1980) reported that 200 mg of caffeine had a negative effect on subjects of low impulsivity and a positive effect on subjects of a high impulsivity in the morning. Broverman & Casagrande (1982) suggested perceptual-restructuring performance was impaired by caffeine at a low-level of practice but aided at a high level of practice for NSD subjects. James (1991) outlined different types of stressors, such as sleep loss or caffeine, may affect different stages of information

processing. For example, if information processing can be divided into four stages; stimulus preprocessing, feature extraction, response choice and motor adjustment, various stressors may act on one or a combination of the four in different ways.

Military personnel have reported improvements in psychomotor performance and discrimination during periods of sleep loss in sustained operations with the use of caffeine as the stimulant (Bonnet, Gomez, Wirth & Arand, 1995). Penetar et al. (1993) reported caffeine improved rating scores of subjective sleepiness and mood after 49 h without sleep, while others have found similar improvements of alertness with caffeine doses between 200-400mg (Muehlbach & Walsh, 1995). Numerous studies have reported beneficial effects of caffeine during sleep loss on low-level tasks such as vigilance and reaction time, and sleep specific tests such as the MSLT and MWT after extended (>40h) sleep deprivation (e.g. Wright, Badia, Myers et al., 1997). While these are interesting and useful studies in their own right, they do not address complex, higher functioning behaviour, which may be susceptible to specific effects of sleep loss. In addition, studies longer than 40 hours are not very applicable to real-world examples of performance under sleep loss conditions, which would typically extend from 24 - 40 hours.

A few studies have addressed the effects of caffeine on more complex behaviour and performance during sleep loss. In an experiment addressing the effects of sleep loss and caffeine on complex cognitive tasks, Harrison & Horne (1999c) reported 350mg caffeine did not reverse the effects of sleep deprivation on two language-based tasks, but served to improve subjective sleepiness ratings. This again suggests both non-specific and specific effects of sleep loss on cognitive performance. Von Gizycki et al. (1998) reported differential effects of caffeine on working memory during a period of sleep deprivation. On a word recognition task, there was an interaction between caffeine and time of testing during the overnight hours and morning, suggesting caffeine was counteracting the generalised sleepiness experienced in the interim night. Conversely, they found that caffeine did not benefit the number of words recalled. While both of these tasks rely on short-term memory, only one (the word recall) requires a verbal or written output. Language production is imbedded in a task testing sleep loss on short-term memory, without a clear understanding of sleep loss effects on language.

The effects of caffeine on reaction time and cognitive performance is equivocal without adding a sleep loss dimension (for review see James, 1991). The history of caffeine testing has produced multiple tests using heterogeneous performance measures and varied findings of positive, negative, and no effects. In an attempt to clarify some of the previous findings of complex, higher functioning during sleep loss, an attempt was made to incorporate caffeine into the study design as a potential countermeasure to sleepiness (See Chapter 2). While it is necessary to further the understanding of executive functioning cognition and sleep loss, it is important to note the difficulty of addressing the staggering number of factors purported to influence the effects of caffeine on cognitive functioning.

1.134 Drug Therapy

Caffeine is addressed individually as it is a widely used stimulant readily available. While the other methylxanthines, theophylline (naturally occurring in tea) and theobromine (naturally occurring in cocoa) are also widely administered (McKim, 1996), the focus for this research will be on caffeine.

Other psychomotor stimulants, such as amphetamines, namely methylphenidate and methamphetamine, have a beneficial effect on cognitive performance and alertness (Lagarde & Batejat, 1995) but also have debilitating side effects such as anxiety and confusion. Historically, amphetamines were widely used during World War II and during the 1950s as a prevention from sleep. Recent pharmacological developments to combat sleep disorders, such as narcolepsy, have resulted in a strong stimulant called Modafinil[TM]. In an experiment of sleep loss and drug therapy, Modafinil[TM] improved subjective measures of sleepiness and some aspects of cognitive performance such as reaction time and logical reasoning, but metacognition, the ability to monitor one's own performance, did not show similar improvements (Pigeau, Angus, O'Neill, & Mack., 1995). Metacognition is a behaviour involved in executive functioning, thought to be exercised by the frontal lobes. Other negative side effects including distorted perceptions of environment and negative effects on mood and interpersonal skills as well as pharmacological dependence (McKim, 1996) detract from the acceptability of Modafinil[TM] and other such stimulants as an appropriate countermeasure to sleepiness.

While most of the above countermeasures have undergone significant testing as appropriate combatants to the effects of sleep loss, most of these experiments have involved measures of subjective sleepiness, mood, and low level tasks. While psychostimulants can improve performance, the improvement may be limited to well-learned, over-practised tasks (McKim, 1996). Judd et al. (1987) suggested stimulants may impair performance requiring flexibility and adaptation of new strategies.

Further research needs to be conducted on the effects of countermeasures on higher-level cognitive functioning.

1.14 *Opposing Theories on the Effects of Sleep Loss*

Task sensitivity in relation to sleep loss has been grouped into two separate categories. Tasks that are typically sensitive to sleep loss share the similar characteristics of being dull, monotonous, repetitive, and of long duration (>10 minutes). Tasks that are not typically sensitive to sleep loss share similar characteristics of being interesting, novel, and of short duration. Complex, convergent thinking tasks that require subjects to determine the appropriate answer out of a selection, such as logical reasoning, reading comprehension, and IQ performance fall under this category. These tasks are generally aided by countermeasures to sleepiness, such as motivation, caffeine, and drug therapy. The hypothesis formulated from these findings is one of Non-Specific Effect. The hypothesis is that sleep loss causes declines in non-specific arousal but does not have specific effects on cognitive performance.

Contrary to the Non-specific Effect theory, Horne (1988) reported specific effects of sleep deprivation on divergent thinking tasks, which require novelty and creativity. Since then, further studies have been conducted on tasks that fall under the category of complex cognition in relation to executive functioning. These tasks are reported to be sensitive to sleep loss, even when administered in conditions that promote alertness (e.g. short, novel, stimulating tasks administered at alert periods in the circadian phase, with the use of countermeasures, such as monetary incentive and caffeine). The findings from this school of thought support the hypothesis of Specific Effects of Sleep Loss. This theory postulates that specific effects of sleep loss can be observed in tasks necessary for executive functioning and non-specific effects are inconsequential because they can be overcome with countermeasures. This leads to the supposition that

if sleep loss has specific effects on behavioural performance tasks, this may mean sleep loss has specific effects on cortical regions associated with those tasks. Proponents of this theory challenge those of the Non-Specific Effects hypothesis to reconsider the use of dull, monotonous, low-level tasks as a true measure of cognitive ability under the stress of sleep loss.

It will be the principal intention of this thesis to test the Specific Effects Theory of Executive Functioning to further the understanding of the brain's response to sleep loss, and thereby to our understanding of why we sleep.

1.2 Executive Functioning Cognitive Performance in Sleep Deprivation

While extensive research has been conducted on lower level cognitive functioning, very little is known about complex cognitive functioning under the stress of sleep loss. This section addresses the literature on complex cognitive functioning to date, and highlights the need for further research in specified areas. 'Executive function' means the integration of mechanisms to optimise performance in situations requiring multiple cognitive processes (Baddeley, 1986).

Harrison and Horne (1999a) defined 10 separate aspects of complex cognition that are sensitive to sleep loss. These areas included many aspects of frontal lobe functioning and have been defined as; appreciating a complex situation, thinking laterally, keeping track of events, developing, maintaining and revising plans, remembering "when" rather than "what" assessing risk, controlling mood and uninhibited behaviour, motivation, metacognition, and effective communication. In the following section the relevance of these complex cognitive processes will be discussed in relation to executive functioning and sleep loss.

1.21 *Definition of Executive Functioning Cognition*
It is difficult to define complex cognitive skills because different researchers label various levels of cognitive functioning as complex. The term 'complex cognitive functioning' will be defined here as integrated cognitive skills, such as learning, memory, language, communication, and understanding of interpersonal situations.

This differs from lower level cognition such as perception and attention and the various tangential studies derived from those processes, such as vigilance and reaction time, and across modalities (e.g. vision, audition, tactile-sensory, psychomotor). In this research, the components of language, communication, and working memory have been chosen as important aspects on executive functioning and will be addressed in a variety of short, novel tasks.

1.22 *Convergent Thinking*
Numerous studies have addressed performance of SD individuals on higher order tasks involving convergent thinking of the type needed to score well on popular IQ tests (Spreen & Strauss, 1991). Convergent thinking involves determining the one 'right' answer, such as the definition of a word, answers to questions about events, arithmetic problems, logical problem solving, and puzzles (Kolb & Wishaw, 1996). Harrison & Horne (1998a) reported convergent thinking ability was not sensitive to the effects of sleep loss after 36 hours, similar to previous reports of no effect of sleep loss on 'interesting' tasks.

1.23 *Divergent Thinking*

Recent expansions of SD testing have included tests designed to assess divergent or lateral thinking (e.g. Horne, 1988) in which creative thinking, novel responses, reaction to new information, and metacognition are important. In cases of divergent thinking, there is no right or wrong answer, performance achievement represents the number and variety of plausible responses.

There have been recent indications of a divergent thinking sensitivity to sleep loss in students (Horne, 1988; Wimmer, Hoffman, Bonato & Moffitt, 1992) and in military personnel (May & Kline, 1987). Particular aspects of divergent thinking that may show a sensitivity to sleep loss include behavioural spontaneity, creative thinking, risk assessment, response inhibition, strategy formation, associative learning, social behaviour, and temporal memory. It is not yet known how long individuals can remain awake before displaying decrements in performance on these 'divergent thinking' tasks and their underlying behaviours, many of which involve language and communication.

1.24 *Memory*

Implicit and explicit memories have been differentiated in hypothesising the neural circuitry related to memory functions in the human brain. At one time it was believed humans stored memories in a specific location, called an engram, however it is now known that many different types of memory and memory processes exist in different lobes of the brain and subcortical structures (Kolb & Wishaw, 1996). Implicit memory, also termed procedural, semantic, knowing how, or memory without record, is procedural knowledge, how we remember to carry out activities such as bicycle riding. Frontal lobe amnesia patients who cannot remember events, have an intact implicit memory such that they can remember how to do things, such as ride a bicycle, cook food, etc. The opposite of implicit memory is explicit memory, also termed declarative, knowing that, episodic, or memory with record and is the type most people refer to as 'memories', the kind that play as scenes from a story. Petri and Mishkin (1994) proposed a multiple neural circuitry for memory involving the prefrontal cortex, which is of interest to this study.

Broadbent (1958) postulated a difference between short-term (or working memory) and long-term memory. Baddely (1986) described working memory as scratch pad memory in which memories are held for a short period of time while they are being used. He further stated short-term memory and long-term memory are parallel activities through which materials are processed separately and simultaneously. Baddely suggested different types of memory and corresponding neural correlates, were located in different areas of the brain, for example, visual spatial memories anatomically separated in location and pathways from phonological memories. These attempts to locate the neural circuit behind the cognitive theories have not yet been substantiated.

Retention of material in memory is not only affected by the passage of time but also by interfering material, such that learning additional associations to a stimulus or overloading a type of stimulus, can cause old associations to be forgotten (Anderson, 1995). This aspect of memory impairment could be associated with the self-ordered pointing task and the temporal memory task described by Harrison & Horne (1999b) however, a specific test on the effect of sleep loss on proactive interference has not been reported in the literature. Memory processes in sleep research have not been fully studied but anecdotal reports from our pilot study suggest there is a deficit in working memory relating to language function, but not necessarily one related to visual-spatial

functioning (See Chapter 4). Recent findings in temporal memory deficits in sleep deprived subjects (Harrison & Horne, 1999b) suggest working memory may be a process sensitive to sleep loss.

1.25 *Mood and Inhibition*

Pilcher & Huffcutt (1996), in their meta-analysis of 19 sleep deprivation studies, reported mood and subjective sleepiness were more greatly affected in sleep loss conditions than psychological/cognitive processes or physiological responses to sleep loss. Deterioration in mood could have serious effects on conversation between individuals, particularly if they are sleep deprived. Reported deficits in mood and cognition during sleep deprivation could be a significant factor in the conversation and interrupted transfer of information. Mood decrements include a withdrawal from interaction with others and are measured by a negative rating on the Performance of Mood States questionnaire. Personality and mood factors can interact and affect performance on psychomotor and vigilance tasks (May & Kline, 1987), therefore it is possible this effect could also occur in higher cognition.

In addition to mood, uninhibited behaviours could be a contributing factor to deficits in complex cognition. Horne (1993) reported indications of lack of appropriate social behaviour, increases in childish behaviour, verbal outbursts, impatience, and suspiciousness in experimental settings of sleep deprivation experiments. Haslam (1984) reported soldiers under the stress of 9 days without sleep remained quiet, docile, and resolved to the situation with an apparent lack of concern in the outcome. The indications that sleep deprivation has a disinhibiting effect on social practice suggest changes in conversation, use of language, and communication between individuals deprived of sleep may be expected.

Cognitive activity unrelated to the performance tasks may have an effect on cognitive performance. Mikulincer, Babkoff, Caspy & Weiss (1990) reported increases in mentation over a period of 72 h sleep deprivation and correlation between increases in thought occurrence and increases in performance deficits. It is possible the lack of inhibition outwardly observed in SD individuals could also be represented by an increase in non-vocalised thoughts, interfering with the primary task. In addition, this may represent enhanced distractability by both external stimuli and internal random

thoughts in sleep deprived individuals. In the pilot study described later, subjects interrupted their speech with brief pauses and change of topic, later explaining they had difficulty keeping their thoughts on task.

1.26 *Metacognition*

A recent development in the SD literature is the detection of decrement in metacognition, an individual's ability to accurately judge his/her own performance. In a study of 44 university students, Pilcher and Walters (1997) reported a decrease in performance ability by SD individuals but an increase in their self-assessment rating over controls – SD subjects overestimated their ability on the performance tasks. On low-level tasks, Dinges et al.(1992) reported individuals were aware of their performance decrements but were unable to compensate for them, but contrary to this, Bard, Sotillo, Anderson et al.(1996) suggested SD individuals displayed overconfidence in their abilities yet did not lose sight of their performance objectives. While metacognition has not been reported in relation to complex cognition, Harrison & Horne (1999b) suggested SD individuals were more confident about their responses to a temporal memory task than NSD controls.

1.27 *Suggestibility*

Blagrove (1996) reported increased suggestibility in subjects who were sleep deprived. In a study involving 43 hours total sleep deprivation, SD subjects were more likely to change their factual accounts following negative feedback from experimenters and were more susceptible to leading questions than NSD controls. This finding is particularly relevant to military and emergency medical applications, where it is vitally important individuals remain resolute in their knowledge.

1.28 *The Frontal Lobe Hypothesis*

Neuropsychological tests oriented to frontal lobe function (e.g. Morris, Ahmed, Syed & Toone, 1993) are increasingly being reported as sensitive to sleep loss. The Tower of London Test, a particular deficit among frontal lobe patients, also has a sleep deprivation sensitivity in healthy subjects (Horne, 1988). Language skills; written word fluency (Horne, 1995; May & Kline, 1987), verbal word fluency, and articulation (Harrison & Horne, 1997) which have been identified by brain imaging as having frontal lobe activation (McCarthy, Blamire, Rothman et al., 1993), are similarly

sensitive to sleep loss. Coincidentally, the divergent thinking deficits of SD individuals described above are similar to impaired divergent thinking performance produced by patients suffering from frontal lobe lesions (Kolb & Wishaw, 1996). The similarity leads us to a discussion of the neuropsychology of executive functioning in attempts to align findings reported in the literature for sleep deprived individuals with our understanding of the human brain.

1.3 Sleep Loss and the Neuropsychology of Executive Functioning

1.31 Brain and Behaviour Relationship

A recent neuroimaging examination of healthy subjects under conditions of 72 hours sleep deprivation by Thomas, Sing & Belenky (1993) showed decreased glucose metabolism in the frontal cortex, a marked decline apparent after one night without sleep. This finding supports the theory of frontal lobe involvement in sleep function (Horne, 1993). While sleep has recently been under neuroimaging examination (Nofzinger, Mintun, Wiseman et al., 1998), more extensive sleep deprivation neuroimaging work has yet to be undertaken for the obvious reasons of PET scanner availability, invasiveness and cost of study. Since many of the functional localisation studies on healthy controls and lesion patients are currently being carried out, validation for these cognitive tasks, including memory, disinhibition and other executive functioning can be sought from functional localisation studies.

1.311 *Neuroimaging*

The frontal lobes have been suggested as an area of the brain particularly sensitive to sleep loss. Current sleep deprivation research (Harrison & Horne, 1997; Horne, 1995; May & Kline, 1987) includes exploration of frontal lobe-associated task ability in SD individuals. If the neuropsychological theory is correct, certain areas of the frontal regions may be responsible for maintaining executive functioning in humans. The prefrontal cortex is most often associated with executive processes in humans (Goldman-Rakic, 1996). A breakdown in the executive process may suggest a sensitivity to sleep loss of the associated frontal regions.

Recent comparisons have been made between the behavioural abnormalities of frontal lobe patients and the behaviour of sleep deprived subjects (Horne, 1993). This unusual behaviour includes inappropriate actions in social situations, such as childish or whimsical behaviour, an inability to carry out plans, lack of divergent thinking, and an indifference or apathy to the consequences of their actions (Carlson, 1995).

An important step in determining the function of sleep is to localise the brain regions responsible for behavioural performance sensitive to sleep loss. To this end it is

necessary to compare performance of SD individuals with non-SD controls, frontal lobe patients, and non-human primates to determine similarities and differences in their performance. Current neuropsychological research on lesion patients and healthy controls employs functional neuroimaging methodology (by functional Magnetic Resonance Imaging fMRI, Positron Emission Tomography PET, Computerised Tomography CT, and Electroencephalographic EEG studies) for tasks involving the frontal lobes. These tasks include executive functioning and working memory.

In behavioural examination of lesion patients, it has been discovered that damage to prefrontal cortex does not impair long-term memory retrieval or knowledge about the external world, rather it impairs the ability to use this knowledge to guide behaviour or update previous information with new information, in 'on-line' working memory (Goldman-Rakic, 1996; Petrides, 1996). Localised damage in the prefrontal region is associated with disinhibition, perseveration, and deficits in memory processes.

The similarities between the findings of lesion patients and those of SD individuals are most easily examined with the use of an example. SD subjects performed poorly on a task requiring inhibition of previously learned responses and updating previous information with new information, the Haylings Sentence Completion Task (Harrison & Horne, 1998a). In this task, SD subjects performed as well as controls on automatic retrieval from long-term memory of the expected response. However, SD subjects performed significantly worse than controls on generating a novel, unrelated response to the verbal cue. The difficulties SD individuals have with the novel portion of the task include perseveration of previous strategies and an inability to inhibit the expected response. It could be argued that this task also requires working memory, in maintaining the understanding of the task and the memory cue before making a response.

Similarities between performance deficits on cognitive tasks of frontal-damage patients and sleep deprived individuals (Harrison & Horne, 1998a; 1999a,b) suggests a similarity between interrupted processing for frontal-lobe damaged individuals and sleep deprived subjects. The following theories of working memory, an important component of executive functioning, formulated in attempts to explain deficits of frontal patients may aid in the understanding of sleep deprived performance, and give us a clue about why we sleep.

Petrides, Alivisatos, Meyer, and Evans (1993) have proposed a two-level hypothesis for functional and anatomical correlates to working memory in the frontal cortex. This hypothesis stipulates there is an anatomical difference between automatic retrieval and active (strategic) retrieval, defined as "conscious (i.e. willed) effort to retrieve a specific piece of information guided by the subjects intentions and plans" (Petrides, 1996, p. 1459). Automatic retrieval occurs as long as posterior temporal cortex and parietal association cortex have intact connections with subcortical structures associated with memory, while active retrieval relies on strong bidirectional connections with posterior regions. The mid-dorsolateral frontal (MDLF) cortex is associated with automatic retrieval while the mid-ventrolateral region is associated with active retrieval (Petrides, 1995). It has been shown by PET that the mid-ventrolateral frontal (MVLF) cortex is active, particularly in the left hemisphere, during retrieval of specific verbal information in free recall, and bilaterally active for spatial working memory (Petrides et al., 1993; Owen, Evans, & Petrides, 1996). In a comparison between free recall and paired association recall, self-generated free recall showed significant activation in the MVLF but no difference in activation in the MDLF (Petrides, 1996) suggesting the MVLF is necessary for active retrieval.

The theory of different levels of working memory represented in different anatomical locations described by Petrides (1996) contrasts an opposing theory suggesting prefrontal cortical architecture of working memory is anatomically separated by modality of stimulus encoding (Goldman-Rakic, 1996). This theory suggests that the underlying function of frontal lobe ability is working memory, and the anatomical location of activation is more specific to modality (e.g. visual vs. auditory) processing than actual working memory function. This second theory is an important consideration when explaining findings of sleep deprivation studies of complex cognition, in that it suggests the behavioural deficits associated with decreased frontal activation are a result of impaired working memory.

While it has been popular to dissociate working memory processes from disinhibition and perseveration processes with frontal lobe patients (Burgess & Shallice, 1996) and SD subjects (Harrison & Horne, 1998a) it is possible the anatomical correlates of the separate functional areas are the same. Goldman-Rakic (1996) interpreted findings of

association between verbal fluency and Stroop-like deficits (see Burgess & Shallice, 1996) as a failure to suppress the primed response due to a failure of working memory to provide the correct response, suggesting disinhibition and perseveration may be a result of working memory neural substrate failure. This convergence of anatomical areas representing multiple functions suggests basic level tasks (e.g. response inhibition, or working memory) should be viewed as combined activities and can be studied together in higher processes, such as language.

1.312 *Topographical Mapping*

The traditional approach to studying brain activity in sleep research involves EEG measures through a polysomnographic (PSG) battery. While the EEG is useful for exploring gross measures of brain activity during wake and sleeping, it does not allow for distinct anatomical localisation of activity. Regardless of this downfall however, the EEG is a useful measure for many aspects of sleep research, including the study of frontal lobe functioning.

Recent research suggests activation in certain body regions during wakefulness have an effect on the sleeping EEG (Kattler, Dijk, & Borbely, 1994). In a laboratory study of night-time sleep EEG, subjects had one hand stimulated for a 6-h period prior to data collection. Results suggested contralateral activity increases in the delta (slow wave) sleep region, suggesting activation of specific neural populations during wakefulness may be reflected in their electrical activity during subsequent sleep.

A difference between brain activity in topographical regions occurs along the antero-posterior axis during all night human sleep, as measured by brain topography power spectra (Werth, Achermann, & Borbely, 1996, 1997). Differences were detected in temporal changes of power across Non-REM (NREM) and within NREM periods, suggesting anterior and posterior cortical areas may have differential involvement in producing sleep electrical activity. Werth et al. (1997) conceded the regional differences in sleep EEG spectra indicate that sleep is a local brain process, reflecting action of various neural populations, and not simply a global brain activity.

The EEG is a valid quantitative measure of human sleep architecture and the microstructure of electrical brain activity measured topographically. Substantial

improvements in this measure have allowed further exploration of sleep and wake brain activity in correlation with sleep and wake performance. The combination of EEG and PET studies in the exploration of executive functioning will be a useful validation measure for the claims made by behavioural neuropsychological research. The proposal that activity during the day (and resulting stimulation of specific neural regions), may be reflected in the subsequent sleep EEG may be extended to executive functioning research. There is a possibility that the involvement of frontal cortex in executive functioning activities, such as language and other divergent thinking tasks, can be correlated with changes in the sleep EEG, and serve as further support for the neuropsychological theory of sleep function. While there is large scope for study in this area, this research will only briefly examine the EEG activity of the brain in sleep as a response to waking activity.

Experimental research and the theoretical understanding of sleep deprived performance as a technique for developing understanding about why we sleep is an important endeavour. However, sleep deprivation research is not only important to advancement of our scientific understanding. The following section outlines why research into sleep deprived performance is relevant in everyday life.

1.4 Not simply a theoretical question: Importance of Communication in Sleep Loss Research

1.41 *Language Function, Decision Making and Sleep Loss*

Communication has been identified as a significant factor in decision making processes (Harrison & Horne, 1999a) and represents a unique human feature in its intricate association with the function of language. Within the scope of this report, the study of human communication will be limited to written and verbal communication. Verbal communication can be studied on many levels, depending on depth of processing. Phonological considerations, articulation, and pronunciation are individual aspects of linguistic evaluation while at the other end of the spectrum, semantic references and speaker's point of view are more often evaluated by qualitative methodology. Components of a sound-based language include phonemes, morphemes, syntax, semantics, prosody, and discourse (Damasio & Damasio, 1992).

Group interaction/communication is an essential factor of group decision making, which is often observed in emergency or long duration work such as military conditions, emergency medical procedures, and disaster situations. Communication between individuals involved in these decisions is essential in maintaining optimum performance, yet this advanced human function has been neglected in sleep deprivation research.

1.42 *Applied Performance in Sleep Loss*

This section contains information on laboratory and field based studies of sleep deprivation and performance. Since military operations are likely to involve high risk, high reward outcomes, organisations reliant on these operations are increasingly requesting information on the effects of sleep loss in command and control settings. Many of the studies discussed below relate to field soldiers or middle ranking military personnel. Research on command personnel, and thus specific research on command decision making has yet to be carried out.

1.421 Military Applications

With recent advances in technology for around-the-clock operations, military personnel are required to participate in continuous operations. Continuous operations can be either sustained operations or extended operations, but for the purpose of this paper, the discussion will be limited to factors involved in sustained operations. Krueger and Englund (1985) reported subjects undergo more than the usual amount of stimulus presentation typical of psychological performance studies when participating in sustained operations (SUSOPS). In a discussion of methodological considerations Krueger and Englund noted SUSOPS studies have highly complex methodologies and data collection techniques.

Extensive military studies on continuous operations most often involve discrete measures of military performance on psychomotor tasks, e.g., map reading, gun firing rates, accuracy at target shooting, and physical performance (e.g. Banderet, Stokes, Francesconi, et al, 1981; Naitoh, 1981; Haslam, 1981; Wilkinson, 1969) but relatively few studies of more complex cognitive tasks have been reported. Many studies (similar

to the findings of Haslam, 1984) report a general decline in the rate of performance with no change in accuracy for tests of psychomotor skills, vigilance, and attention. From the relatively few studies on complex cognitive tasks, an important study conducted by Angus and Heslegrave (1985) addressed aspects of performance such as encoding/decoding, short-term memory, paired-associative learning, and message processing. In this novel study of 54 h continuous operations conducted on twelve women, aged 19 to 24, the more cognitively demanding environment produced greater decline in functioning than previous, less demanding studies. With the use of continuous measurements, subjects had more substantial mood and performance declines during periods when they were on task compared to rest periods. While this laboratory-based study was one of the few which objectively examined complex cognitive performance, the methodology required individuals to work alone with minimal external contact.

Another large, intensive measure of continuous cognitive performance was carried out as a field study with active military personnel volunteering as subjects (Haslam, Allnutt, Worsley, et al., 1977; Haslam, 1978). Termed the 'Early Call' operations, the study involved multi-level measures, the first of which included 3 platoons of infantry in 3 conditions; no sleep, 1.5 h sleep, and 3 h sleep, in the 9 day test period. Again, cognitive tests were used for map plotting, encoding, short term memory and logical reasoning. Haslam et al. (1977) reported well learned tasks were the least affected by sleep loss while the more difficult tasks were greatly affected, and little change was found on short term memory performance.

In addition to the typical psychomotor performance tasks, verbal communication were recorded qualitatively (Haslam, 1978). Following 44 hours without sleep, commander's orders were not given clearly and were misinterpreted by soldiers. This decline in communication continued when, after 68 hours without sleep, the commander lost control of his men, orders were misunderstood, and basic military rules were broken without concern by the SD subjects. Haslam (1978) concluded cognitive functioning in continuous operations is highly sensitive to one night of sleep loss and this sensitivity, and resulting severe decline in performance, greatly increases throughout the period of sleep deprivation. The sensitivity is markedly pronounced during circadian troughs (early morning hours 0100h - 0600h and afternoon dips 1400-1700h).

In a review of methodological consideration in continuous operations research, including research involving sleep deprivation, Krueger and Englund (1985) pointed out that many SD studies measure periodic task performance, using standardised laboratory tasks, specific to psychological ability. These tasks include dependent measures of "accuracy scores, reaction times, evoked and event-related potentials in sensory, perceptual, psychomotor, vigilance, memory, and cognitive tasks; physical, psychological, physiological, electrophysiological, and biochemical measures; histories, questionnaires, self-administered scales of subjective states (mood, fatigue, beliefs, symptoms) and performance ratings." (Krueger & Englund, 1985, p. 588)

1.422 Emergency Medical Personnel

Not only are the military subjected to continuous operations, civilian medical personnel frequently undergo periods of total sleep deprivation or restricted sleep also. Resident doctors, or doctors-in-training are among the most frequently SD population due to long on-call shifts. Their duties involve making decisions regarding medicating and operating on patients, communicating their needs to other medical staff, patients, and families, and carrying out well-practised medical routines (Krueger, 1994). Lingenfelser, Kashel, Weiser, et al. (1994) reported cognitive performance and mood decrements in resident doctors during periods of restricted sleep. While the cognitive performance tasks were previously labelled as sensitive to sleep loss, they did not measure a communication or group interaction component. It is important to note individual declines in performance and mood may be exacerbated in a group scenario.

Difficulties in assessing performance of doctors on call are inherent in the task since patients rely on optimum performance at all times. Tasks used to previously assess doctors' abilities, such as serial reaction time and critical flicker fusion (Ford & Wentz, 1984), are lacking in their approximation of real-world scenarios and their monotony. In a study of tasks more closely associated with actual medical duties, Deary & Tait (1987) measured logical medical memory in immediate and delayed recall, and ECG record examination. They reported large individual differences between the three conditions of off duty, on call and emergency work but the amount of sleep taken by each doctor in the three conditions was not controlled. One notable measure was impaired memory performance on immediate recall in the emergency work condition.

Mood changes with increasing sleep loss were similar to laboratory-based sleep loss findings.

Errors on medical monitoring tasks, grammatical reasoning, and realistic sustained attention increased with advancing sleep loss (Leonard, Fanning, Attwood & Buckley, 1998). While no reported studies have examined complex cognition and communication during sleep loss in the medical field, Goldman, McDonough, & Rosemond (1972) reported resident doctors' planning ability declined with sleep loss and they were more hesitant to make recommendations with procedures.

1.423 Other Applications
There are many other areas in which sleep deprivation, both total and partial, plays a debilitating role in the performance of individuals working a 24-hour clock. In seasonal fire outbreaks, both sight fire-fighters and the commanding staff are required to work long hours on a 24-hour shift schedule, often engaging in continuous operations during risky situations. Research with this specialised group of continuous operators has yet to be carried out nevertheless speculation on their performance includes the cognitive and mood deficits reported in other fields, as well as increased stress associated with life-threatening situations.

Space flight personnel and space station personnel are on 24-hour watch with particular life-threatening risks associated with sleep deprivation during emergency periods. Even in the world of business and education, groups of people will pull 'all-nighters' to meet a deadline or finish a project, and therefore are subjected to the deficits associated with sleep loss. One factor notable throughout this review is that difficulties in creating real-world scenarios in laboratory-based sleep loss studies bear. It is inevitable that sleep loss studies, including the military field studies, lack the imminent danger and stress associated with real world disasters, such as the Challenger explosion, the Three-Mile Island Disaster, and Chernoble. Investigations into these incidents have implicated lack of sleep as a major contributing factor to personal errors responsible for the disasters.

1.5 Sleep Deprivation and Language Skill

While many of the tasks used to test performance of SD individuals use language, very few tasks have specifically addressed language skill.

Surprisingly little research has been conducted on the language function and the effects of sleep deprivation. Some recent reports by May & Kline (1987), Horne (1995), and Harrison & Horne (1997) report deficits in word fluency, with the latter also reporting problems with articulation and increasingly monotonic voice intonation. In particular, subjects have difficulties with word generation and a tendency to become fixated in a particular semantic category in self-generated word fluency tasks (Harrison & Horne, 1997). In a study of military aircrew on simulated operations, Whitemore & Fisher (1996) reported word duration and voice parameters, such as fundamental frequency, fluctuated with increasing levels of sleep loss up to 36 hours, in correlation with circadian rhythm patterns. Interpretative communication errors include inaccurate message interpretation or failure to receive incoming messages, while external communication errors include poorly articulated information, or lacking information. These studies have focussed on the phonological aspects of speech and language. While phonological and other types of language errors have been anecdotally identified as increasing with sleep loss, they have not been systematically studied.

A historic study examining the effects of sleep loss on communication was reported by Schein (1957). Since communication is important in any co-operative task, Schein studied the effects of sleep loss on the ability to receive and send complex instructions. He reported subjects had difficulty receiving and generating messages, following 55 h of sleep loss. Angus & Heslegrave (1985) reported a decline in using newly communicated information to update map plans and an increase in reaction time responding to the information. In their study, 12 women underwent isolated laboratory measures of complex military tasks. In an applied military setting, increased communication errors were reported among military air crew undergoing partial sleep deprivation (Neville, Bisson, French, & Boll, 1994). While communication skills appear to deteriorate during sleep loss, Ritter (1992) suggested conversation helped to maintain alertness in fatigue conditions.

To further our understanding of the contribution of language to the findings of sleep deprivation and conversely the effects of sleep deprivation specifically on language we must first establish the relevant aspects of language and how they relate to the primary goal of this research (See Chapter 3).

1.6 Summarising the Research Questions

Sleep loss has Non-Specific Effects on human functioning, a generalised sleepiness that increases with increasing sleep loss. This fact is undisputed. The question remains if sleep loss has Specific Effects on certain higher-order cognitive functions as well. Horne (1988, 1993) and Harrison & Horne (1997, 1998a, 1999a,b,c) have argued this point convincingly, providing examples of sensitive tests of sleep loss, i.e. those that are novel, interesting and stimulating, that by critical accounts should not be effected by sleep loss. However, numerous questions remain and further evidence is needed to make more specific claims about the effects of sleep loss. Figure 1.1 provides a summary of the questions to be answered in the following chapters.

Furthering the Knowledge of Executive Functioning during Sleep Loss

- What is the effect of a nap as a countermeasure to sleep loss effects on executive functioning tasks?
- What is the time course of decline in executive functioning during sleep loss?
- What is the effect of caffeine as a countermeasure to executive functioning tasks?

Questioning the Robustness of Executive Functioning Sensitivity to Sleep Loss

- What are the important components of the executive functioning tasks that make them sensitive to sleep loss?
- If untested tasks are divergent/executive in nature, will they too show a sensitivity to sleep loss?

Attempting to Understand the Role of Language as a Tool and as an Executive Functioning Task

- What role is the reliance on language a confounding variable in the executive functioning tasks?
- Does sleep loss have a specific effect on language?

Theorising the Answer to the Specific vs. Non-Specific Question of Sleep Loss

- Is there really a Specific Effect of Sleep loss on executive functioning tasks or are the previous reports related to Non-specific effects?

Figure 1.1 Research Questions

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Chapter 2
Period of Decline and Countermeasures in Executive Functioning Tasks Sensitive to Sleep Loss

2.0 Period of Decline and Countermeasures in Executive Functioning Tasks Sensitive to Sleep Loss

Numerous sleep deprivation studies have been carried out to assess varied psychological performance following one night of sleep loss (cf. Pilcher & Hufcutt, 1996). As mentioned in Chapter 1, very few of the SD studies conducted have used short, novel, stimulating tasks in an assessment of sleep loss. There is a need for assessing SD performance under conditions of high incentive and in a novel situation in order to alleviate boredom effects and lack of motivation associated with a general decline in arousal. In fact, Horne & Pettitt (1985) demonstrated that when monotonous tasks are presented in a novel, interesting, stimulating environment there is little evidence to support their sensitivity to sleep loss. They reported that with increasing incentive over a 36-hour period, SD individuals were able to maintain baseline levels of performance on the Wilkinson Auditory Vigilance Test. After 36-hours of deprivation, subject performance worsened but remained above the level for non-incentive subjects until the third day, at which time subjects were unable to maintain performance despite high monetary incentives.

Harrison & Horne, (1998a) reported if simple cognitive tests were short, novel, and interesting or subjects were highly motivated to perform, then one night of sleep loss did not have any effect on performance. They used this argument to outline the possibility of frontal lobe deficits in SD individuals after one night of sleep loss. They reported SD individuals performed poorly on tests of divergent thinking such as word fluency, novel sentence completion, anticipating future consequences, and applying novel thought to decision making and strategic planning after 36 hours of sleep deprivation. Many of the tasks used were previously reported to be sensitive to the effects of prefrontal cortical damage in neurological patients (Milner & Petrides, 1984). The repeated findings of task sensitivity for divergent thinking reported by Harrison and Horne suggest that these abilities are susceptible to decline in situations where divergent thinking may be required for optimum performance.

In further expansion and in support of the theory of Specific Effects (see Chpt.1), Harrison & Horne (1999c) reported that 350 mg of caffeine did not improve SD performance on executive functioning tasks at 36 hours. The influence of caffeine on SD performance is well documented for simple cognitive tasks and cognitive-motor

tasks, such as driving. Caffeine has been found to improve visual vigilance (Baker & Theologicus, 1972), and to improve reaction time after both normal and restricted sleep (Rosenthal et al., 1991). It has been reported that caffeine tends to relieve subjective sleepiness and promote alertness and attention to task performance for these tasks. Conversely, Linde (1995) and Harrison & Horne (1999c) reported that caffeine intake had no effect on the performance of sleep deprived individuals for cognitive tasks, even though the caffeine did serve to decrease the subjective sleepiness reported by subjects. The effects of caffeine on cognitive performance in alert individuals have produced varied reports dependent on impulsivity (Revelle et al., 1980), level of practice (Boverman & Casagrande, 1982), and type of task (Linde, 1995). The effect of a nap on complex, executive functioning tasks has not yet been reported.

As is discussed in Chapter 1 (see Page 6), napping is widely assumed to have beneficial effects on subjective alertness and performance during periods of sleep deprivation. While the definition of a nap continues to be debated in the sleep literature, for this study a nap is considered a period of sleep approximately equal to one sleep cycle, or 90-minutes. In previous studies of sleep deprived performance following a nap, beneficial effects of a nap were reported to be dependent upon prior time awake and length of the nap. Bonnet (1991) reported improved performance in military sustained operations following 0-8 hr naps in a dose response fashion only up to the second day without sleep. Performance testing include logical reasoning, digit symbol substitution, immediate free recall, vigilance, and addition, but did not include executive functioning tasks. The Bonnet (1991) results contribute to the hypothesis of this study that a 90-min nap will have beneficial effects on complex, executive functioning performance at 36-hours. Bonnet further reported that beyond 48 hours, the beneficial effects of a prophylactic nap are no longer sufficient to overcome the marked sleepiness. It appears that beyond 40 hours, napping helps to reduce the effects of sleep loss but not to eliminate them. Dinges et al. (1987) recounted that following 42 hours without sleep, a nap did not improve simple reaction time but it prevented further deterioration in reaction time when compared to no-nap controls. Haslam (1985a,b) reported to maintain performance at baseline levels, a daily nap of 4-6 hours duration is required during military sustained operations exercises.

Angus, Pigeau, & Heslegrave (1992) reported the effects of sleep loss can be reversed with a 2h nap following 46-hours without sleep however, the effects they described were simple cognitive tasks such as those involving visual/auditory monitoring and measuring physical reaction time.

The timing of the nap in this study was chosen to allow a significant length of sleep loss before the nap, a sufficient period following the nap to overcome sleep inertia before testing, and placement during a characteristic sleepy period, the 'post-lunch dip'. Dinges et al. (1987) reported beneficial effects of a nap on visual reaction time regardless of where it was placed within a 54-h period of sleep deprivation.

In previous studies of executive functioning and sleep loss, the minimum length of time subjects were awake preceding the task was approximately 36 hours and continued to beyond 50 hours. Testing generally occurred during the evening peak in alertness on the circadian rhythm scale, attempting to relieve as much of the 'general tiredness' or "sleepiness" as possible, including in one study administering caffeine as a psychostimulant at a dose reported to improve alertness (McKim, 1996). This type of testing session has been referred to as one night without sleep. While beneficial in establishing the sensitivity of these complex tasks to sleep loss, the 36-hour deprivation studies do not give an indication of the time course of performance decrement for executive functioning tasks.

While motivation in the form of intrinsically interesting tasks, encouragement, and monetary incentive and caffeine have been previously used as countermeasures to test the sensitivity of executive functioning tasks, a short nap has not. In addition, it was noted that in the Harrison & Horne (1999c) study of caffeine's, caffeine was only administered to the SD group and caffeine effects were not tested in control subjects.

No practice was given prior to the tasks completed in this thesis, which is an unusual methodological practice, one which is not widely used. Following the research published by Harrison & Horne (1997,1998,1999) this methodological practice was used to maintain novelty, to prevent subjects developing strategies during learning which could then be employed during SD, and to keep the tasks short and interesting.

For the same reasons, no baseline data was collected. See Chapter 1 for further discussions of novelty and complex cognitive tasks in relation to sleep loss.

The main aim of the first study was to assess the effects of a nap on SD performance at 36 hours of sleep loss on executive functioning tasks previously reported to be sensitive to sleep loss and on complex language-based tasks suspected of executive functioning orientation, however it is arguable that language tasks are executive tasks. The hypothesis was that a one-hour nap would have beneficial effects on SD performance for executive functioning tasks.

The main aim of the second study was to assess the effects of 27 hours without sleep. In addition to sleep loss, the effects of caffeine (200 mg) versus placebo were also assessed to test the theory of Non-Specific vs. Specific Effects. The hypothesis was that if there are Specific Effects of Sleep Loss on Executive Functioning performance at 27 hours without sleep, SD individuals should perform worse than controls, regardless of caffeine intake. The caffeine dose (200mg) was not expected to have an effect on alert individual's performance. In addition, a second control group was tested to verify the control findings from the first study and to help reduce the standard error in the baseline group.

The main aim of the third study was to verify the effects of caffeine on alert individuals observed in the second study, using a sample of 4 of the performance tasks. A third control group was tested to further expand the sample, and thereby reduce error of the baseline group.

36 Hours without Sleep & a Nap as a Countermeasure

In order to assess the effects of a 2-hour nap opportunity on complex cognitive tasks it was necessary to test subjects at 36 hours without sleep, a time at which they previously showed sensitivity to sleep loss on the executive functioning tasks. As mentioned in chapter 1, the differences between executive and non-executive tasks defined in this thesis is dependant on their conformity with the definition of executive functioning cognition: "Integrated cognitive skills, such as learning, memory, language, communication and understanding of interpersonal situations." (Chapter 1, page 12). Refer to the description of each task in the results section of this chapter for the specific measurement of deficit for that task. It is common sense to understand that the best measure for counteracting the effects of sleep loss is to sleep. The question posed by napping as a countermeasure is: Will a 2-hour nap opportunity encompassing the first 90 minutes of sleep, or the first sleep cycle, be sufficient to restore executive functioning to baseline levels from their previously documented sleep deprived deteriorated levels?

2.1 Method

2.11 Subjects

Participants were thirty-one, non-smoking volunteer subjects, 15 women and 16 men, (mean age = 20.1, $\underline{SD}$ = 1.9, min = 18, max = 26), who were selected from respondents to posters around campus at Loughborough University, UK. Subjects were screened according to the normal protocol (see Section 2.13) and paid for their participation in the study. Initially 40 subjects were recruited for participation in the study however, 6 were removed from the study for speaking English as a second language, and 3 were removed for not obeying instructions in the experimental protocol.

2.12 Design

The subjects were randomly allocated within gender to one of three conditions, the two sleep deprived conditions consisting of 10 subjects, and the control condition consisting of 20 (See Tables 2.1 & 2.2). The three conditions were:

1. sleep deprived without a nap opportunity[SD]
2. sleep deprived with a 2 h nap opportunity[NAP]

3.   non-sleep deprived without a nap opportunity [NSD]

Table 2.1 Experimental Conditions

Experimental Groups			
Control	11 subjects	W:5 M:6	
Sleep Deprived - No Nap	10 subjects	W:5	M:5
Sleep Deprived - With Nap	10 subjects	W:5	M:5

Note: In statistical analysis, all control subject data has been pooled such that the control group results are the same for each set of analyses in this chapter.

Table 2.2 Independent Variables

CONDITION
Sleep Deprived (SD) ■ Arose between 7-8 am 36 hours before testing session ■ Did not sleep between arousal time and testing session ■ At time of testing had been awake for 34-37 hours
Sleep Deprived (NAP) ■ Arose between 7-8 am 36 hours before testing session ■ Subjects had a 2-hour nap opportunity between 1.30pm and 3.30pm, positioned in the circadian trough ■ A two-hour period post-nap was given prior to testing to overcome the sleep inertia. ■ At time of testing had been awake for 2 hours
Non-Sleep Deprived (NSD) ■ Arose between 7-8am 36 hours prior to testing ■ Had a sleep opportunity between 11pm and 7am ■ At time of testing had been awake for 8-10 hours

2.13 Materials

a) Screening forms

Initial screening excluded those with sleep difficulties; those who were on medication that cause sleepiness or affect sleep, and those suffering from epilepsy, diabetes, or migraine headaches. All participants were selected on the basis of the following criteria; they had a regular sleep/wake cycle of 7 to 9 hours per night they had no major health concerns as indicated by the Loughborough University Health Screen for Study Volunteers (see appendix 1) and the Health Questionnaire (see appendix 2), and

they fell within the range defined for students (0 - 18) on the Epworth Sleepiness Scale (Johns, 1992). The mean score on the Epworth Sleepiness Scale was 5.7 ($\underline{SD}$ = 2.5) with a range of 1 to 12 on the 24 point scale. All participants were assessed as being moderate to good sleepers as determined by the Sleep Pattern Questionnaire (Monroe, 1967; see appendix 3). All subjects were in the self-rated health range of fair to excellent health, were non-smokers, and mild-moderate caffeine drinkers. Everyday activities including exercise, nicotine intake and caffeine intake were screened and monitored by self-report for the 48 hours prior to the testing session.

b) Actimeters

Subjects wore ambulatory activity monitors on the dominant wrist [Type: Z80-32K V1; available from Gaehwiler Electronic, Eichtalstrasse 20, CH-8634 Hombrechtikon, Switzerland] to assess their compliance with the protocol. The actimeters detect the average body movement in one-minute epochs during periods of sleep and wakefulness and have been shown to be sensitive measures of sleep and wakefulness, predicting polysomnographic sleep and wake with 93 percent accuracy (Levine et al., 1986). They have also been shown to be sensitive measures of sleep restriction and increased time in bed (Levine et al., 1988). Sleep onset was monitored using software previously validated with EEG recordings (Horne, Pankhurst, Reyner, Hume, & Diamond, 1994). In addition to recording the subjects' movement prior to the testing session, the actimeters also served as a reminder to the subjects that they should comply with the protocol. Since time awake was the critical factor in this study, physiologically recorded sleep and wakefulness of the SD and NSD and NAP groups was deemed unnecessary. Actimeter data was lost for 4 NAP subjects.

c) Questionnaires

1. <u>Karolinska Sleepiness Scale</u> (SSS) (appendix 4)

    Developed by Akerstedt & Gillberg (1990) the Karolinska Sleepiness Scale measures subjective ratings of sleepiness and alertness on a 9-point scale, ranging from:

    1   EXTREMELY ALERT

    ↓

    9   EXTREMELY SLEEPY, FIGHTING SLEEP, EFFORT TO STAY AWAKE

All subjects rated their subjective sleepiness every hour from 0800h the morning prior to testing until the completion of the study. During testing subjects rated their

subjective sleepiness every 15 minutes. Obviously, NSD subjects and NAP subjects did not rate their sleepiness during their sleep periods.

2. Epworth Sleepiness Scale (ESS) (appendix 5)

> Developed by Johns (1992), the Epworth Sleepiness Scale is a measure of everyday sleepiness and the likelihood of falling asleep in different situations. Johns (1992) defined ranges for groups of individuals, e.g. 'normal' subjects (2 - 15), students (0 - 18).

> The rating scale ranges from:
>> 0 = would *never* doze
>>
>> 1 = *slight* chance of dozing
>>
>> 2 = *moderate* chance of dozing
>>
>> 3 = *high* chance of dozing

> This scale is applied to a series of 9 scenarios, for instance, watching TV, or sitting quietly after lunch without alcohol. This questionnaire was used as a part of the screening battery.

3. Sleep Pattern Questionnaire (appendix 3)

> Developed by Monroe (1967) this questionnaire is a series of ten questions assessing difficulty of going to sleep or staying asleep and was used here as an additional measure of sleep patterns. The questions address various areas of sleep ability such as number of times awake during the night, difficulty of returning to sleep, and enjoyment of sleep.

4. Nap Opportunity Questionnaire (appendix 6)

A Nap Opportunity Questionnaire was administered to the NAP subjects, and was modelled after the Sleep Pattern Questionnaire (Monroe, 1967) to assess subjects subjective sleep quality during the nap opportunity. This combined with readings from the Actimeters was used to determine amount of sleep taken by the NAP group.

d) Apparatus

Three of the written tasks described below were administered en masse in a large testing room, paper and pencil style and timed accordingly.

For two of the tasks (Verb Generation and Haylings Sentence Completion Task - see description below) subjects' responses were recorded in a sensory muted room with a Sony TCM-359V Cassette Recorder and taped voice recordings played on a Sanyo TRC-8080 Memo-Scriber with adjustable volume. Subjects were alone in the testing room during these tasks.

The individual tasks were arranged thus to prevent subject inhibition of their responses by the presence of the experimenter in the room. The presence of an experimenter has been documented as having a deleterious effect on subject performance (Weeks & MacLean, 1998) and was noted as having an inhibitory, confounding effect in the pilot testing of this study (see Chapter 4, Pilot Study two).

e) Tasks Previously Reported to be Sensitive to Sleep

1. Trail-Making Task (appendix 7)
This task was written and subject paced.

Subjects were given oral instructions via a tape recorder to connect letters in alphabetical order as quickly and accurately as possible. This task was based on the trail-making task described by Wimmer, Hoffmann, Bonato et al., (1992). One form of the 20-character task was created, and was administered only once to each subject, in order to maintain novelty. Each form was printed on half a standard writing paper (8.5" x 5.5"). The characters were mixed in a random pattern on the page. The subjects were instructed not to remove their pen from the paper and to connect the characters alphabetically (i.e. A,B,C,D,...). This task was subject paced and took approximately 60 seconds to complete.

2. Word Fluency
These tasks required oral production and were experimenter paced.

a) L Prompt and P Prompt
Subjects were verbally instructed to generate in one minute as many spoken words as possible beginning with the letter 'L' in one attempt, and the letter 'P' in a second attempt. The two trials were separated by three other language

tasks. This task is a variation of the Thurstone Word Fluency Test reported to be sensitive to sleep loss (Harrison & Horne, 1997; Horne, 1988). The letters were chosen for their equivalent frequency in the use of words beginning with those letters in the English Language (Thurstone, 1938; Benton & Hamsher, 1983). Subjects were instructed to avoid using proper nouns, such as names. Harrison & Horne (1997) reported a significant deterioration in word generation on this type of task following 36 hours of sleep deprivation in a repeated measures design. They used 8 letters presented in groups of three, and the test was administered three times over a 36 hour period. Since boredom has a detrimental affect on the motivation of individuals to perform repeated measures testing (Horne & Pettitt, 1985), repeated measures were avoided in this study. The subjects were only given two letter prompts with an interim task versus the 3 per session reported by Harrison and Horne (1997). Harrison and Horne reported discarding the first letter in each session as practice. Total duration of this task, including both letter prompts, was 2.5 minutes (including instruction time).

b) Verb Generation
Given a noun prompt, the Verb Generation task required subjects to produce related verbs. This task was used by Harrison & Horne (1998a) to examine word fluency in individuals deprived of sleep for 36 hours. Given a noun, subjects were asked to say aloud as many verbs as possible in 20 seconds. Subjects were given an example before testing, e.g. given 'apple', subjects may respond 'peel, eat, chew, bite, crunch, etc., and six noun prompts; pen, knife, shoe, cup, game, and cinema. This task had a duration of 4 minutes.

3.   Haylings Sentence Completion Task
This task required oral production and was subject paced.

Based on findings reported by Burgess & Shallice (1996), this task of language inhibition was used to test subject's abilities to resist negative priming. Burgess and Shallice (1996) reported patients with frontal lobe lesions had difficulty making incongruous responses to finish sentences with a highly predictable ending (>80%; Bloom & Fischler, 1980). Harrison & Horne (1998a) have reported a reduction in language flexibility for this task in individuals deprived of sleep for 36 hours. In the Haylings Sentence

Completion Task subjects were asked to produce spontaneous, unrelated endings to sentences that have strong conspicuous endings, such as: The children went outside to ____ . In the first section of the task, subjects were asked to respond with a congruent ending to 20 sentences, (e.g. At first she refused, then she changed her ____. The predicted ending of 'mind' has a >80% probability (Bloom & Fischler, 1980). In the second section of this task, subjects were asked to produce an incongruent response. It was stressed to the subject that the response should definitely not fit in with the overall meaning of the sentence (e.g. The gambler had a streak of bad ____. An example of a completely incongruent ending is 'telephone or elephant'). Subjects were given an example of each type of ending before the relevant section of the task. Total duration for this task was 12 minutes.

4. Temporal Memory (appendix 8)
This task was written and experimenter paced.

Subjects were given oral instructions to study two lists of faces, 12 faces in each list, separated by a distracter task (see Alternate Uses below). Following this, subjects were asked to recall whether they had seen the faces before when presented in a serial list amid 24 distracters. In addition, subjects were asked to determine whether they had seen the faces in the first or second list and their confidence about their answer. This task was based on the recognition and temporal memory task described by Parkin, Hunkin, and Walter (1995) in the ageing brain literature, and used by Harrison & Horne (1999b) with sleep deprived subjects. The protocol for the task was modelled after the Harrison & Horne description for task presentation. Total task duration for this task was 17 minutes.

f) Tasks Suspected of Executive Functioning Orientation
Based on descriptions of divergent thinking and executive functioning (e.g. Horne, 1988, Kolb & Wishaw, 1993; Goldman-Rakic, 1996) the following tasks were chosen for their potential executive functioning behaviour. The frontal lobe orientation of these tasks have not been verified with PET scanners however, they have been published as 'divergent thinking' tasks. They require subjects to accurately read or listen to instructions and to carry out those instructions in a given time limit. It is not known whether these tasks have a prefrontal cortical orientation, however they have been included as tasks that may be sensitive to sleep loss.

The following tasks required written production and were experimenter paced.

5. **Verbal Grouping/ Following Instructions** (appendix 9)
    This task was based on an aptitude test described by Pelshenke (1993) to test creativity and ability to follow instructions in normal individuals. The task was used to assess ability at recognising similarities and forming groups of similar words. Subjects were given written instructions to create coherent groups of three words from the list of 30 available and for each group created, to write an appropriate generic term for the group. Pilot testing was conducted to determine familiarity with the list of 30 words and use of an appropriate example. Subjects were provided with the example: PEN, PAPER, PENCIL - tools for writing.

    All of the words in the list provided were animal names, e.g. TROUT, HIPPO, MOUSE. Assigning a generic term to each group indicated the subjects' ability to articulate their perceptions of the similarities between the three words, distinct from the other 27 words given. In addition, the task required the subject to follow the instructions, particularly forming groups of a defined quantity. Task duration was 3.5 minutes.

6. **Picture Observation - answering questions** (appendix 10)
    This task was based on an aptitude test described by Pelshenke (1993) to measure attention to detail and to measure working memory, a prefrontal cortical behaviour. Subjects were given 30 seconds to study a black and white abstract picture with multiple foci depicted. They were then allowed 90 seconds to answer 10 'yes/no', quantity, or direction questions about the picture's details, such as 'How many crosses (+) were present in the picture?'. The production effort of this task is mixed recognition and recall. Task duration was 2 minutes.

7. **Fact Recall - Written Presentation, Written Production** (appendix 11)
    Pelshenke (1993) described a task in which participants read a fact-based passage and then related the facts in written form. This task is also a test of attention to detail and working memory, a prefrontal oriented behaviour. Schein (1957) reported difficulty of individuals to send and receive verbal messages of spatial location after 55h of sleep deprivation. Subjects were given a passage to

read for one minute, detailing names, ages, occupations, housing location, and family relations of four groups of people in a building. Following this, they had two minutes to write down as many facts as they could remember from the passage. The total number of facts present in the passage was 43. Subjects had two minutes to write as many facts as could be remembered. The production effort of this task is free recall only. Task duration was 3 minutes.

8. **Alternate Uses Test** (appendix 12)
This task was written and experimenter paced.

This task was based on the test described by Parkin & Lawrence (1994) to test spontaneous flexibility in the normal elderly. Subjects were instructed to consider six noun prompts (common objects: WOODEN PENCIL, CAR TYRE, EYEGLASSES, SHOE, KEY, BUTTON) in two presentations of three and told the most common use for those objects. They were then instructed to generate as many alternate uses as possible for the three words, given three minutes. This task was used as a measure of spontaneous flexibility, and also as a distracter task between the presentations for temporal memory items (see description above). Total task duration was 6 minutes.

g) Tasks assessing specific language function
There were additional tasks in this experiment used to assess specific language function during sleep loss and with countermeasures. For a description of these measures and their analysis refer to Chapter 5.

2.2 Procedure

All subjects were given KSS diaries and daily routine diaries following initial screening and were asked to report to the laboratory at 1700h the evening before testing to receive their actimeters and final instructions. Sleep deprived subjects were instructed to remain awake and to make half-hourly phone calls to the laboratory beginning at 2230h and to fill in the sleepiness diaries every hour during the sleep loss period. Control subjects were instructed to go to bed at 2300h and to rise at 0700h. All SD subjects phoned the lab every half-hour during the night while the control subjects did not phone between the hours of 2300h and 0700h, given that they were asleep. SD subjects were escorted to the laboratory at 0900h the morning of testing and were required to remain in the laboratory environment until the completion of the

study that evening. Upon arrival in the laboratory, their compliance with the protocol was checked with measurements taken from the actimeters, KSS diaries, Daily Routine Diaries, and the recordings of half-hourly phone calls. All subjects were asked if they had slept and the most difficult time they had with staying awake. Subjects reported they had to keep one another awake on occasion but that in one another's presence, staying awake was not overly difficult.

Following arrival in the laboratory, SD subjects were randomly assigned to the SD group or NAP group and were informed of their inclusion in either group at 1245h, 30 minutes prior to being escorted to their rooms for a two-hour nap opportunity. The NAP group were instructed to go to bed immediately upon arrival in their rooms and to remain in bed for the full two hour period. They were then escorted back to the laboratory and asked to remain there for the remainder of the study. Testing began approximately 2 hours following the completion of the sleep opportunity (approximately 1730h). All NAP subjects filled out a nap opportunity questionnaire to assess their ease and subjective experiences of sleep. Actimeter data was lost for 4 nap subjects (subject numbers 6, 7, 21, 28).

During the time in the laboratory, subjects were offered three separate set meals at 0930, 1230, and 1630h, and snacks of fruit and toast, and decaffeinated, low sugar drinks were available ad lib. All caffeine consumption was halted prior to 0900h.

Tasks presentation was randomised. During individual testing, subjects were alone in the experimental room. When not participating in individual testing, subjects remained together in a lounge room and were instructed not to discuss the tasks until the session was complete so that novelty was maintained. Data was collected for two other experiments but will be reported elsewhere (Coles, 1999; Hook, 1999). Subjects were instructed that they would be in the laboratory until 2200h on the second day and were not informed of the number of tests or the final test before the debrief session. This was to prevent the characteristic improvement in performance by improvement in mood towards the completion of the study. Haslam (1985a) reported an improvement in performance in military continuous operations towards the end of the operations due to improvements in mood and psychological outlook. Soldiers appeared to increase their compensatory effort when approaching the end of the study.

Following completion of individual testing, all subjects were debriefed and sleep deprived subjects were escorted home, and instructed to sleep immediately. They signed waivers acknowledging their sleepy condition and stating they would not engage in hazardous activities until having slept.

2.3 Results

Analysis for this experiment was conducted in two separate designs. Firstly, a one-way ANOVA design was used with three levels of sleep condition, Control, Sleep Deprived (SD), and Sleep Deprived with a Nap (NAP) as the factors. Unless otherwise stated, post hoc analysis was conducted using Tukey$_a$ HSD tests, in order to fix the error rate at $\alpha = .05$ for each of the possible null hypotheses. The one-way ANOVA and Tukey$_a$ combination was chosen for its conservative nature when testing multiple means. Secondly, an a priori comparison was planned to test differences between the Control vs. SD condition, and the SD vs. NAP condition. T-tests were conducted for the a priori comparisons, since the experimental hypothesis proposed that SD subjects would perform worse than Control subjects, and NAP subjects would perform better than SD subjects. Since only two comparisons were made, the Family Wise error rate would be a maximum of 0.10, because both comparisons were made at the $\alpha = .05$, which was deemed acceptable. As will be evident in the analysis, significance of the statistical findings is dependent on the test chosen. Since this experiment is looking for trends in the data, and is subject to individual differences, the more relaxed a priori comparisons may be the most useful.

For four of the tasks, the control group (N=31) has been derived by collapsing data from the three Control-placebo conditions (see Study 2 and 3 for further description) to help decrease error and have a more accurate measure for baseline performance. Since the Temporal Memory and Alternate Uses Tasks were not repeated in Studies 2 and 3, The Control group for those tasks have N=10. The remaining tasks have a control group N=22. Initially, collapsing the control data proved to be a dilemma because of its effect on the sample sizes for each variable measured. However, by examining the control data, it was obvious that any differences between the control performance were random occurrences (i.e. there were no significant differences between the sub-groups in the control sample) and therefore the data was collapsed together to provide a more substantial baseline group for comparison with the experimental manipulations.

2.31 Tasks Previously Reported Sensitive to Sleep Loss

1. Trail Making Task (Control Group N = 31)

This task was measured for time taken to completion (latency), and for number of errors (including number of lifts from paper and number of wrong direction lines on paper).

One-way Anova

There was a significant difference between the conditions for latency $(F (48, 2) = 3.70; p = .032)$ but not for error $(F (48, 2) = 1.89; p = .16)$. Post-hoc analysis indicated the SD group took longer to complete the task than the Nap group $(Tukey_a = -15.6, p = .031)$. Post-hoc analysis between the SD and control group approached significance, $(Tukey_a = -10.6, p=.08, **ns)$. There were no apparent differences between the Control and Nap latency. The mean number of trail making errors was very low, and not surprisingly, there were no differences. It appears from this analysis that SD individuals may be decreasing the rate of their performance in order to maintain accuracy.

A priori Comparisons

When using the t-tests, the control group were significantly faster at completing the trail making task than the SD group $(t = -2.04; p = .048)$ (See Figure 2.1). Similar to the findings of the ANOVA, the NAP group also performed better on latency to completion than the SD group $(t = 2.693, p = .015)$. There were no significant differences for number of errors, however the Levene's test for Equality of Variances indicated there was a significantly larger variance in the SD group data than the NAP data $(F = 15.66, p = .001)$. It must be noted that since the means are the same, by statistical convention, no significant difference between groups can be claimed, especially considering it is not known whether such a large standard deviation would have been present at a baseline non-SD testing for this group. It is worth noting however, that differences in variance should be addressed in all experimental manipulations and is particularly worthy of consideration in psychological testing (Haravon, Obler & Sarno, 1994).

Figure 2.1 Graph of Trail Making Latency for Sleep Condition

Table 2.3 Means and Standard Deviations for Trail Making Latency

LATENCY (SEC)		
	Mean	StDev
Control	51.5	13.5
SD	62.1	16.5
NAP	46.6	7.8

2. Word Fluency

a) 'L' Prompt and 'P' Prompt   (Control Group N = 22)

This task was measured for number of correct responses, and number of errors including repeats. While the test relies on selective access of information in long term memory through phonetic or semantic cueing (Harrison & Horne, 1997), this data was not analysed for semantic or phonetic similarity. Errors were defined as any proper nouns, any repeats, or any non-words. There were no significant differences between any of the groups for single letter prompt word fluency or word fluency errors on neither the one-way ANOVA analysis nor the planned comparisons. It was observed that most individuals used phonetic cueing, even repeating the sound made by the prompt letter in order to retrieve further words from their long-term memory. Frequently this use of phonetic cueing continued from one vowel sound to the next when the subject could not recall any further words with one vowel sound. A similar finding was reported by Harrison & Horne (1997) in their examination of sleep loss and speech. Subsequently, they used the Verb Generation task as a measure of word fluency because the single letter prompt appeared too easy for subjects.

It could be argued that measurements of correct responses and errors may only be measuring fatigue rather than executive functioning, and that perseveration is necessary to measure executive functioning. Qualitative analysis of the data did indicate some repeating of words (i.e. perseveration) which were included in the errors measure however, there were not enough errors to justify sub-dividing the error measurement into specific types.

b) Verb Generation   (Control Group N = 31)

The first two noun prompts were discarded as practice although subjects were not told that any of the noun prompts were practice. Data from the remaining four noun prompts were randomly transcribed and scored by two independent judges who were blind to the experimental condition of the subjects. The judges were instructed to score an error for responses that were not verbs or were verbs that did not relate to the noun given. Data from the final four noun prompts were pooled together for analysis. A reliability analysis on Inter-rater scoring indicated an $\alpha = .98$, and Pearson's correlation between scores was $r = .963$, $p < .01$).

One-way Anova

There was a significant difference between groups for number of correct verbs generated ($F(47, 2) = 4.42$, $p = .017$), and for number of errors ($F(48, 2) = 3.80$, $p = .029$) (See Figures 2.2 and 2.3). Post hoc analysis indicated the SD group generated fewer correct responses (Tukey$_a$ = -4.20) and more errors (Tukey$_a$ = 4.5) than the NAP group. Once again, there were no significant differences between the Control group and the NAP group performance. Surprisingly, contrary to the reports by Harrison & Horne (1998a) there was no statistical difference between the Control group and the SD group for this task, although the Tukey test indicated an approach to significance (Tukey$_a$ = -2.17, $p = .071$ **ns).

A priori Comparisons

The t-test analysis revealed control subjects generated more verbs than SD subjects at a level approaching significance ($t = 1.99$, $p = .054$, **ns). As was evident in the ANOVA, the NAP group generated significantly more verbs than the SD group ($t = -2.516$, $p = .022$). Levene's tests for equality of variances revealed that there was a significantly higher variability in the number of errors

produced by the SD group than the control group (F = 23.53, p < .001) and the NAP group (F = 13.94, p = .002) (see Figure 2.3)

Figure 2.2 Graph of Verb Generation Correct Responses

Verb Generation - Correct Responses

Table 2.4 Means and Standard Deviations for Verb Generation Correct Responses

VERBS/MIN		
	Mean	StDev
Control	10.8	2.7
SD	8.6	3.7
NAP	12.8	3.7

Figure 2.3 Graph of Verb Generation Errors (with Variability)

Verb Generation - Errors

Table 2.5 Means and Standard Deviations for Verb Generation Errors

ERRORS/MIN		
	Mean	StDev
Control	1.7	2.0
SD	4.9	8.0
NAP	0.4	0.4

3. Haylings Sentence Completion Task (Control Group N = 31)

Plausibility Analysis

Every sentence completion for this task was transcribed in random order and scored for plausibility by two independent judges blind to the experimental conditions of the subject. The following rating scale was used:

Answer	Score
Meaningful ending to the sentence	5
Related category to (5) - possible but less likely	3
Plausible ending to the sentence but unlikely	2
Sentence is grammatically correct with some connection between words, but overall meaning is lost or response classifies as slang	1
sentence is completely incongruent	0

An example was provided for the independent judges:

'The children went outside to....'

SWIM/PLAY	5
EAT/SIT	3
SLEEP	2
KILL THEMSELVES	1
DOG	0

Bloom & Fischler (1980) reported the response that rated 5 (e.g. play in the above example) was highly probably (0.85).

One-way Anova

In Section One, analysis for plausibility rating showed no difference between groups in their ability to give congruent endings to the sentences. Subjects averaged between 4-5 on plausibility, conforming to the responses or their synonyms predicted by

Bloom and Fischler (1980). Interrater reliability analysis indicated α = .90, Pearson's r = .83, $\underline{p}$ < .01. Judges' scores were averaged for analysis.

In Section Two, analysis of the errors (in this case a score above 0) indicated no significant differences between groups for the error score (F(47, 2) = 2.94, $\underline{p}$ = .063, **ns). While this analysis approaches significance, the findings of Harrison & Horne (1998a) that SD subjects have difficulty inhibiting the correct response cannot be confirmed with the one-way ANOVA and Tukey$_a$ combination. Interrater reliability analysis indicated α = .80, Pearson's r = .91, $\underline{p}$ < .01 . Judges' scores were averaged for analysis.

A priori Comparisons

T-tests indicated the expected no differences on scores for Section One, and similar no differences on Section Two, due to an inequality in variances. Levene's test for equality of variances indicated there was a significantly larger variance on the error scores for SD than Control (F = 6.37, $\underline{p}$ = .016), and on the variance of error scores when comparing SD and NAP (F = 8.7, $\underline{p}$ = .009) (See Figure 2.4 for illustration). While the trend indicates SD subjects produce more errors than Control subjects and NAP subjects, the significant increase in variance of the SD performance makes statistical confirmation of an experimental difference difficult.

Latency of Responses

The latency to responses was also measured for the Haylings Sentence Completion Task. Using a web version of Cool Edit^{TM} 98, latencies were measured between the final utterance of the experimenter's spoken prompt, and the first utterance given by each subject for their sentence completion. Auditory data were recorded onto a computer and graphically analysed using time differences between complex sound waves. Data were measured to a thousandth of a second, and the means taken for the 40 responses given by each subject, sub-grouped into Sections One and Two.

One-way Anova

In Section One, as expected, no difference was found between groups for latency to response in this task. However, no difference in latency for response was observed

for Section Two (F (48,2) = 2.88, p = .066, **ns), although differences between the SD and NAP group approaches significance, (Tukey$_a$ = -.883, p = .061, **ns).

A priori Comparisons

No differences were found on Section One, as expected. A t-test revealed a nearly significant difference between SD and Control performance on Section Two latencies (t = -1.77, p = .084, **ns), indicating SD subjects took longer to give a response. A t-test between the SD and NAP group indicated the SD group took significantly longer than the NAP group to give a response (t = 2.63, p = .017). Once again, it is evident that the choice of statistical test can have a profound effect on whether one argues no effect or a significant finding.

Figure 2.4a Illustration of Section Two Error Score

Haylings Sentence Completion - Error Score

Table 2.6 Means and Standard Deviations for Haylings Error Score

ERROR SCORE		
	Mean	StDev
Control	.51	.34
SD	.82	.59
NAP	.44	.24

Figure 2.4b Illustration of Section Two Latency to Response

Haylings Sentence Completion - Latency

Table 2.7 Means and Standard Deviations for Haylings Latency (Part II)

LATENCY (SEC)		
	Mean	StDev
Control	1.6	0.9
SD	2.2	0.9
NAP	1.3	0.6

4. Temporal Memory (Control Group N = 11)

This task was analysed for delayed memory recognition by number of correct positive identifications (hits), number of incorrect positive identifications (false alarms), an error score (hit rate- false alarm rate). The temporal memory component of this task was identified by an accuracy score called z sensitivity (Parkin, 1995; Harrison & Horne, 1999b). This score accounts for the increase in an accurate temporal memory (recency) when fewer faces are recognised. In addition to this, subjects rated their confidence on the recency discrimination, and this was analysed for confidence on correct judgements and confidence on errors.

One-way Anova

There were no significant differences for delayed memory recognition, measured by hits (F $(27, 2)$ = 2.55, p = .097, **ns), false alarms, or the error score. This is similar to the findings reported by Harrison & Horne (1999b). In contrast to their report, however, there were no differences between groups for the z-sensitivity (F $(27, 2)$ = .54, p = .59, **ns) (See Figure 2.6a for illustration).

A t-test was used to determine if there was a difference on confidence for correct and incorrect recency judgements. It was found that generally, all subjects rated their confidence higher when they were correct than when they were not $(t(29) = 9.69, p < .001)$. There were no differences between groups, however, when assessing their confidence on correct responses or on incorrect responses. On correct responses subjects had a mean rating of 3.95 (SD = .54) and on incorrect responses, a mean rating of 2.96 (SD = .72). This finding also differed from the findings of Harrison & Horne (1999b) in which SD subjects rated their confidence higher than controls when judging both correct and incorrect responses.

A priori Comparisons

The planned t-tests indicated SD subjects generated significantly more hits than control subjects $(t = -2.15, p = .045)$ (See Figure 2.5). No differences were apparent between SD and NAP subjects. No differences were apparent on the measures of false alarms, error score, or z-sensitivity. No differences were found for confidence judgements (See Figure 2.6 for illustration).

Figure 2.5 Temporal Memory - Number of Hits

Table 2.8 Means and Standard Deviations for Temporal Memory Hits

NUMBER OF HITS		
	Mean	StDev
Control	20.3	2.2
SD	22.1	1.4
NAP	21.8	2.0

Figure 2.6a Temporal Memory - Illustration of z-sensitivity (Note non-significant finding)

Temporal Memory z-sensitivity

Table 2.9a Means and Standard Deviations for z-sensitivity

Z-SENSITIVITY		
	Mean	StDev
Control	2.38	0.7
SD	1.93	1.5
NAP	2.30	0.8

Figure 2.6b Temporal Memory - Illustration of Confidence Score for Correct Answers

Temporal Memory Confidence on Correct Answers

Table 2.9b Means and Standard Deviations for Confidence Scores on Correct Judgements

CONFIDENCE SCORES		
	Mean	StDev
Control	4.15	0.4
SD	3.71	0.6
NAP	3.98	0.6

(Note non-significant finding)

2.32 Tasks Not Previously Reported in the Sleep Literature

1. Memory Recall for Facts (Control Group N = 31)

In this reading task of a short fact-based passage, followed by written immediate memory recall in two minutes, measurements were made for total number of facts given, and for number of errors (i.e. incorrect facts). No differences were found for either correct facts or errors, for both the one-way ANOVA and the planned comparisons. The mean number of correct facts presented was 9.9 (SD = 5.4), while the number of errors was 2.6 (SD = 2.3).

2. Verbal Grouping/Following Instructions (Control Group N = 22)

This task was measured for number of groups of three created from the list of 30 available nouns and for the number of definitions given for the groups of three created. Again, no differences were found between groups on this task either for number of groups created or number of definitions created, using both a priori comparisons and a one-way ANOVA. It was observed that this task required subjects to accurately read the instructions. While some people properly created groups of three, others failed to read the instructions carefully and organised the list into three groups. This finding was not specific to any sleep condition. The time limit imposed and the right vs. wrong way of completely this task suggests that it may be one of convergent, versus divergent thinking, and therefore would not be expected to be sensitive to sleep loss.

3. Picture Observation - Answering Questions (Control Group N = 22)

This task involved studying a detailed, abstract drawn picture for 30 seconds and subsequently answering questions about the picture without having the picture available. Measurements were made for number of correct responses and for number of errors (wrong answers). No differences were observed on this task either, using both a priori comparisons and one-way ANOVA. The small number of questions and the time limit imposed seemed more suited to testing individual differences on accurate observation than effects of sleep loss.

4. Alternate Uses Test   (Control Group N = 11)

This task was used as a distracter during the temporal memory test (described above) and was measured for number of alternate uses generated. No significant differences were found between sleep condition for this task (F(27,2) = 2.24, p = .126, **ns), when measured with one-way ANOVA. When using planned comparisons, however, control subjects generated significantly more alternate uses than the SD group (t = 2.26, p = .041) (See Figure 2.7). Since Levene's test for equality of variance indicated a significant difference in the variances between the Control and SD groups for this task (F = 5.6, p = .029), the t-test reported was calculated without the equal variances assumption. Once again, differences are apparent between the conservative one-way ANOVA and the more flexible a priori comparisons.

Figure 2.7 Alternate Uses - Number of Uses

Table 2.10 Means and Standard Deviations for Alternate Uses

NUMBER OF USES	Mean	StDev
Control	19.6	7.8
SD	13.3	4.2
NAP	15.2	7.8

2.33 Subjective Overnight Sleepiness

Scores on the Karolinska sleepiness scale are shown in Figure 2.8 for the SD and Nap group from 2300h the night before testing, until 0900h the morning of testing. Note the increase in sleepiness between 0400 - 0700h (See Figure 2.8).

Figure 2.8 Graph of Subjective Overnight Sleepiness

Karolinska Sleepiness Rating

Time

2.34 Estimated Nap Sleep

Subjects reported mean sleep time was 1h 35min (SD = 18 min), with a mean latency to time asleep as 12 min (SD = 14 min). Subjects rarely awoke during their sleep period (mean number of awakenings = .40, SD = .52). On a 4-point scale of how rested they felt with 0 = not rested at all and 4 = very rested, the mean response from the NAP group was 3.1 (SD = .57). On a 3-point scale for difficulty falling asleep, subjects reported moderate difficulty (mean = 1.4, SD = .52), and on a 4-point enjoyment scale of the sleep period (0 = no enjoyment, 4 = much enjoyment), the mean response was moderate (mean = 2.0, SD = .67). Karolinska sleepiness ratings during the day are shown in Figure 2.9 for both the SD and NAP group.

Actimeter analysis indicated a mean sleep time of 1h 38 min (SD = 7 min). The mean number of awakenings for the nap group was 2.25. For two of the nap subjects, their awake time lasted for 24 minutes although for all subjects. Refer to Appendix 13 for an example of the actimeter printouts for Nap sleep.

Figure 2.9 Subjective Sleepiness during the day of NAP & SD subjects

2.35 Subjective Sleepiness During Testing

Subjective sleepiness during the test period was measured every 15 minutes. Results are shown in Figure 2.10. As is evident, the NAP group was more alert during testing than the SD group (t (18) = 2.50 p = .022).

Figure 2.10 Subjective Sleepiness During Testing

2.4 Discussion

While there are many good reasons why every effort should be made to minimise the number of Type I Errors in any statistical analysis, it is also important to remember that Type II Errors exist and can also have an effect on conclusions drawn from a study. It is important for the experimenter to look at the means and variance of the raw data to determine whether an effect is evident, and if that effect has a bearing on the hypothesis and theory behind the phenomena being studied. In this instance, when considering all of the evidence as a whole, it is possible to state that there is a decline in performance following 36 hours of sleep loss that can be overcome with a 90-minute nap.

Therefore, a first cycle nap opportunity (90 minute period) in the afternoon circadian dip, is sufficient to overcome the effects of 36 hours of sleep loss on short-duration, executive functioning tasks. This finding is comparable to the literature measuring performance on simple cognitive tasks (Haslam, 1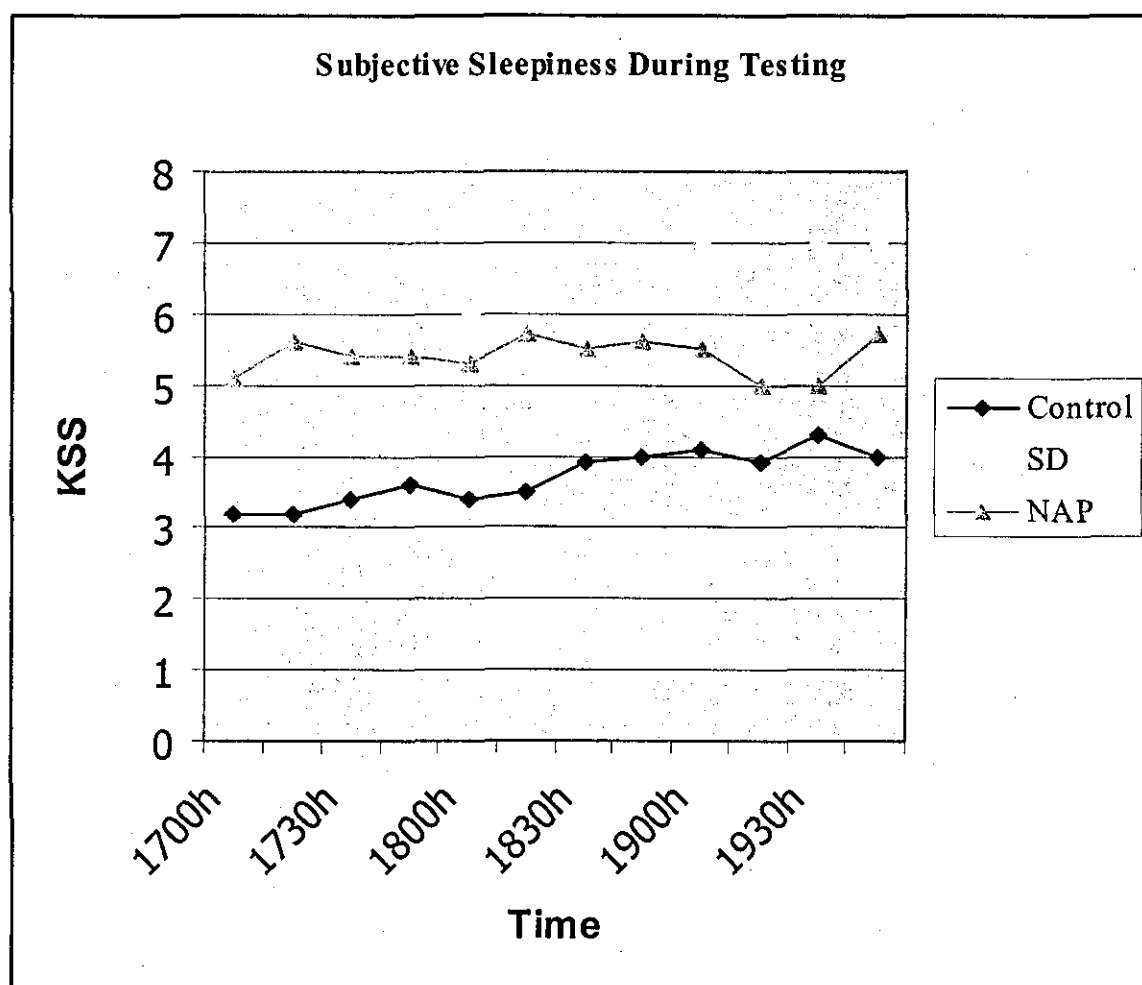985; Dinges et al., 1987; Bonnet, 1991). This result was observed on tasks that were previously reported to be sensitive to sleep loss at 36 hours. The sleep architecture of the nap cannot be confirmed, but it is suspected that the nap would be dominated by slow wave sleep, due to the sleep pressure built-up in the preceding 31 hours without sleep. Experimenter observations at the conclusion of the study indicated nap subjects were interacting with their peers and did not show outward signs of sleepiness. Two nap subjects commented on how good they felt at the completion of the study, even though the sleep inertia following the nap had negatively effected their mood prior to testing.

A surprising finding of this study was that not all of the tasks that have previously been documented as sensitive to sleep loss displayed statistical significant sensitivity in this study. When the statistical effects were observed, they were not profound. When compared to tasks that show a hypersensitivity to sleep loss, i.e. vigilance reaction time (e.g. Dinges & Kribbs, 1991; Dinges et al., 1992), the executive functioning tasks used in this study display relatively minor effects of sleep loss. It could be that 36 hours is the beginning of the critical period in which the effects of sleep loss become apparent on the complex, executive functioning tasks, which is why the findings from this study may have differed from the results discussed by Harrison

& Horne (1998a). It is also believed, however, that boredom effects can still have an effect on performance, even when the tasks are short, novel, and stimulating.

Researchers have made attempts to explain deficits on frontal –type tasks as 'cognitive slowing', which, while a valiant attempt, could be considered a spurious argument. "When any body organ fails through, illness, overwork, aging etc, one could explain these changes in terms of a generalised "slowing down" or becoming "less efficient" in some way. But this is a rather superficial explanation, as there are invariably components of these organs that malfunction or deteriorate in qualitatively different ways, leading to the overall slowing down. That is, some components remain working normally whilst others do not. In view of the great diversity in the structure and function of brain tissue it is reasonable to propose that there are some regions more affected by sleep loss and that these differences might be qualitative, rather than quantitative. We have argued that as the PFC is probably the hardest working cortical area during wakefulness, then it may be more vulnerable to sleep loss, if sleep provides a specific recovery from the effects of wakefulness. Despite their best efforts to compensate, and working at their own speed, sleep deprived participants still show impaired performance at PFC tasks. Thus while the "cognitive slowing" hypothesis might argue that during SD this slowing is simply greater in the PFC, it does not adequately explain why sleep deprived people can not compensate if they work at their own pace, as seems to be the case for less PFC oriented, rule-based tasks." (Horne, 2000)

In the Harrison & Horne studies reporting sensitivity to sleep loss, subjects were cloistered in the laboratory for the 48 hour period with the exception of the control group being escorted to their own beds for an 8h sleep opportunity during the interim night. SD subjects remained in the laboratory during that time and throughout the second day, a situation that obviously would promote high levels of boredom and potential restlessness. In contrast, during this study, subjects did not report to the laboratory until the morning of the second day. SD subjects remained in their own environment, in pairs or groups, and were monitored with alternate methods (see methodology for description). This difference in experimental protocol could have a significant effect on the subjects' outlook to the study and their approach to the tests. While attempts to make the tasks short, novel, and interesting, and motivate the

subjects with incentives and encouragement are commendable, these countermeasures may not be sufficient to overcome the boredom effects of laboratory confinement for 48 hours. In fact, the differences between SD and control performance in the tasks they have reported may be exaggerated by the Control group being allowed to leave the laboratory environment and engage in other activity. Normal bedtime routines, such as brushing teeth, chatting with housemates, etc. may be helpful in combating the boredom associated with laboratory confinement, thereby increasing the difference between SD and Control performance.

The significant findings observed in this study and the trends towards SD impaired performance on other tasks, suggest that executive functioning is indeed, affected by sleep loss. In addition, if the test length were increased, or if test time delayed to 40 hours and beyond, it is not known if the nap would have similar benefits. Furthermore, it is not my intention to suggest that a 2-hour nap is sufficient for executive functioning optimal performance in normal human rest-activity cycles. That statement cannot be made based on the evidence provided from this study. The evidence from this study does suggest however, that a nap is sufficient at overcoming the effects of 36 hours of sleep loss for short-duration executive functioning tasks.

It was not the intention of this thesis to group all tests together as a battery and I planned the data collection such that subjects were not repeatedly administered tests. In this regard, the tests are examined individually and have not been grouped as a battery for conclusions.

27 Hours without Sleep & Caffeine as a Countermeasure

2.6 Method

2.61 Subjects

Participants were forty-four volunteer subjects, 29 women and 15 men, aged between 19 and 28 (mean age = 20.9, $\underline{SD}$ = 1.6), who were selected from respondents to advertisements in a biological psychology class and around campus at Loughborough University, UK. One female participant was removed from the study due to illness. She was replaced through further recruitment.

2.62 Design

The subjects were randomly allocated to one of four conditions, each consisting of eleven subjects. The four conditions were:

1. sleep deprived with caffeine [SD-Caffeine]
2. sleep deprived with placebo [SD]
3. control with caffeine [Ct - Caffeine]
4. control with placebo [Ct]

Table 2.11 Four experimental conditions with both genders

	Caffeine	Placebo
Control	11 subjects W: 8 M: 3	11 subjects W: 9 M:2
Sleep Deprived	11 subjects W:6 M:5	11 subjects W: 6 M: 5
Reminder: In statistical analysis, all control subject data has been pooled such that the control group results are the same for each set of analyses in this chapter.		

W = women; M = men

The independent variables included:

a) Alert Conditions   - 2 levels - SD vs. Ct

b. Caffeine   - 2 levels - C vs. NC

Table 2.12 Independent Variables

CONDITION	
Sleep Deprived (SD)	**Control (Ct)**
Arose at 7am 27 hours before testing session Did not sleep between arousal time and testing session During testing session, subject had been awake for 27.5 - 30 hours	Arose at 7 am 27 hours before testing session Sleep opportunity from 11pm to 7am night before testing session During testing session, subject had been awake for 3.5 - 6 hours

CAFFEINE DOSE	
Caffeine (C)	**Placebo (NC)**
• Drank 1 cup of decaffeinated coffee/tea immediately upon arrival in testing laboratory • Cup contained 200mg caffeine tablets, ground • Subjects were unaware of added caffeine • Caffeine was administered double blind • Testing began 30-40 minutes after intake to allow for caffeine absorption	• Drank 1 cup of decaffeinated coffee/tea immediately upon arrival in testing laboratory • Cup contained 0 mg caffeine • Subjects were unaware of no added caffeine • Placebo was administered double blind • Testing began 30-40 minutes after intake to maintain blind testing conditions

2.63 Materials

a)   Screening forms

The mean score on the Epworth Sleepiness Scale was 6.4 (SD = 3.2) with a range of 1 to 15 on a 24 point scale measuring daytime sleepiness in adults. Similar to Experiment 1, all participants were assessed as being moderate to good sleepers as determined by the Sleep Pattern Questionnaire (Monroe, 1967; see appendix 3). Daily routine was assessed for 48 hours prior to study to ensure compliance with the protocol and suitability for testing. The Health Questionnaire indicated that all subjects were in fair to excellent health. Of the forty-four participants, 5 were casual smokers and the remaining 39 were non-smokers. All participants were moderate caffeine drinkers.

b)   Actimeters

Subjects wore ambulatory activity monitors (for description see 2.13b) to assess their compliance with the protocol beginning at 2000h the night before testing and continuing through until testing commenced.

c)   Questionnaires

Questionnaires administered included the Karolinska Sleepiness Scale (KSS) (for description see 2.13c) (appendix 4). SD subjects rated their subjective sleepiness every half-hour from 2200h to 0800 hr during the interim night and all subjects rated their sleepiness every twenty minutes from 1000h until the conclusion of the study. The Epworth Sleepiness Scale (ESS) and the Sleep Pattern Questionnaire (for descriptions see 2.13c) (appendix 5& 3) were also measured to determine suitability for testing and prior sleep habits.

c)   Apparatus

The tasks used were the same as those described in Experiment 1 (refer to 2.13e & 2.13f for description) with the exception of two deletions, the Temporal Memory task and Alternate Uses Test

Caffeine, in the form of crushed and dissolved ProPlus^{TM} tablets, was administered in 250 mL quantities of decaffeinated coffee or tea. For the caffeine condition, 4 tablets equalling 200 mg Caffeine Anhydrous Ph. Eur., were dissolved in the drink.

2.7 Procedure

All subjects reported to the laboratory at 1700h the evening before testing to receive their actimeters and final instructions. Sleep deprived subjects were instructed to remain awake and to make half-hourly phone calls to the laboratory beginning at 2230h and to fill in the sleepiness diaries every hour during the sleep loss period. Control subjects were instructed to go to bed at 2300h and to rise at 0700h. All subjects reported to the laboratory to morning of testing at 1000h. Sleep subjects were escorted to and from the laboratory for their own safety and were required to sign declarations stating they understood they had undergone a period of sleep deprivation and were not to engage in any activities which may bring harm to themselves or others until they had slept. All SD subjects were instructed to sleep immediately upon returning home.

Following arrival in the laboratory, subjects were randomly assigned to the caffeine or placebo group and were given cups of coffee or tea to drink. Testing began 30-40

minutes following consumption of the drink in order to allow the caffeine to have an effect on the CNS.

Tasks were randomised, although the written tasks administered en masse were conducted before the individual testing. During individual testing, subjects were alone in the experimental room. When not participating in individual testing, subjects remained together in a lounge room and were instructed not to discuss the tasks until the session was complete so that novelty was maintained.

In order to motivate the participants to perform well throughout the testing session, a competitive reward was offered to the individual who had the best score on the task measures and all participants were advised to put as much effort as possible into each task. The competitive reward was also offered to the control subjects.

Following completion of individual testing, all subjects were debriefed and sleep deprived subjects were escorted home.

2.8 Results

Analysis is in a 2 x 2 Between Subjects Factorial ANOVA design with sleep condition and caffeine dose as the independent factors. For four of the tasks, the control-placebo group (N=31) has been derived from collapsing data from the three Control-placebo samples from studies 1,2 & 3 (see Study 1 and 3 for further description). As previously stated on Page 51, there were no significant differences between the sub-groups in the control sample. Unless otherwise stated, post-hoc analysis was conducted using Tukey$_a$ test. The alpha level for this experiment was set at .05.

2.81 Tasks Previously Reported Sensitive to Sleep Loss

1. Trail Making Task   (Control Group N = 31)

Analysis showed no differences between sleep condition or caffeine dose for this task on either latency to completion or number of errors. Mean latency for this task was 52.2 sec (SD = 14.4).

2. Word Fluency

a) 'L' Prompt and 'P' Prompt (Control Group N = 22)

Analysis indicated no significant differences for the number of words for either sleep condition or caffeine dose. Analysis of the errors revealed that SD subjects had more errors than Control subjects (F = 19.93, p = .002). There was no effect of caffeine on number of errors and no apparent interaction.

Figure 2.11 Graph of Word Fluency Errors for Condition

Word Fluency

Table 2.13 Means and Standard Deviations for Word Fluency Errors

NUMBER OF ERRORS		
	Mean	StDev
Control	2.2	2.6
SD	5.0	3.7

In an attempt to conduct a more accurate measure of performance on this task, a third dimension was measured involving subtracting the number of errors from the number of correct responses. This measure was not significant between conditions.

b) Verb Generation   (Control Group N = 31)

Analysis was conducted separately for number of verbs generated and number of errors produced. There was a significant interaction of verbal fluency on this task $(F(59,1) = 14.3, \underline{p} < .001)$. Post hoc analysis indicated the control group generated more correct words than the control-caffeine condition (Tukey$_a$ = 3.78, $\underline{p}$ < .01) and the SD condition (Tukey$_a$ = 3.57, $\underline{p}$ < .05). There was no difference between the Control group and the SD-Caffeine group (See Figure 2.12). This task indicated that Caffeine appears to be hindering Control performance while improving SD performance of verbal fluency.

Figure 2.12a Graph of Word Fluency - Verb Generation Correct Responses

Verb Generation Fluency

Table 2.14 Means and Standard Deviations for Verb Generation

VERBS GENERATED		
	Mean	StDev
Ct - Caffeine	7.0	3.9
Ct - Placebo	10.8	2.7
SD - Caffeine	10.2	3.9
SD - Placebo	7.2	3.9

It is important to compare number of correct responses with number of errors produced when determining the effects of caffeine. Analysis indicated a significant difference between caffeine groups for number of errors produced ($F(60,1) = 4.8$, $p = .032$) (see Figure 2.13), but no effect of sleep condition and no interaction. In assessing the results together, it appears caffeine is having an effect on verb generation verbal fluency by decreasing the number of correct responses and increasing the number of errors for the Control condition. In addition, on number of correct responses, caffeine appears to be aiding SD performance. Overall, decreases in verb generation verbal fluency at 27 hours without sleep are countered by the effects of caffeine at that time.

Figure 2.13 Graph of Word Fluency - Verb Generation Errors

Verb Generation Errors

Table 2.15. Means and Standard Deviations for Verb Generation Errors

NUMBER OF ERRORS		
	Mean	StDev
Placebo	2.0	2.6
Caffeine	4.0	3.1

3. Haylings Sentence Completion Task   (Control Group N = 31)

In Section One, no differences were observed between groups on correctness of their response. Generally, subjects had a mean score between 4 and 5 on the 5-point scale (See Figure 2.14a for illustration). Unexpectedly, there was an effect of sleep condition on the latency for responses in Section One ($F(54, 1) = 11.4$, $p = .001$) (See Figure 2.15a). Computer recordings were impaired for five subjects' responses hence their data is not included in this latency. The slowing of SD subjects' performance is an indication of generalised sleepiness following 27 hours without sleep.

In Section Two, there was also no significant difference between sleep condition or caffeine for giving an unrelated response. This is in contrast to the findings reported by Harrison & Horne (1998a). Most subjects averaged a score of between 0 - 1.5 on the 5-point scale (See Figure 2.14b for illustration). Note errors are scores above 0. There was a significant effect between of sleep condition for latency on Section Two ($F (54, 1) = 5.67$, $p = .021$) (see Figure 2.15b), and a significant interaction between sleep condition and caffeine. The SD group took significantly longer to give a response than the Control group ($Tukey_a = 1.14$, $p < .005$) and Control - Caffeine

groups (Tukey$_a$ = 1.09, p < .05). (See Figure 2.16). Note from the graph that, while not significant, caffeine appears to be aiding SD performance by speeding up the response time, without increasing error. The findings for Haylings Sentence Completion Tasks suggest there is a general decline in speed of processing or speaking following 27 hours without sleep, rather than a specific effect of inability to inhibit negative priming. This decrease in speed appears to be reversed to some degree by Caffeine.

Figure 2.14a Graph of Haylings Sentence Completion - Illustration of Correct Score (Section One) (Note non-significant findings)

Table 2.16a Means and Standard Deviations for Haylings Correct Score - Section One

CORRECT SCORE		
	Mean	StDev
Control	4.9	0.2
SD	4.9	0.1

Figure 2.14b Graph of Haylings Sentence Completion - Illustration of Error Score (Section Two) (Note non-significant findings)

Table 2.16b Means and Standard Deviations for Haylings Error Score - Section One

ERROR SCORE		
	Mean	StDev
Control	0.5	0.3
SD	0.6	0.3

Figure 2.15a Graph of Haylings Sentence Completion - Latency for Section One

Latency to Response - Section One

Table 2.17a Means and Standard Deviations for Haylings Latency - Section One

LATENCY (SEC)		
	Mean	StDev
Control	0.91	0.26
SD	1.23	0.45

Figure 2.15b Graph of Haylings Sentence Completion - Latency for Section Two

Latency to Response - Section Two

Table 2.17b Means and Standard Deviations for Haylings Latencies - Section Two

LATENCY (SEC)		
	Mean	StDev
Control	1.58	0.88
SD	2.34	0.97

Figure 2.16 Graph of Haylings Sentence Completion - Latency for Section Two Interaction

Table 2.18 Means and Standard Deviations
for Haylings Latencies - Section Two
Interaction

LATENCY (SEC)		
	Mean	StDev
Ct - Caffeine	1.61	0.87
Ct - Placebo	1.57	0.89
SD - Caffeine	1.76	0.52
SD - Placebo	2.71	1.03

2.82 Tasks Not Previously Reported in the Sleep Literature

1. Verbal Grouping/Following Instructions   **(Control Group N = 22)**

Analysis of this task indicated a significant effect of sleep condition for creating coherent groups ($F(51, 1) = 25.7$, $\underline{p} < .001$) and on giving definitions to those groups ($F(51,1) = 24.4$, $\underline{p} < .001$) (See Figure 2.17). No significant effects of caffeine were observed on this task, and no interactions were apparent. The significant differences are attributable to the SD subjects inability to correctly read and obey the instructions. This was evident from subjects' statements following the task debrief in which they stated they had not read/understood the task instructions properly. Performance on this task was typically a score of 4 or a score of 0, with very few intermediate scores, indicating comprehension of instructions or failure to understand the instructions. This is possibly a result of the SD subjects increasing the speed with which they read the instruction passage, and thereby a decrease in the accuracy of their reading. As was indicated in the analysis of this task for the 36h-sleep deprivation session, this task is susceptible to large individual differences in performance. Following analysis of the instructions and patterns in responding, I attributed the errors as resulting from a misunderstanding of the instructions. Sleep deprived subjects often interpreted the phrase, "...put into sensible groups of three and write the appropriate generic term next to the groups.", as 'create three groups of words and label'. An example was provide for the subjects which contained three words in a group, followed by a label for the group.

Figure 2.17a Graph of Creating Coherent Groups

Table 2.19a Means and Standard
Deviations for Creating Word Groups

NUMBER OF GROUPS		
	Mean	StDev
Control	3.8	1.7
SD	1.5	1.6

Figure 2.17b Graph of Creating Coherent Definitions for Groups

Table 2.19b Means and Standard
Deviations for Creating Definitions

NUMBER OF GROUPS		
	Mean	StDev
Control	3.8	1.7
SD	1.5	1.7

2. Picture Observation - Answering Questions   (Control Group N = 22)

Analysis indicated a significant main effect on this task for number of correct responses (F (51,2) = 3.2, $\underline{p}$ = .049). Analysis also indicated significant main effects of condition (F (51,1) = 4.1, $\underline{p}$ = .049), caffeine (F (51,1) = 6.9, $\underline{p}$ = .012) (See Figure 2.18a,b) and an approach to significance on the interaction (F (51,1) = 3.3, $\underline{p}$ = .073, **ns) (See Figure 2.18c for illustration). The analysis indicates a detrimental effect of caffeine, possibly by increasing agitation, and a detrimental effect of sleep loss, indicating a generalised sleepiness.

Figure 2.18a Graph of Errors in Picture Observation: Condition

Table 2.20a Means and Standard Deviations for Observation Errors

NUMBER OF ERRORS		
	Mean	StDev
Control	0.6	4.5
SD	3.3	2.7

Figure 2.18a Graph of Errors in Picture Observation: Caffeine Dose

Table 2.20b Means and Standard Deviations for Observation Errors

NUMBER OF ERRORS		
	Mean	StDev
Placebo	0.4	4.5
Caffeine	3.6	2.3

Figure 2.18c Graph of Interaction: Errors in Picture Observation

Interaction: Observation Errors

Table 2.20c Means and Standard Deviations for Observation Errors

NUMBER OF ERRORS		
	Mean	StDev
Ct - Caffeine	3.5	2.5
Ct - Placebo	0.9	4.6
SD - Caffeine	3.7	2.1
SD - Placebo	2.9	3.2

3. Memory Recall for Facts   (Control Group N = 31)

Analysis indicated no differences for sleep condition or caffeine dose for number of correct facts recalled, nor for number of errors. Upon debrief, subjects indicated the difficulty of this task due to the memory load and not knowing how it was going to be assessed when they were instructed to read the passage.

2.83 Subjective Overnight Sleepiness

Analysis of the overnight subjective sleepiness ratings for all of the SD subjects showed the expected trend of increased sleepiness overnight. The mean sleepiness rating at 2230h was 2.6 (SD = 0.9), while the mean sleepiness rating at 0800h was 6.5 (SD = 2.5) (See Figure 2.19).

Figure 2.19 Trend Graph of Overnight Sleepiness

Karolinska Sleepiness Rating

2.84 Subjective Sleepiness During Testing

The Subjective Sleepiness during testing (See Figure 2.20) indicated that SD subjects who received caffeine had a decrease in subjective sleepiness over the testing period. The Control subjects who received caffeine also appeared to have a decline in their subjective sleepiness.

Figure 2.20 Trend Graph of Subjective Sleepiness During Testing

2.85 Actimeter Measurements

Analysis of Actimeter recordings and overnight sleep recordings indicated the SD subjects remained awake while the Control subjects had a normal night sleep. Refer to appendix 13 for sample actimeter outputs of overnight SD activity versus Control activity, and daytime awake versus Nap activity.

2.9 Discussion

The question of whether sleep deprivation has a distinct impact on frontal-lobe type tasks or those previously defined as divergent thinking appears to be more suited to sometime after 30 hours without sleep. The findings of 27 hours without sleep using 200mg of caffeine as a countermeasure suggest that there are no Specific Effects of sleep loss on Executive functioning activity after 27 hours without sleep, effectively one night of sleep loss. In addition, the findings indicate that caffeine has a differential effect on SD performance, sometimes aiding and sometimes hindering it. The findings do indicate the expected decrease in alertness, increase in subjective sleepiness, and a slowing of performance following 27 hours without sleep, all Non-Specific Effects of sleep loss.

The effects of caffeine observed in this study are similar to the Yerkes-Dodson (1908) hypothesis that there is an optimum level of arousal for successful functioning on tasks, depending on the task difficulty level. The occasional effect of 200mg caffeine on Control performance was unexpected. Much cognitive information to date supports the Yerkes-Dodson (1908) Inverted-'U' relationship, in which a negative quadratic relationship is predicted between arousal and performance. In addition, the 'task difficulty' hypothesis suggests a lower level of arousal is necessary for optimal performance on more difficult tasks than easier tasks. However, recent studies have challenged this hypothesis with evidence of observed linear arousal-performance relationships (Neiss, 1988 from Watters, Martin, & Schreter, 1997). Watters et al. (1997) reported findings in three tasks of basic cognitive procedural ability in the alphanumerical domain which supported the inverted 'U' hypothesis for arousal resulting from 0-600 mg caffeine dosage. They did not find support for the 'task difficulty' hypothesis.

The findings of this study are consistent with the inverted-'U' hypothesis on some of the tasks in that very high arousal (the Control-Caffeine condition) and very low arousal (the SD- Placebo condition) inhibit performance while moderate arousal (control - placebo and SD-Caffeine) promotes optimum performance. The findings further suggest that performance inhibition can arise from relatively low levels of caffeine when taken at high arousal times in the circadian cycle. The effect of caffeine in this study appeared to be an increasing speed in processing and

performance and occasionally, with the increasing speed a decreasing accuracy. The 200 mg caffeine dose was not expected to have an effect on executive functioning performance. However, since the finding was detected a literature search provided comparable results. Caffeine has also been reported to have negative effects on young, alert adults on the speed of searching short-term memory (Hogervorst, Riedel, Schmitt et al., 1998). The findings of caffeine on control performance were unexpected and therefore repeated in a follow-up study to test the effect of increasing caffeine dose on alert subjects (See Experiment 3).

There were obvious individual differences in performance on all tasks. Some SD individuals appeared to not be affected by the sleep loss at all, while others had great difficulty maintaining concentration. In addition to this, individual differences in response to caffeine were present, with some individuals responding well, becoming more alert, focussed and able to concentrate. Others responded poorly by becoming overly excited, restless and unable to concentrate. It has been stated before that Individual Differences is an area of sleep loss yet to be explored. The findings of this study suggest these differences should be documented soon in order to advance the information available about the effects of sleep loss, and who is better at responding to sleep loss. In addition, the variable response of different subjects to caffeine in both the Control and SD conditions indicate that caffeine should be excluded from any study hoping to examine the effects of sleep loss solely. As a countermeasure to sleep loss used along side, novel tests, motivation, shortness of tasks, it should be excluded due to its own undocumented individual effects. In applied conditions, it appears that caffeine will aid SD performance on executive functioning tasks however caffeine alone may have a detrimental effect on performance (See Experiment 3 for further analysis).

In summary, the findings from this study prompted further work regarding the effects of caffeine on cognitive tasks. There does not appear to be a significant effect on short response language skills at this time of the day when reviewing performance on all tasks, however, sleep deprived individuals are beginning to show a deterioration in functioning, e.g. the memory processes of the picture observation task. As memory is a complex cognitive task, contributing heavily to the central executive, it in itself warrants further research.

Effects of Caffeine without Sleep Loss

A follow up study was conducted on the effects of caffeine on four executive functioning tasks in the late morning, to assess the effects caffeine alone has on tasks of complex cognition. According to the Yerkes-Dodson Hypothesis, there should be an Inverted 'U' effect of arousal, and a linear task difficulty effect of arousal. This study aimed to test that hypothesis.

2.10 Method

2.101 Subjects

Participants were 27 volunteer subjects, 15 women and 12 men, with a mean age = 21.1 (SD = 4.9), who were selected from respondents to posters around campus at Loughborough University, UK.

2.102 Design

The subjects were randomly allocated to three caffeine conditions, each consisting of 9 subjects. The three conditions were:

> 0 mg caffeine
>
> 100 mg caffeine
>
> 200 mg caffeine

Reminder: *In statistical analysis, all control subject data has been pooled such that the control group results are the same for each set of analyses in this chapter.*

2.103 Materials

a)   Screening forms

The mean score on the Epworth Sleepiness Scale was 6.7 ($\underline{SD}$ = 3.6) with a range of 1 to 13 on a 24 point scale measuring daytime sleepiness in adults. Similar to Experiment 1, all participants were assessed as being moderate to good sleepers as determined by the Sleep Pattern Questionnaire (Monroe, 1967; see appendix 3). The Health Questionnaire indicated that all subjects were in fair to excellent health. All subjects were non-smokers and moderate caffeine drinkers.

b)   Questionnaires

Questionnaires administered included the Karolinska Sleepiness Scale (KSS) (for description see 2.13c) (appendix 4). SD subjects rated their subjective sleepiness every twenty minutes from 1000h until the conclusion of the study.

c)   Apparatus

The tasks used were four of the tasks used in Experiments 1 & 2, the Verb Generation word fluency task, the Haylings Sentence Completion Task, the Trail Making Task and the Fact Recall task. The first two were chosen for their frequent use when studying sleep deprived, executive functioning performance, the third was chosen as a sensorimotor activity and the fourth as a short-term memory task.

Caffeine, in the form of crushed and dissolved ProPlus^{TM} tablets, was administered in 250 mL quantities of decaffeinated coffee or tea. For the 100mg caffeine condition, 2 tablets equalling 100 mg Caffeine Anhydrous Ph. Eur., were dissolved in the drink. For the 200mg caffeine condition, 4 tablets equalling 100 mg Caffeine Anhydrous Ph.Eur. were dissolved in the drink.

2.11 Procedure

All subjects reported to the laboratory at 1000h the morning of testing and were given a cup of coffee or tea. The caffeine dose was administered single blind to the subjects, however upon scoring and analysis of data at the completion of the study, the condition each subject was in was also blind to the experimenter. All subjects were questioned about their adherence to the study protocol, which included no caffeine intake after 1800h the evening before testing and a normal bedtime between 2300 - 2330h, and a normal rising time between 0700h-0730h. Once it was established that all subjects had followed the protocol instructions, they were given the beverage.

Following arrival in the laboratory, subjects were randomly assigned to the caffeine groups or placebo group and were given cups of coffee or tea to drink. Testing began

30-40 minutes following consumption of the drink in order to allow the caffeine to have an effect on the CNS.

The four tasks were randomised. During individual testing, subjects were alone in the experimental room. When not participating in individual testing, subjects remained together in a lounge room and were instructed not to discuss the tasks until the session was complete so that novelty was maintained.

Throughout the testing session, subjects filled out the Karolinska Sleepiness Scale every twenty minutes to establish their alertness levels and to measure the effect of caffeine (if any) on the caffeine groups.

2.12 Results

Analysis is in a one-way ANOVA design with each of the three conditions represented separately. The control group for this study, as in Experiments 1 & 2, have been pooled such that Control N = 31. Unless otherwise stated, post hoc analysis was conducted with Tukey$_a$ tests.

1. Trail Making Task

Analysis showed no differences between conditions for latency to nor in errors. Mean latency for this task was 51.3 sec (SD = 13.1). This finding suggests caffeine does not have a beneficial nor a detrimental effect on this sensorimotor task.

2. Verb Generation Task

Analysis indicated no effect between groups on verbal fluency nor on number of errors (F (45,2) = 2.58, p = .087, **ns) for this task however there is a trend towards increasing errors with increasing dose of caffeine in alert subjects (See Figure 2.16 for illustration).

Figure 2.21 Verb Generation - Number of Errors

Table 2.21 Means and Standard
Deviations for Verb Generation

NUMBER OF ERRORS		
	Mean	StDev
0 mg	1.8	1.9
100 mg	4.2	5.7
200 mg	5.7	9.2

3. Haylings Sentence Completion Task

In Section One, as expected, there were no differences between groups on providing a correct response or on latency to that response. In Section Two, there was also no effect of caffeine on providing a correct response or on latency to that response. It appears that caffeine does not have an effect on alert performance for this task.

4. Fact Recall Task

There were main effect differences for number of correct facts $F(46,2) = 3.77$, $p <$ .05) however the Tukey analysis was not significant in a test between individual groups. The main effect difference was due to a decreasing number of correct facts produced with increasing caffeine dose (See Figure 2.17). There were no significant differences between groups on number of errors ($F(43,2) = 1.19$). Note this analysis was conducted with the extreme scores removed. There appears to be an increasing variability in response to caffeine with increasing caffeine dose on this memory task. This variability contributes to increasing decrements in performance on various tasks.

Figure 2.22 Fact Recall - Number of Correct Facts

Table 2.22 Means and Standard Deviations for Fact Recall

NUMBER OF FACTS		
	Mean	StDev
0 mg	11.2	6.3
100 mg	7.4	3.0
200 mg	6.3	2.6

2.13 Gender Differences

To determine any effects of gender on the tasks used in the experiments, t-tests were conducted on the four tasks in which the Control group had N = 31; Trail Making Task, Verb Generation, Haylings Sentence Completion Task, and Fact Recall. The t-tests indicated no differences between men and women in the Control group for any of the tasks. In this analysis there were 19 women and 12 men. This analysis does not take into account men and women may be affected by sleep loss differently. Along with individual differences, gender differences is an area of sleep loss research that needs to be explored.

2.14 Discussion

Increasing caffeine dose appears to have an effect on individuals' ability to maintain and recall information from short-term memory and a trend towards declining verbal fluency. Both of these factors (memory and verbal fluency) contribute to the test collection described in Experiment 2 and may account for the differences observed.

In Chapter 1, the variability of findings from caffeine studies on alert individuals were described along with James'(1991) suggestion that the findings of caffeine having positive, negative, and no effect on cognitive performance are attributable to the heterogeneity of performance measures and individual differences in response to caffeine and ability at performing, along with a host of other confounding variables. All of these findings suggest that as a methodological intervention in conducting basic research on the effects of Sleep Loss, the use of caffeine is inadvisable because of its variable effects. However, findings from Experiment 2 suggest that as a countermeasure to generalised sleepiness, caffeine may have a beneficial effect on sleep deprived performance up to 30 hours. Critics of this research may argue that due to caffeine's effects on generalised sleepiness, it may not be possible to disentangle general from specific effects. The following chapters document the attempt to further the understanding about the effects of sleep loss on language skill.

Figure 2.18 Answering the Research Questions

Furthering the Knowledge of Executive Functioning during Sleep Loss
- A 90-min nap is an effective countermeasure for counteracting the effects of sleep loss on executive functioning performance. This may be due to the high levels of SWS expected during the first 90-min cycle.
- While some aspects of executive functioning appear to be starting a decline after 27 hours without sleep (such as increases in errors), the Specific effects of decrements in executive functioning are hypothesised as occurring sometime after 30 hours. In fact, the critical period may be sometime after 36 hours, as indicated by the lack of difference between SD and Control performance at 36 hours. Boredom effects, and the Non-Specific effects of sleep loss have a profound effect on subjects ability to function, and should not be underestimated when attempting to assess Specific Effects of Sleep Loss. It is proposed that these boredom effects contributed to positive findings in previous reports of executive functioning sensitivity to sleep loss.
- Caffeine is an appropriate countermeasure for sleep loss on executive functioning tasks at 27 hours without sleep.

Questioning the Robustness of Executive Functioning Sensitivity to Sleep Loss
- Important components of executive functioning tasks appear to be inhibition of unnecessary information, verbal fluency, and memory. Verbal fluency will be further analysed in Chapter 5.
- Not all tasks that are labelled divergent thinking in the aptitude literature display sensitivity to sleep loss. Tasks that have components of inhibition, verbal fluency, and memory load are more likely to display sensitivity to sleep loss.

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Chapter 3
Language and Sleep Loss

3.0 Language and Sleep Loss

3.1 What is Language?

In order to accurately judge the effects of sleep loss on language, a brief review of our current understanding of language, including its cognitive and cortical basis, is necessary to outline the processes and explain the most appropriate methods for testing those processes under conditions of sleep loss.

Language is a widely studied phenomenon and one that incurs much debate about its true form. Unfortunately, there is no universally accepted definition of language. Whether sign language is in fact a language is a topic of current debate in Britain, but beyond that the study of communication in animals also raises the question of whether primitive forms of communication can be considered language. Generally, however, a definition of human language includes the use of words as referents for ideas or 'things' and understanding that the compilation of words in different strings alters their meanings (Kolb & Whishaw, 1996). For the purposes of this thesis, language will be defined as the use of words and compilation of words in verbal and written communication, encompassing comprehension and production. It will be shown later in this chapter that disorders of language can be divided into disorders of comprehension and production, and can also be isolated into verbal or written modes.

3.2 Language in Communication

Experimental communication has previously been defined as the comprehension and production of language between experimenter and subject (see Chapter 1). Communication, though, extends beyond simple speech. Gestures, tonal emphasis, eye glances, body language all contribute to the communication between individuals. Communication also involves conveying emotion. Language is only one aspect of a very large area of communication but for the sake of brevity the focus taken here will be solely on written and spoken language. Critics of the experimental manipulation of language as a form of communication suggest that it is impossible to separate language from communication. In an attempt to resolve this dilemma, the following chapter describes a pilot study conducted looking at communication in a simulated real-life environment and a second pilot study examining only language processes.

3.3 Cortical Areas of Language Function

Damasio & Damasio (1992) suggested that the brain processes language through three interconnecting structures: the neural systems to categorise non-language sensory inputs, a small number of neural systems in the left cerebrum that represent the 'rules' of language (e.g. phoneme combinations, syntax), and a third neural set that act as a 'go-between' for the first two. For instance, the third set of neural substrates can stimulate the production of word forms about a concept when presented with the concept. The theory behind the Damasios' work suggests the brain classifies sensory inputs and associates phonemic codes with the inputs in order to represent the concepts in an easily categorised way.

Through studies of lesion patients, PET studies, electrophysiological studies and stimulation of 'normal' human brains, the localisation of language in the human brain has been conducted. The generalised concept of Broca's and Wernicke's areas (the former important for language production, and the latter important for language comprehension) has recently been refuted with experimental findings. The main point being that the data do no support a model of strict localisation of language, since stimulation of anterior and posterior speech zones have similar effects on speech function. Petersen & Fiez (1983) and Petersen et al. (1988) conducted PET experiments on the localisation of language presented visually or aurally. They discovered that in sensory comprehension (or processing) of single words presented visually, there was increased blood flow bilaterally in the primary and secondary visual areas whereas when the information was presented aurally, there was increased bilateral blood flow in the primary and secondary auditory areas. This finding suggests that there is no overlap in brain activity when processing language presented to separate modalities in a sensory task.

Furthering their tasks, Petersen et al (1988) asked subjects to repeat words presented to them and finally to generate a use for a word, similar to the Verb Generation task described and conducted in Chapter 2. In a simple repeat of the word, there was increased blood flow in the primary motor cortex, as would be expected considering there is a motor output in speaking words. However in the generating a verb task

there was increased activity in the left inferior frontal task and in the posterior temporal cortex, the anterior cingulate cortex and the cerebellum. This finding was comparable to the activation of the left dorsolateral prefrontal cortices and the medial frontal cortex reported by Tatsumi et al. (1999) in their study of verb generation in unilingual speakers of Japanese. They suggest that regions for verb generation are independent of particular languages. Posner & Raichle (1994) suggested that a number of left posterior temporal regions are involved in processing words.

In relation to previous findings of sleep loss studies, and the decrements in performance on the verb generation task (Harrison & Horne, 1998a) while not on tasks of repeating words suggests that the frontal lobe may be more affected by sleep loss than other parts of the brain, and it is the act of generating a novel response that is affected versus the language processing. However, qualitative reports of subject behaviour and speech patterns when not being tested by single word responses (i.e. when present in the laboratory between testing times or in an applied setting) (Schein, 1957) indicated that there may be more of an effect on speech than the above findings suggest.

3.4 Disorders of Language and the Similarity to Sleep Loss

Schein (1957) conducted an elegant study on the ability of subjects to send and receive verbal messages during a period of sleep loss from 55 to 70 hours. He reported a progressive increase in the time subjects required to send their messages and a significant decrement in receiving messages. He included qualitative analysis of subjects' verbal behaviour over the course of the experiment.

> "In the sending task, Ss [subjects] showed some alteration in their verbal behaviour. When sleep-deprived they slowed down noticeably, dropped the intensity of their voice, paused for long intervals without apparent reason, enunciated very poorly or mumbled instructions inaudibly, mispronounced, slurred or ran words together, and repeated themselves or lost their place in the sequence of pieces despite the fact that they were numbered." (Schein, 1957, pg. 251)

Morris et al. (1959) reported similar changes in sleep deprived subjects over a period of sleep loss of 90 hours. They documented the changes in the speech patterns thus:

> "Alterations in rhythm, tone, and clarity of the subject's speech were among the most striking of observable changes during sleep deprivation...As sleep loss progressed, speech usually became slower, softer, and contained more

unexpected breaks in rhythm. Slurring and softening were often sufficiently
marked that the listener could not understand the subject's statements...The usual
variation in loudness was attenuated in most subjects producing a curious
"flatness". " (Morris et al., 1959, pg. 252).

Morris et al. (1959) rated their subjects' performance on a 5-point Cognitive
Disorganisation Scale. At approx. 36 hours, subjects were rated at 1, indicating a
slowing of mental processes, along with difficult in thinking of words with no undue
interference with normal communication. At 90 hours subjects were rated at 3,
including symptoms of loss of train of thought, leaving statements incomplete (called
aposeiopesis: the abrupt termination of one thought without completion), and sudden,
unexplained shifts in trend of thought or speech. More recently, Harrison & Horne
(1997) documented an increase in sleep deprived subject's production of words in
"bursts, separated by lengthy periods of silence." (pg. 875). They further reported a
decrease in capacity to generate words following 36 hours without sleep loss.

The observations from the sleep deprivation studies are similar to symptoms listed for
a neurological disorder of language, termed aphasia. Aphasia is defined as 'a disorder
of language apparent in speech, writing, or reading produced by injury to brain areas
specialised for these functions'. (Kolb & Whishaw, 1996). Aphasia can be further
separated into disorder of comprehension, such as poor auditory or visual
comprehension, versus disorders of production, such as poor articulation, word-
finding deficit, loss of grammar and syntax, low verbal fluency, and loss of tone in
voice (Goodglass & Kaplan, 1972). In addition to this classification system, aphasia
has been classified into different syndromes, such as Fluent Aphasia, Anomia
Aphasia, etc., based on the type of speech production and language errors present in
patients output (Kolb & Whishaw, 1996). One of the Aphasic Syndromes,
Transcortical motor Aphasia, has a marked similarity of symptoms to the reports
given in the above extracts from sleep deprivation studies. Specifically, Transcortical
motor aphasics have a marked tendency to reduction and inertia, without articulatory
disorders, presenting with good repetition. Their language errors include
uncompleted sentences and anomias (incorrect naming) however naming is better than
spontaneous speech. The similarity between aphasic patients' symptoms and the
changes in speech reported during sleep loss deserves further exploration.

3.5 Cognitive Model of Language

Garrett (1995) suggested that analysis of language must be treated as an intertwining, but multiple system. For instance, language production and comprehension are distinct processes but intertwined, they both are enacted in real time, and they draw on multiple cognitive sources. She outlined findings from brain-imaging studies, ERP studies of sentence processing and aphasia studies in support of a model of modular processes for language. See Figure 3.1.

Figure 3.1 Flow of information for language production and comprehension
from Garrett. 1995

ERP evidence from neuropsychological studies suggest that there are distinguishable ERP activities for interpretative and syntactic processes (Garrett, 1995), similar to the PET findings discussed above (Petersen et al., 1988). It is a possibility that the language deficits described from the sleep loss studies above relate to difficulties in syntactic and prosodic construction and interpretation of language. Morris (1959) and Horne (1988) reported flattened affect or aprosodia of speech following sleep loss, which could be associated with the prosodic construction. In addition, the abrupt terminations of speech reported by Morris (1959) along with the bursts of speech followed by periods of silence reported by Harrison and Horne (1997) could be associated with the syntactic construction (see Figure 3.1). Further study of the particular decline in language performance needs to be assessed to make further

statements about the possible cognitive, language processes affected by increasing sleep loss (see Chapter 5).

3.6 The Need to Address Sleep Loss Effects on Language

In Chapter 2, performance on language based tasks was assessed during a period of sleep loss, using countermeasures of caffeine and a nap, to test the theory of a specific effect of sleep loss and particular processes associated with frontal lobe activity, focussing on executive functioning. Some of the tasks were chosen for their presence in the sleep literature and previously reported sensitivity to a short (36 hour) period of sleep loss, (e.g. Verb Generation, Haylings Sentence Completion Task). These tasks were used as a benchmark to determine the effect of the countermeasures and the time course of sleep loss effects. The remainder of the tasks described in Chapter 2 were chosen for their language basis and claims of their divergent thinking nature (Pelshenke, 1993). These tasks incorporated aspects of short-term memory, and varied verbal or written comprehension and production in their assessment. All of the tasks used were expected to show a decrement in performance following sleep loss.

This chapter serves to outline the aspects of language that are important for understanding the following assessment of specific language performance during a period of sleep loss. While the Chapter 2 tasks usually involved short one-word or phrase answers, and tested memory processes along with spontaneity, inhibition and other frontal lobe activity, Chapter 4 and 5 examine more fluent speech. Chapter 4 is a compilation of language pilot studies conducted to qualitatively assess the effects of sleep loss on language, the possible effects of language on sleep and the appropriateness of tests of aphasia for healthy, sleep deprived individuals. Chapter 5 is an extended analysis of fluent SD speech using aphasia tasks and not relying on memory processes. It is an attempt to quantify the previous observations reported by Schein (1957), Morris (1959), Horne (1988), and Harrison & Horne (1997) on sleep deprived subjects' speech.

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Chapter 4
Sleep Loss and Group Interaction

4.0 Sleep Loss and Group Interaction

4.1 Exploration of Sleep Loss and Communication

While language function has been examined on the level of speech pronunciation and rates (Harrison & Horne, 1997, Bard et al., 1996) language function in a group setting has not been documented, and reports of spontaneous language function are rare. The following pilot studies were conducted in order to allow experimenter observation of the decrements associated with one night of sleep loss, to test procedures and to further define aspects of language that may be sensitive to sleep loss.

The first pilot study was carried out to explore the historical background of sleep deprivation experiments and the previous work done on communication in sleep loss. The need for communication between sleepy individuals is apparent in real world situations where decisions are being made under this form of duress. It will be shown group interaction and communication in sleep deprivation, along with the individual differences associated with these activities, is a missing component of sleep loss research relating to real world scenarios. The neuropsychological impact of sleep loss and its interaction with communication and decision-making will also be explored.

4.2 Methodology and Evaluation of Group Interaction

While recommendations have been made to use conversation as a method of combating sleep deprivation (Ritter, 1992), differences between group interaction under alert and sleepy conditions have yet to be reported. Following is a discussion addressing three areas of interest during group interaction under conditions of sleep deprivation.

4.21 *Goal Oriented Interaction*
In everyday situations involving sleep deprivation, individuals will rarely choose to remain awake simply to perform a task at the end of the deprivation period, and yet the methodology of many sleep loss studies involves such practice. While it is a useful method for isolating one task or set of tasks, it does not have realistic value. In most cases of 'real-world' sleep loss, the period of deprivation involves continuous performance in order to achieve an end goal. While this study will not consider the

area of shift work, it is important to note shift work is an apt example of performance under fatigue conditions in which vigilance, attention, and cognition are important factors. In this chapter, however, the discussion will concentrate on goal-oriented behaviour.

In non-emergency situations, reasons for remaining awake for a long period of time are diverse. In school or university situations individuals deprive themselves of sleep in order to complete a pre-set, usually externally imposed task, to meet a deadline. In these situations the deadline involved is often an exam or paper submission. In instances where a group of people must work together to complete the tasks, successful interactions between group members are important to complete the individual objective. During NSD conditions, factors such as interpersonal relations, communication ability, and mood, interact and impact on the dynamics of the group and the achievement of the goal. In situations of sleep deprivation these abilities may decline, suggesting interaction between the various factors becomes an important consideration in completing the goal.

It is anecdotally reported that under conditions of stress, communication between individuals deteriorates while personality and individual differences become more noticeable. In conditions of sleep deprivation, these differences could be exacerbated. It is of interest to test the change (if any) during group interaction under these conditions.

More striking, of course, are the changes of group interaction in sleep deprivation during emergency conditions. In the previous chapters, various scenarios associated with sleep loss tasks were described, the most widely studied being military applications. In real-world scenarios where accurate communication and group cohesion are essential, little is yet known about executive functioning abilities, personality changes, and individual differences under the stressful condition of sleep deprivation. Theoretically, the study of language and sleep loss is relevant to the question of executive functioning during sleep loss. In applied research, it is important to document the expected changes in sleep deprived continuous operations, including communication, in order to find appropriate countermeasures to performance decline.

4.22 *Interpersonal Relations and Individual Differences*

Personality and Individual Differences research highlight the differences between individuals in every day situations. While it is an important factor in performance, individual differences have yet to be extensively studied in sleep loss condition. Two notable exceptions are Hill et al. (1996) on locus of control and Smith & Maben (1993) on extroversion. In fact, most sleep deprivation researchers will agree that in most groups of test subjects, at least one will appear immune to the detrimental effects of sleep loss. Individual differences are an important area of exploration in sleep research, particularly in their interaction with group performance and communication. Personality is an important factor in every study of human behaviour, but in this research it will be accepted as a given and undeniable factor during group interaction.

4.23 *Group Dynamics*

Many businesses rely on research addressing factors associated with group teamwork, group interactions, and communication skills. Understanding Group Dynamics factors is important in order to manipulate situations to optimise group performance and to minimise difficulties in group cohesion. In situations of sleep deprivation, group dynamics have not yet been studied, although from the literature it is hypothesised that group dynamics will alter, potentially improving due to response inhibition but expected to breakdown after the stress of sleep loss, due to changes in mood, response inhibition, and communication. These changes are expected to be detriments in mood, mood swings and lack of inhibition which can translate into 'saying something you wouldn't otherwise', thereby impacting group dynamics. Leadership skills, ability to follow directives, and ability to work in a group are all factors yet to be addressed by the sleep field. Krueger and Englund (1985) reported frequently in SUSOPS (sustained operations) research that group, team or crew performance on tasks must be measured but rarely has this research been reported in the literature. In group tasks, not all members of the group are exposed to the same stimuli and this differential exposure could have an impact on group performance.

4.24 *Goal Achievement*

Motivation has recently been addressed as an important factor in sleep deprived performance (see Chapter 1). Current means of motivating SD subjects include

monetary and academic reward, but it is important to point out that during goal – oriented tasks, the subjects must be intrinsically motivated to complete their task. In business, this goal achievement could obviously have a monetary value but other motivators may be more or less important to the individual. For example, promotion, preventing job loss, high grades, and preventing course failure can all be high motivators to perform, depending on their importance to the individual. Due to ethical considerations, research determining whether positive motivators or fear of negative motivators would be more highly motivating to individuals is not justified. While it is beyond the scope of this research to address the question, it is important to note in non-emergency situations, fear of negative consequences may not have as great an effect on motivation compared to emergency situations. In simulated studies, it is impossible to re-enact the highly emotive situations surrounding certain scenarios, such as life threatening activities, and thus, the studies are missing an important stress factor.

4.25 *Other Considerations*

4.251 Experimenter effect

In most of the sleep literature, as in most of the scientific, laboratory based literature to date, the effect of the experimenter or the experimental manipulations have been neglected as a source of confound in the findings. Since this research will be addressing language and conversation, it is important to discuss the conflicting views of language and experimenter influence on the research. In continuous performance studies needed to approximate real-world scenarios of continuous operations, it is not sufficient to select tasks which are known to be sensitive to sleep loss and further expand the sleep deprivation research on those tasks (Krueger & Englund, 1985). It is important to study activities that are not yet known to show a sensitivity to sleep loss to evaluate any interactive effects and to approximate an individual's ability at carrying out important tasks.

4.252 Method of Analysis

Conversation, in its varied and fluid nature, is very difficult to assess accurately. While many of the social sciences will rely on content analysis, thematic analysis, and discourse analysis in order to document 'facts' relayed during conversation, using these methods in the first pilot study is a lengthy and unnecessary undertaking. Since

the research contained in the following studies is based on quantitative analysis, only a brief overview of qualitative research will be given here, but again it is an important consideration in the study of group interaction. In any study of interaction, it is not the actual fact of occurrence of speech but rather the interpretation of the facts by the various participants in the conversation, an interpretation which can be 'interpreted' by examining the discourse involved. In this type of qualitative analysis it is understood that the researchers themselves add a further dimension of fact construction by their own interpretation. While much of the data to be analysed in this thesis will be done through quantitative measures, the inclusion of qualitative measures and observational experimenter reports will help to define the areas of interest and perhaps to illicit further understanding of the difficulties of this research. In all examinations of quantitative data, researchers bring to the evaluation their pre-conceived notions about what they will find. Even in studies where 'double blind' methodologies are assessed, there is an intrinsic confound in choosing one test over an other, and one method of analysis over another. If a different test were chosen, or a different wording to the question used, results may differ. In any study of group interaction, even in a study in which there is a heavy reliance on quantitative techniques and measures, the influence of the experimenter must be addressed in the planning and analysis of that study.

4.26 *Experimental Planning*

The following section is a discussion of three pilot studies: the first two studies were carried out as exploratory measures of sleep loss and its influence on communication, group interaction, and language, while the third was an exploratory attempt to assess the effects of language on subsequent sleep. The first study was an endeavour to approximate real-world conditions of sleep loss and group interaction to observe the nature of sleep loss and spontaneous language. In response to observations from the first study, the second study was necessary to define and test appropriate procedures for examining specific verbal and written language errors for individual subjects. In an attempt to address the brain/behaviour relationship between sleep and language, the third study manipulated the amount of language used during the day to assess possible changes in subsequent sleep. The third pilot study was outside the scope of the research questions and therefore, was not followed up with a full study. However, the questions raised by the literature (Kattler, Dijk & Borbely, 1994) and the findings

of the third study are a prompt for future enquiry into the effects of daily cognitive activity on subsequent sleep.

4.3 Language and Group Interaction During one Night without Sleep

The first pilot study was a 36-h period of sleep deprivation in which a group of 5 second year undergraduate students spent a night studying for an exam, in individual and group sessions. With the exception of breaks, the students were on task for the final 24 hour period and the session finished with a mock exam and a debrief.

4.31 Subjects

Five subjects (2 male, 3 female, mean age = 20.4 years) were selected from respondents to advertisement within a biological psychology class at Loughborough University, UK. Initial screening excluded those with sleep difficulties, those who were on medication that cause sleepiness or affect sleep, and those suffering from epilepsy, diabetes, or migraine headaches. All participants normally slept between 7 and 9 hours a night and were healthy non-smokers. In order to motivate participants to perform well throughout the study they were offered a reward for successful group completion. Individual tasks were awarded based on competition between subjects in order to provided further incentive.

4.32 Design and Procedure

Subjects participated in one 36-hour testing session, without sleep during the interim night. Sleep diaries were used in the 3 nights previous to maintain normal bedtime hours between 2300 h and 0700 h approximately.

Actimeters (Levine et al., 1986) were worn during the 36-hour period to ensure no sleep was taken before or during the laboratory session. During sleep deprivation, subjects were confined to the laboratory for the final 24 h period; 21.00 h on the first day until the termination of the study. During revision sessions and between sessions they remained in a large living area equipped with study desks and lounge furniture. They were permitted to watch television and talk between study sessions, but were prohibited from discussing revision material outside of the group meetings. Non-

caffeinated beverages were available ad lib and caffeinated beverage consumption was limited to 5 cups per night (1 cup equivalent to level teaspoon of Goldblend™ coffee) [av = 4.2; SD = 1.3]. All caffeinated beverages were halted at 10.00h on the second day. This manipulation was comparable with previous 36-h sleep deprivation studies (Harrison & Horne, 1997, 1998a) for testing at 36-h without sleep. It allowed at least 8 hours before final testing. Meals were provided at 08.30h, 13.00h, and 16.30h. Snacks e.g. fruit and cereal bars, were available ad lib. At the termination of the study subjects were escorted home.

As this was an observational study, at the beginning of the testing period subjects were told the study was a general assessment of sleep loss and its affects on communication ability, both verbal and written. This was communicated to the subjects in order to promote subjects openness with the experimenter when they felt there was a change in communication/understanding with other subjects. They were further instructed that decisions were to be made as a group. Subjects were requested to avoid discussing revision material outside of the group meetings. In addition to the tasks described below subjects also participated in a relational learning task to be reported elsewhere (Gibson, 1998).

4.321 Group Interaction

Three 45-minute tape-recorded group sessions were made at 0100h, 0700h, and 1200h. At the outset of the testing sessions subjects were presented with a list of revision questions based on the text of the module. They were advised to split the questions into 3 main areas of study. Once completed they were then instructed to divide the questions amongst themselves for each of the sections. Each subject revised only the questions in their assigned section. They were asked to refrain from sharing written material. During the group sessions, each subject contributed answers of their assigned sections to the rest of the group through verbal instructions. They were told at the outset that an equal reward would be available to each of them if the group successfully completed the assigned tasks. They were also told if the group did not successfully complete the combined tasks, the reward would not be given to any member of the group.

The tasks included:

1. The subjective sleepiness ratings were to be filled out by every member of the group once an hour, until the termination of the study.
2. The auditory review sessions were to be played at the scheduled times 2200h, 0400h, and 1030h.
3. The group sessions were to be recorded according to the scheduled times.
4. The revision material was not to be discussed outside of the group session.
5. The individual study time was self-directed but based on group decisions and without disturbing others. There was typically a period of 1.5 hours of individual study before the 45-min group session, during which time each subject was required to read up on their topics and summarise them for presentation at the group session.

The taped sessions were qualitatively analysed and sections thought to be relevant were extracted and transcribed for further analysis. Subjects sat at a fixed distance from the microphone and recording level remained constant. Intonation and types of speech were monitored by the experimenter through observational reports.

Group interaction ended following a group interview with the experimenter at 18.15 h on the second day. This debrief included questions regarding attitude towards experiment, revision, and the group as well as own performance during the overnight sessions, changes to revision techniques, and self-analysis of ability during sleep deprivation.

In addition to the continuous group interaction, three short, novel tasks were also used to assess cognitive functioning. These tasks were derived from the neurological literature and chosen as possible executive functioning tasks.

4.322 Response Inhibition

A version of an Opposites priming task that was previously shown to affect the dorsolateral prefrontal cortex (Frith, Friston, Liddle, & Frackowiak, 1991) was used as a possible executive functioning task. Subjects were given a word as a prompt and asked to give the antonym of the word. Their responses were audio recorded. Following the first trial, the subjects were given the same list again with words in mixed order and asked to repeat a completely unrelated word. This task was

conducted individually and subjects were asked not to discuss the task with other members of the group until everyone was finished testing.

4.323 Self-Ordered Pointing: Working Memory

A version of Petrides (1996) self-ordered task was used in which subjects were given 15 different presentations of 15 separate stimuli. Subjects were required to choose a different stimuli on each attempt and therefore constantly compare the responses already made with the ones yet to be made "i.e. events in working memory must be closely monitored" (pg. 1455). Subjects were encouraged to do their best and were offered a competitive reward incentive to motivate them. Comparisons were made between SD and a NSD control group.

4.324 Proactive Interference of Working Memory

A version of semantic categories memory tests (Cermack & Butters, 1972) was used in which subjects were presented with 4 lists of words. They were asked to study each list of words for 1 minute and then to recall the list in the following 30 second interval. The first three lists were of the same semantic category (e.g. animals) and the fourth list was in a different semantic category (e.g. fruit). Following the four recall sessions subjects were given an unrelated mathematical problem and then were asked in delayed recall format which of the lists the 7 final prompts originated in. Analysis was conducted on immediate recall of the 7 words in each list, and on the number of the list in which the delayed recall words were presented.

4.33 *Results*

4.331 Group Interaction

The first group interaction session was productive for members of the group. They organised their presentations according to the time available (i.e. the 45-min time limit) and in turn, each subject presented on their assigned topics. The session was punctuated with laughter, anecdotes unrelated to the task and frequent interjections during individual presentations from other members of the group. Oral explanations during the presentations were fluent, typically articulated in sentences, and definitions were expanded with sentences. The group managed to discuss all of the Session 1 points.

The second group interaction session was markedly different from the first. Presentation of material was slow and laborious resulting in two member of the group not having enough time to present their data in the 45-min timeslot. The mood of the group was sombre and there were frequent requests of the presenter to slow their speech, to spell difficult words and to repeat their sentences. During the debrief, subjects reported an inability to summarise the material being presented into coherent notes and therefore, they simply recorded word for word, the information presented. Speech tones became flatter and some members of the group began to mumble. The change in speech patterns interfered with communicating and therefore, tension began to rise as the listeners frequently requested repetition of the material. Time between sentences was much longer than in the first session, allowing for listeners to write down every utterance.

The third group session was similar to the second in the need to repeat words, and to spell words at the request of the audience. There were more frequent interruptions in asking for explanations and definitions, however the mood of the group improved and the speed increased.

The debrief provided a wealth of information about how the subjects were subjectively feeling throughout the 36-h period. Subjective verbal reports at 18:05 on the second day (34 hours without sleep) suggested they were not feeling the effects of sleepiness as much as during the interim night. Subjects reported the greatest difficulty in conversing at the 0700 session. They further reported more difficulty initiating speech than writing, yet great difficulty maintaining written train of thought when completing the one-hour exam. One subject contributed almost no conversation to the debrief, and in fact had not spoken much after 0900h. When questioned about it, she stated that she felt very tired and withdrawn from the group. During the audio - recorded short test sessions, her voice is barely audible. Some reported the most difficult part of the task was the final one-hour exam, while others reported paraphrasing words most difficult during the 0700 session. They articulated their improved subjective feelings as 'getting over it [the sleepiness]'. One subject stated that she had repeated dips and rises. The following is an extract of her statement [NB: The transcriptions are exact. Brackets denote pauses in speech. Bracketed numbers indicate delay in seconds]:

> ED: The thing (.) the thing was I found that dips and rise sometimes I'd have several in an hour (.) and (.) like so I'd say on here I was fine and then five or ten minutes later I'd be absolutely awful (.) I'd say I was awful-

It is interesting to note the language difficulties she has in articulating how she is feeling. The debrief occurred at 36h sleep deprivation.

The subjects also indicated a difficulty retaining information in working memory while trying to write information on paper. Subjects stated they would begin to write a sentence and then forget what they had written or what they were thinking about during a practice exam period. Upon rereading what they had written, some subjects reported they could not recall writing it. They did not report a deficit in learning the information, rather a difficulty in maintaining it in short-term memory long enough to relate it. This observation suggests that future sleep deprivation work needs to be conducted on the effects of sleep loss on working memory, which could be the basis for previous findings of executive functioning deficits.

When questioned directly, they suggested their language skills 'went to pot' at 0400h and word finding was difficult. The following extract documents one subject's experience of production:

> ED: I I I trying to find the right word I can sort of get across what I want to say but I can't necessarily say it in the way I want to.(2) particularly found out in left actually but in the essays sort of (.) having an idea but not being able to put it on in words on the paper.

The subjects were questioned about their comprehension of others and the following discussion ensued. The lengthy extract is used to illustrate their speech patterns along with their sentiments:

> AT: I found everybody else quite clear.
> ED: yeah
> AT: yeah ***-
> JP: I Found people'd say something and (.) I'd hear the words and then (.) I'd realise I hadn't listened to it
> AT: yeah, but I think it just depends on what the other person was talking about if they were talking about-
> DM: speed
> ED:-that-
> AT: - was very complicated (.)-or if it was words you were familiar With-
> ED: -That that's what I was saying If it was something we'd already done in the lecture I think you could follow it and write notes and that was fine but it's when it's new stuff.
> DM: Yeah....yeah
> AT: -and I'd we write ***-
> ED: I think that's a lot of the more-

DM: especially-
ED: - more indepth stuff that we've not really touched on were-.

When asked about their attention, one subject replied with the following statement. It is of note his language difficulties at describing how he was feeling.

> AH: At the end I was *really* affected because I was writin' thing down (.) I had a thought in my head (.) and then (.) sorry I'd just switch off and then I'd write something and mmm I'd read what I'd written and think that makes no sense at all I don't know where I've got those words from I can't-

They suggested that the 0700h session had the greatest impact on revision, even though it was only 24 hours into the sleep deprivation period. One subject suggested this:

> ED: basically I'd I'd be reading the notes and its just going (.) over my head. I mean I couldn't take it in at that point and I jus decided to cut off.

Furthermore, by the second session the subjects articulated that they were no longer concerned with social communication and were intent upon reaching the end of the session.

The language difficulties most noted in analysis of their group sessions and the debrief were grammatical problems, clearly articulating their thoughts, abrupt termination of thoughts and beginning speaking on a new topic, and excessively interrupting one another. It should be noted that this was an observational study used as an exploration of group interaction during sleep loss and thus, comparative control data is not available to determine if observed changes in behaviour were statistically significant from a control sample. In a comparison of these observations with literature on language (Smyth et al., 1994;Anderson, 1995;Kolb & Wishaw, 1996) and memory (Smyth et al., 1994; Anderson, 1995) deficits, it was determined that their were a number of similarities between the speech of sleep deprived individuals and documented symptoms of language aphasia. This prompted further investigation into studies of language disorders and methodology for systematic analysis of language disorders.

4.332 Response Inhibition

Measurements were mode on response latency and strategies for generating unrelated words. Using nonparametric analysis due to the small number of subjects used, a

paired comparison was conducted between the latencies for giving opposite responses and those giving unrelated. The latencies were measured to 1.0×10^{-3} sec using a computer analysis program, CoolEdit^{TM} (see Chapter 2 for further description). No significant difference was found between response times. The mean response time was 0.411 (SD = .18). Due to the lack of difference between response times for this group, the Opposites/Unrelated response inhibition task was not used in further testing due to the ceiling effect of performance for young, healthy adults. The expected difference in this task was latency between giving opposite responses versus unrelated responses. It should be noted that this was an observational study used as an exploration of group interaction during sleep loss and a methodological learning experience for the experimenter and thus, comparative control data is not available to determine if observed changes in behaviour were statistically significant from a control sample.

4.333 Self-Ordered Pointing: Working Memory

This task was a variation of the task used by Harrison & Horne (1999b) as a distractor in their testing of temporal memory. The task used in this pilot study was varied to include only abstract shapes, removing the ability of the subjects to use word grouping strategies in responding to the task. A t-test comparing the SD group with a gender matched control group (N=5) showed no significant differences on number of correct responses. Mean number of correct responses was 11.8 (SD = 1.3). It should be noted that the gender matched control group were not recruited prior to the overnight sleep session and were recruited by responding to advertisement to a sleep deprivation study. In retrospect, random allocation should have been exercised and this fact was a learning point for me. Upon debrief subjects indicated that they had used a strategy for the abstract shapes by choosing all square-based shapes first, followed by all circle-based shapes. This chunking of information into manageable amounts is a common phenomenon when using short-term memory (Anderson, 1995) and is similar to the strategies described by Harrison (1998). Due to the repeated failure of the self-ordered pointing task to show sensitivity to sleep loss, including multiple variations of this task, it was determined that this task would not be used in further sleep deprived testing. The multiple variations of this task were not employed within this pilot study, and therefore do not affect the overall alpha. Other variations

of this task were used as 'filler' tasks in other experimenter's sleep deprivation studies within the Loughborough Sleep Laboratory.

4.334 Proactive Interference of Memory

This task was developed as a similar task to Harrison & Horne (1999b) reported task on temporal memory however, on initial testing it was deemed as too easy for the subjects, with only 7 words in each list. During development it was thought that decreasing the number of words per list while increasing the number of lists would provide a sufficient memory load for the subjects however all five sleep deprived subjects scored 100% on both the immediate and delayed recall task. It was determined following this pilot study that proactive interference of memory was outside the scope of the research questions and would require an undue effort to further develop the task. It did provide preliminary evidence, however, that sleep deprived subjects are performing far better than frontal lesion patients (Cermack & Butters, 1972) on this task at 36 hours without sleep loss.

4.335 Subjective Sleepiness

Subjects reported their subjective sleepiness every hour from 2100h on the first night until 1800h on the second day. Graph 4.1 illustrates their ratings. Note the peaks in their sleepiness during the circadian dip at 0700h, during the second session. Also note the decrease in sleepiness during the typical period of morning alertness at 1000h and subsequently at 1300h, during their third group session. It appears that the generalised sleepiness they experience during the early morning second session was not overcome by their motivation to conduct the group session, while the afternoon dip, which typically occurs between 1300 and 1600h did not occur until after the third session was conducted. The motivation to conduct the third session may have been enough to overcome their generalised sleepiness at that point.

Graph 4.1 Mean Subjective Sleepiness Rating

4.34 Discussion

Findings from the first pilot study were comparable to reports in the literature on sleep deprivation effects on speech and communication. The qualitative reports by the subjects themselves indicated a need to further examine the specific effects of sleep loss on language skill using reliable tools. To this end, a review of the literature was conducted to find an appropriate measure for healthy adult individuals' language patterns, during alert and sleep deprived conditions. The second pilot study was conducted to test the appropriateness of the chosen measures.

4.4 Testing Appropriateness of Aphasia Measures on Healthy Adults

4.41 Subjects

Five subjects (2 men, 3 women, mean age = 22.8, SD = 0.8) were recruited from poster advertisements around Loughborough University Campus, UK and personal contact. Initial screening excluded those with sleep difficulties, those who were on medication that cause sleepiness or affect sleep, and those suffering from epilepsy, diabetes, or migraine headaches. All participants normally slept between 7 and 9 hours a night and were healthy non-smokers, with normal or corrected-to-normal eyesight.

4.42 Design and Procedure

Three of the subjects were participating in a larger sleep loss and divergent thinking study (Harrison, Horne & Rothwell, 1999c) and agreed to participate in this pilot study as an adjunct to the main study. The two remaining subjects were recruited as alert controls. It should be noted that the gender matched control group were not recruited prior to the overnight sleep session of this pilot study and were recruited by responding to advertisement to a sleep deprivation study. In retrospect, random allocation should have been exercised and this fact was a learning point for me. Subjects participated in one 30-hour testing session, during which sleep deprived subjects went without sleep during the interim night. Sleep diaries were used in the 48 hours prior to the beginning of the study to monitor activity and ensure normal bedtime hours between 2300 h and 0700 h approximately.

Actimeters (Levine et al., 1986) were worn during the 30-hour period to ensure no sleep was taken before or during the laboratory session. Sleep deprived subjects were required to adhere to a protocol for three days before testing and to remain awake the for 30 hours prior to testing. Compliance was assured by monitoring subjects with sleepiness diaries, phone calls to the lab, actimeters, and polysomnographic recording. Subjects were tested at approximately 1130 h.

Based on literature investigations, the Western Aphasia Battery was chosen as an appropriate measure of language skill. From the multitude of tests available from the battery, short tasks were extracted that were deemed appropriate for exploration in

assessing verbal fluency and language skill. The tasks for this study were divided into two sections. The first section required oral responses and the second required written output. On the verbal tasks, subjects were tested for spontaneous speech, auditory verbal comprehension and repetition of words and sentences. On the written tasks, subjects were tested for writing on request, written output, and writing to dictation, as per the Western Aphasia Battery (Kertesz, 1982).

4.421 Verbal

Subject responses were recorded on a Sony TCM-359V Cassette Recorder using TDK D10 Cassettes. Speech was transcribed and analysed according to the Western Aphasia Battery Criteria. Spontaneous speech was measured by scoring subjects' responses to open-ended questions such as, 'How are you today?', 'what is your occupation?', and by describing a picture from a cue card. In addition, subjects were asked to create a story including six random objects observed from a cue card. Auditory verbal comprehension was tested by yes or no responses to short questions. Repetition involved the subject verbally repeating words and phrases presented by the experimenter.

4.422 Written

In the presence of the experimenter, subjects were asked to look at a cue card from the Western Aphasia Battery depicting a picnic scene and to describe the picture in written form. In addition, according to the Western Aphasia Battery they were asked to record their name and full address and to write to dictation the sentence, "Pack my box with five dozen jugs of liquid veneer." (Kertesz, 1982).

4.43 *Results*

Subjects' responses were transcribed and analysed according to the Western Aphasia Battery. Since observations from Pilot Study One noted subtle changes in language performance that progressively deteriorated over the course of the sleep deprivation period, it was not expected for subjects to have clinical levels of aphasia, as indicated by the Western Aphasia Battery protocol.

Analysis showed no differences between sleep deprived and control performance on gross measures of speech production and comprehension, e.g. number of words

produced, articulation. Note: As this was a pilot study, sophisticate4d statistical analysis were not conducted and significant differences could not be calculated due to the low number of controls. As expected, the rudimentary aspects of the Western Aphasia Battery were not sensitive to changes between sleep deprived and control subjects. While subjects appeared tired and voice levels and intonation were flattened, no significant differences were observed between sleep deprived and controls on repetition, and auditory verbal comprehension.

4.44 Discussion

While some of the signs of language difficulties observed and reported by subjects in Pilot Study One were noted in Pilot Study Two, such as flattened tone and shortened answers, there were no apparent significant differences between sleep deprived and control subjects. While the observed language difficulties suggested an effect of sleep loss, there were too few pilot subjects to be able to discount individual differences in the observed changes. In addition, subjects were answering questions and responding to directives with relative ease. It was observed that the presence of the experimenter was having an effect on the individuals, who appeared hesitant or embarrassed when delivering answers, and frequently succumbed to or had difficulty masking fits of laughter. It was also noted that the speech patterns observed in Pilot Study One at the time of final testing (1900h) were not mimicked in Pilot Study Two at time of testing (1130h). Testing for Pilot Study Two occurred approximately 6 hours earlier in the period of deprivation. Caffeine intake was another difference between the two studies. Due to the main Sleep Loss and Divergent Thinking test that Pilot Study Two subjects were taking part in, caffeine had been prohibited during the interim night. The low subject numbers may have accounted for the lack of language findings, as might the time of testing.

These findings prompted further honing of the experimental measures to improve sensitivity for healthy normal controls. To this end the rudimentary language skills, such as the yes/no answers, speaking and writing one's own name and address, and repeating a phrase by dictation were dropped from the full study. Instead, the fluent aspects of the WAB along with one measure, the Boston Cookie Theft Picture, from the Boston Aphasia Examination (Goodglass & Kaplan, 1972) were combined into a number of short (2-3 minute) tests for the main study of language fluency (see

Chapter 5). Haravon, Obler, & Sarno (1994) used a picture from the Boston Aphasia Examination (Goodglass & Kaplan, 1972) to study adult normal discourse and further, to measure discourse in clinical populations. They developed a micro-analysis technique that was modified for analysis in this pilot study. The measure, which included coding words into their grammatical categories (e.g. nouns, verbs, functors) and errors into the common errors of speech, was deemed appropriate for the population used in the full study (further description available in Chapter 5).

4.5 Exploratory Analysis of Language Effects on Sleep

When the research for this thesis was in the planning stage a pilot study was conducted to examine the effects of a verbal 'busy day', similar to Rothwell & Horne's (unpublished research) study on visual busy days, to determine if language use would have an effect on the following slow wave sleep of subjects. In a cognitive sense, this comparison is similar to the findings of Kattler, Dijk & Borbely (1994) and Klein et al. (1995). Kattler et al. discovered that repeated somatosensory stimulation of one hand produced increased activation in the subsequent sleep EEG in the brain region corresponding to somatosensation. Klein et al. (1995) reported an increase in cerebral blood flow in the left inferior frontal cortex during a bilingual examination of word generation. They concluded that common neural substrates are responsible 'within- and across language searches' and activation of the left inferior frontal region occurs in response to both phonological and semantic cueing. The PET evidence that language activates the frontal lobes in Brodmann's areas 46, and 8, areas also thought to be responsible for memory and inhibition, combined with the Katter (1994) claim that repetitive stimulation of a physical area correlated with increases in sleep EEG corresponding to that area, prompted this investigation into a cognitive stimulation study. While this avenue of research was not explored beyond the pilot phase, in favour of the more psychological/cognitive aspects of sleep loss research, the following is a brief account of the pilot study and an interesting area for future research.

4.51 EEG Analysis of Sleep Following Intensive Word Generation & Translation

The EEG Power spectra include differential constituents for wake, REM sleep, and NREM sleep. The deeper sleep stages, characteristically known as Stages 3 & 4, are grouped together as Slow wave sleep (SWS), and are represented by increases in high voltage, low frequency waves in the delta (0.25-4.5 Hz) and theta range. Extending the duration of wakefulness before sleep results in an enhanced power density in the delta and theta (4.5 - 8.0 Hz) frequency ranges (Borbely et al, 1981; Brunner et al., 1990). Activity in the prior wakefulness period may determine increases in specific EEG activity during subsequent sleep. Horne and Reid (1985) reported passive body heating during a period before sleep resulted in increases of delta power in the ensuing sleep. Since there are topographic anterior posterior differences in spectral power across the human sleep EEG (Werth, Achermann & Borbely, 1996) it is possible that anterior and posterior cortical regions may have different involvement in the activity of sleep.

Local activation of neuronal regions has a differential affect on different regions of EEG recordings during subsequent sleep (Kattler, Dijk & Borbely, 1994). In a study of 8 male subjects, researchers reported an increase in delta activity in the contralateral, somatosensory cortical region following unilateral vibration stimulus of the dominant hand. Previous PET studies have reported increased regional metabolic activity following unilateral somatosensory stimulation of the hand. (Seitz & Roland, 1992). A hypothesis has been advanced for activity during wakefulness being reflected during subsequent sleep suggesting regional increases in metabolic activity during wakefulness may result in increased EEG synchrony reflected in increased Power density for that region during NREM sleep (Kattler et al., 1994).

The purpose of this study was to investigate whether activation of specific language regions of the brain during wakefulness will result in increased EEG NREM power density during subsequent sleep. Previous PET studies have indicated increased metabolism in the left inferior frontal gyrus corresponding to Brodmann's areas 8, 46, 47, and 45 following a bilingual word generation, translation task suggesting common neural substrates are involved in within- and across-language searches (Klein, Milner, Zatorre, et al., 1995). Increased metabolic activity during activities known to be sensitive to sleep loss (Harrison & Horne, 1998a) have been reported in the middorsolateral frontal cortex (corresponding to Brodmann's areas 8, 46) (Goldman-

Rakic, 1996; Petrides, 1996) and the midventrolateral frontal cortex (Brodmann's areas 47, 12 (Owen, Evans, & Petrides, 1996). This increased activation corresponding to stimulation suggests there could be corresponding increases in sleep EEG power density during subsequent sleep following these activities. It is hypothesised there will be increases in left hemisphere delta and theta activity in the frontal regions and possible similar increases in temporal regions following multilingual word generation and translation.

4.52 Method

Two right-handed male subjects, both aged 26yrs, underwent three conditions of EEG sleep recordings. They were screened for bilingual ability (as measured by the TOEFL), health, and sleep habits. Handedness was assessed by a collection of tasks in an inventory proposed by Annett (1970).

Subjects slept in their own beds for each of the nights in the study and home polysomnographic recordings were taken on 3 intermittent nights, with one non recording night between each recording. Subjects sleep recordings took place in their own beds with the use of Medilog recorders in a polysomnographic montage. Polygraph recordings including EEG, EMG, EOG were made on three separate nights. EEGs were derived from F3, C3, P3, O1, F4, C4, P4, and O2 recordings, referenced to location A1 and A2, according to the 10-20 system (Jasper, 1958). The signals were amplified and recorded by a polygraph and analysed with the Rhythm software. Sleep stages were determined from the C3-A2 derivation according to standard criteria (Rechtschaffen & Kales, 1968). Four-second epochs with artefacts were to be visually identified and not used for analysis. The data was to be analysed with SPSS statistical procedures, and paired t-tests used for pair-wise comparisons to baseline. Subjects were requested to refrain from drugs and alcohol for 48 hours prior to the testing session. They were also asked to refrain from caffeinated beverages for 24 hours prior to the testing session if they did not normally consume them, and if they did, to drink in moderation. All caffeine intake was halted at 1200h prior to subsequent sleep recordings. Subjects were also asked to maintain their regular sleep habits for 48 hours prior to testing. To assess compliance with the experimental protocol, subjects completed a Daily Routine Diary and a Sleep Log during the 48 hours prior to testing. Subjects were tested in pairs. During test week, subjects were

required to maintain a sleep schedule of 2300h - 0700h. Compliance was tested with wrist rest/activity monitors.

4.521 Design

Condition 1: adaptation, data recordings were not used in analysis. Polysomnographic equipment was attached between 1400 - 1600 h each day of the testing sessions, and remained on overnight while subjects slept.

Condition 2: control, subjects engaged in regular activities. Daily routine diaries were maintained with hourly recordings of activity. Subjects recorded daytime sleepiness for the 8 hour period prior to sleep on each of the recording days. Analysis of the routine diaries revealed nothing unusual in their activity patterns.

Condition 3: experimental, prior to the night sleep recordings, subjects engaged in a word generation & translation activity intermittently between 1600 h and 2230 h. (Language task on: 20 min, language task off, 10 min). There was a 30min break between 1930 h - 2000h for supper.

4.522 Language Task

Subjects were presented with the task of verbally generating a novel, fictitious story with highly descriptive paragraphs in each 20-minute session. Subjects selected randomly one of 12 word prompts from a pile (e.g. MOUNTAIN, WILL, LIFE, TECHNOLOGY) and were asked to generate a novel, descriptive story in either English or German for 4 minutes. At the end of each sentence, the other subject translated the sentences into the alternate language. Each 20-minute session was organised into 4-minute periods of 5 stories with translation. Subjects alternated generating stories and translating, as well as alternating English or German story telling. The basis for the novel story telling and translation over a long period was an attempt at cognitive loading language use, and hypothetically, continuous use of the left dorsolateral inferior frontal cortex.

4.53 Results

4.531 Language Task Observation

Subjects stated they enjoyed the task, and expectedly had ease with the translation of English into German. They found the task more difficult when they had to translate the German sentences into English, because their English vocabulary was not as profound as their German. They showed signs of sleepiness in the final two hours of the task and made more translation errors. Speech slowed and their voices lost normal changes in tone, in fact, at the end of the session, their speech had flattened affect. The stories and observations became less elaborate towards the end of the session and they took more time between sentences. 45 minutes after the beginning of the language study, one of the subjects repeated the German sentence in German and failed to realise he had not translated into English until it was pointed out to him. 2 hours into the language session, subjects had difficulty word finding and perseveration of previous words. Four hours into the session, subjects were making paraphasic errors (substituting one word for another, inappropriate word), and in the final hour subjects were mumbling their sentences, not fully pronouncing words, and showed signs of giddiness. At the completion of the session, both subjects expressed pressing sleepiness and were anxious to go to sleep. It should be noted that the above observations of language changes (e.g. slowed speech, flattened affect and perseveration) indicated fatigue of language skills and was a reported observation to indicate neuronal activity (and fatiguing of that functional area) in the brain. This was to be followed with an EEG analysis to determine if the verbal 'busy day' affected subsequent sleep. The changes in speech themselves do not indicate anything about sleep function.

4.532 EEG Analysis

Unfortunately, EEG Analysis could not be conducted on either subject's data. Data for one subject was lost due to a Medilog recording failure on the experimental night. Data for the remaining subject was processed according to Medilog procedures, however, was lost during the digitising/analysis step of the procedure due to a computer failure. While very disappointing, this Pilot Study was not a failure in that the qualitative observations during the language task were helpful in formulating hypotheses regarding the effects of generalised sleepiness on language skill. These observations, when compared with the observations from Pilot Studies One and Two, suggest a pattern of generalised sleepiness on language skill including aprosodia, or flattened affect, increased time spent choosing and generating words, and lack of

articulation of words, or mumbling. These observations helped to formulate the hypotheses for Sleep Loss Effects on Language Skill: A Systematic Analysis (see Chapter 5).

While it was outside the scope of the research questions for this thesis, and due to failure during data collection no analysis of the potential EEG changes were observed, the effects of daytime activity having a specific effect on sleep patterns is an intriguing area of future study. With improving brain scanning techniques, it may be possible to make a more significant statement using PET or MRI, versus the gross measures of EEG.

4.6 Discussion

Experimenter observation and subject reports suggest that sleep loss has an effect on language similar to symptoms of an aphasia disorder. Horne (1993) suggested that speech in sleep deprived individuals shows aprosodia, or a loss of intonation in speech. This was further reported in Harrison & Horne (1997) who reported lack of appropriate use of intonation in reading aloud from a written passage. Results from the pilot studies indicated a need to further examine varied areas of language function associated with spontaneous speech and divergent thinking tasks. In order to further examine systematically the changes associated with language function in sleep loss, prompts from the Western Aphasia Battery (Ketesz, 1982) and Boston Diagnostic Battery (Goodglass & Kaplan, 1972) were adapted to test subjects on spontaneous language function. In response to further findings from the pilot studies, the experimental tasks were to be delivered to subjects alone in a test room, to minimise the experimenter's influence on subject performance. To decrease subjects' testing time, the rudimentary aspects of the Aphasia Battery, such as 'yes, no' questions, repetitions of words, and generic questions (e.g. What is your name/occupation?), were left out of the following studies. The comparison between Pilot Studies One and Two suggested length of time awake would prove to be an important factor in sleep loss and language skill.

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Chapter 5
Microanalysis of Language
and Sleep Loss

5.0 Microanalysis of Language and Sleep Loss

5.1 Sleep Loss and Language Performance

In the current 24-hour environment it is not unusual for people to go without sleep for one night and continue working into the following day. Particularly in the defence and emergency services industries, and increasingly in the business community, situations arise in which managers must engage in decision making, strategic planning, and novel thought to achieve success in a given situation following a period of sleep loss. In a review of sleep loss and decision making studies, Harrison & Horne (1998a) suggested that this type of thinking includes;

> *appreciating a complex situation,*
>
> *creative thinking,*
>
> *monitoring a changing situation,*
>
> *developing and revising plans,*
>
> *temporal placement and sequencing events,*
>
> *motivating oneself and others,*
>
> *controlling mood and behaviour,*
>
> *showing insight into one's own performance and the performance of others,*
>
> *and communicating effectively.*

While many of these behaviours have been examined in recently reported studies of sleep loss, effective communication has been neglected, even though it is an integral aspect of many of the tasks used to assess sleep loss effects. Effective communication, and the underlying abilities of language comprehension and production, both in verbal and written form, require further study to assess their sensitivity to sleep loss.

Communication represents a massive area of psychological examination and has many diverse, multi-faceted fields of psychology derived or associated with it. Language itself has been studied from base sound formation of phonemes and morphemes, to the written symbols of letters and words, to the complex integration of all aspects of language necessary for the production of verbal and written speech. Historical accounts of speech content and pattern changes in response to sleep loss

have been reported anecdotally in the literature but the examination of speech changes has not been studied systematically. In a simulated communication task of sending and receiving complex messages Schein (1957) reported that subjects had more difficulty receiving than sending messages however, there were also changes in speech production including; slowing down, poor enunciation, mispronouncing words and repeating themselves or losing their place in speech (forgetting what they are saying). These reports were made after two nights (approximately 50 hours) without sleep.

Written comprehension has previously been reported to be unaffected by two nights of sleep loss (Webb, 1986) but sustaining performance on a reading task was reported to be difficult for sleep deprived subjects. Webb tested middle-aged subjects in a circadian trough following two nights (approximately 50 hours) of sleep deprivation and reported 4 of 10 subjects could not perform the reading task and only 3 subjects were able to maintain their initial performance level across the task. Reading comprehension with short-term deprivation is not known.

Harrison & Horne (1997) reported difficulty for sleep deprived individuals in the spontaneous generation of words in a word fluency task and changes in the articulation of speech during a vocalised reading task after 36 hours of sleep loss. Horne (1993) mentioned certain effects of sleep loss mimicked an aphasiac tendency to aprosodia (loss of intonation) however, no further examination of language deterioration has been systematically analysed and documented.

While communication and divergent thinking can occur continuously in a typical night without sleep (e.g. between managers/emergency service providers/military personnel) the evaluation of these activities presents a problem to applied psychology researchers when attempting to define and study the behaviours individually. In addition, there is added difficulty in resolving these highly complex processes to their component behaviours such as memory, speech production and comprehension, written production, and written comprehension. In order to isolate the effect of sleep loss, i.e. by removing the boredom effects of continuous measurement, it is necessary to give tasks that are novel, short, and interesting to evaluate the underlying behavioural decrement associated with the task. This deviates from 'real-world'

conditions of a working night without sleep (which would typically include periods of boredom and continuous work), nevertheless is necessary when examining specific language performance rather than the non-specific, sleepiness factor.

Following from the previous research discussed, this chapter attempts to focus on the specific language difficulties associated with sleep loss. While previous research has explored various aspects of speech and communication, none have specified the *exact* language difficulties observed during sleep loss, and many of the reports have been anecdotal. Since time of testing has been found to be an important factor in task sensitivity to sleep loss (see Chapter 2; Webb, 1986), this chapter will examine decrements in language function following 27 hours and 36 hours without sleep, with and without countermeasures.

In an attempt to document the effects of sleep loss on language and communication, discursive tasks from the Western Aphasia Battery and the Boston Aphasia Diagnostic Battery were used to examine error patterns in language during periods of spontaneous speech and written communication. The main aim of this study was to document detailed effects of sleep loss solely on two aspects of language, spontaneous oral and written language production. At this point, it is unknown whether the effects of sleep loss on language is a specific or non-specific effect of sleepiness.

5.2 Method

5.21 Subjects, Design and Materials

For a review of the subjects, design, and other materials used in this study refer to Chapter 2, pg 40-41 & 69. For a review of how the groups differed with regard to the other tasks performed, refer to Chapter 2 Results, pg 51-94. As stated on pages 40 and 69, subjects were randomly allocated to groups. The information presented here relates specifically to the tasks of systematic language analysis.

The control group (N=22) has been derived by collapsing data from the two Control-placebo conditions (see Chapter 2, Study 1 and 2 for further description) to help decrease error and have a more accurate measure for baseline performance. As stated

in Chapter 2, initially, collapsing the control data proved to be a dilemma because of its effect on the sample sizes for each variable measured. However, by examining the control data, it was obvious that any differences between the control performance were random occurrences (i.e. there were no significant differences between the sub-groups in the control sample) and therefore the data was collapsed together to provide a more substantial baseline group for comparison with the experimental manipulations.

Table 5.1 Group Composition for Analysis

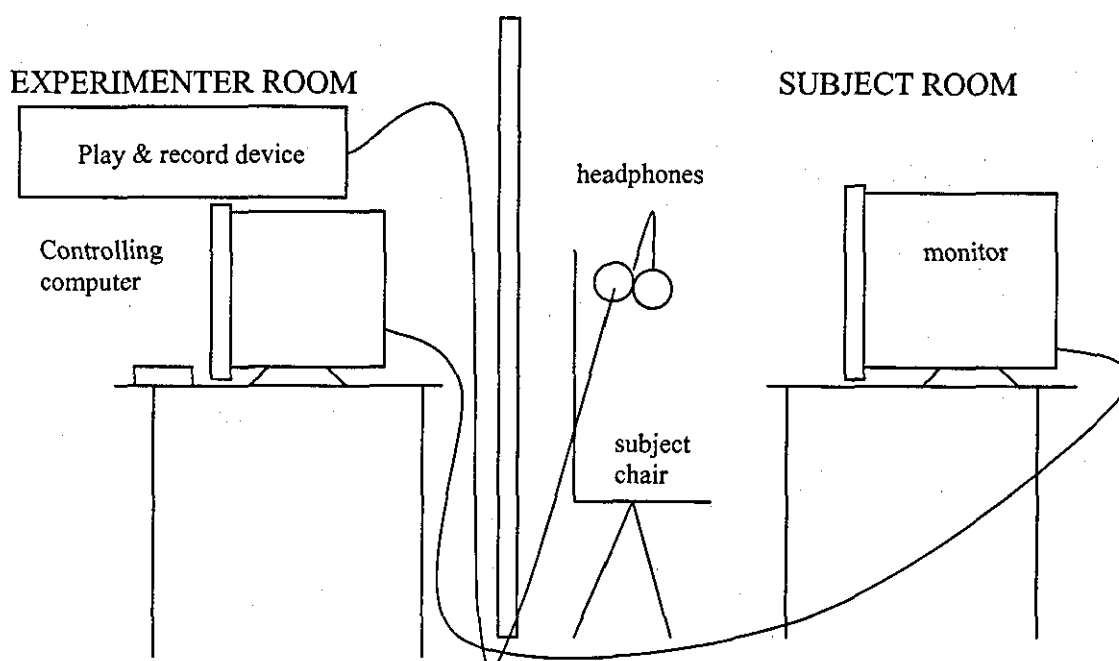| Experimental Group	Symbol	# of Subjects
Control	Ct	22
AM Control – Caffeine	AM Ct - Caffeine	11
27-h SD	AM SD	11
27-h SD – Caffeine	AM SD - Caffeine	11
36-h SD	PM SD	10
36-h SD – NAP	NAP	10

5.22 Materials specific to language performance tasks

The individual testing was carried out in a sensory-muted room where the subject sat at a table in front of a 26 - cm computer monitor (type CTX). The monitor was adjusted to a proper viewing height and the subjects were fitted with adjustable sound head phones (Genexxa HMP010) and attached microphone (see Figure 5.1). The subject computer monitor was connected through linked cable to the experimenter monitor and computer (PC-486) in an adjacent room. The experimenter controlled subject viewing of the diagram prompts (see descriptions below) from the control PC.

The headphones and microphone were connected to a stereo play and record system such that the voice recorded instructions could be played through the subject headphones and timed according to the subject pace for the appropriate tasks. The instructions and subjects' responses were recorded via the Genexxa microphone and amplifier such that the voice recorded instructions and the subjects' responses were recorded onto individual FUJI DR IEC1/Type 1 90-minute tapes together. The system was linked to computer speakers so that the experimenter could listen to the subjects' responses and the voice recorded instructions and time the visual displays accordingly.

The language tasks were taken from the Western Aphasia Battery (Kertesz, 1982) with one task selected from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972). These tasks were tested in a pilot study (see Chapter 4, Pilot Study Two) for sensitivity to this age and education level. Anecdotal evidence from the literature suggested there would be a deterioration in language skill, although it was expected that this would be subclinical. Therefore, the tasks were selected from the battery which were appropriate for this level, and could be analysed with the expectation of homogeneity within groups.

Figure 5.1 Subject testing display

1. **Verbal Production (The Boston Cookie Theft Picture)**

   Subjects were given oral instructions to verbally describe what they saw

   occurring in the back and white drawn picture, entitled the Boston Cookie Theft

   Picture (Goodglass & Kaplan, 1972) (appendix 14). This task was based on the

   examination of spontaneous speech described by Kertesz (1982) in the Western

   Aphasia Battery. Obler, Au, & Kugler (1994) reported that healthy elderly

   subjects have a highly variable response to this task. The Boston Cookie Theft

   Picture is part of the Boston Aphasia Battery and is typically used to test

   individuals with frontal lobe damage to assess their spontaneous speech

   production. By allowing the individual to view the picture during the entire task,

   the picture observation task is not a test of memory. In addition, this task is

   subject paced and encourages spontaneous speech by allowing the subject to

   speak for however long they feel is necessary to accurately describe the picture.

2. **Written Production (WAB -Picnic Scene)**

   Subjects were given three minutes to write a story about a black and white

   drawn picture from the Western Aphasia Battery (Kertesz, 1982) (appendix 15).

   The picture was available for the subjects' reference for the entire three minutes.

This task examines writing on request and measures written fluency. No memory load is imposed on the subject for this task.

5.23   Method of Analysis

5.231 Objectivity

The data has been transcribed and analysed by computer coding every word according to dictionary definitions/classification and manually counting the words by category. The manual counting was carried out by two judges who were blind to the experimental conditions, had strict written guidelines (see Appendix 19) and practice in scoring (for examples of unscored and scored data, see Appendix 20-22). Due to budget constraints, I was one of the two independent judges. A number of steps were taken in an attempt to maintain objectivity when scoring both spoken and written speech. All data, both spoken and written, was transcribed into Microsoft Word. Spoken data was transcribed and checked three times for each subject to ensure accurate transcriptions. I performed all transcriptions myself at the end of each data collection period (approximately 2 months), rather than after each session to avoid bias through familiarity with the subjects' voices. All subjects were given the same subject code for each study (e.g. SBR22/REC13) followed by a number so that the subjects' condition could not be determined by reading the subject code.

The computer coding was performed simultaneously on all subjects' data for each task to ensure reliability in coding, i.e. all data was stored in one file and each word was colour coded for the entire file by 'Find/Replace' functionality. The analysis for the language tasks was modelled after the methods of Haravon, Obler, and Sarno (1994) who documented a methodology for microanalysis of speech specific to the Boston Cookie Theft Picture. Their method of analysis was used to measure normal, healthy adult speech of 4 separate age groups. They derived the method in order to analyse the speech of fluent aphasic patients and brain damaged patients who are not aphasic but whose language patterns are similar to aphasics. For a more general review of the neuropsychology of language, I would recommend Kolb & Wishaw (1996) Fundamentals of Human Neuropsychology, 4th ed, which offers an excellent review of the neurological perspective of language function.

The analysis relied on coding length of speech, speech rate, errors in speech and use of lexical items in morphology and syntax. It is a word-by-word classification and analysis system. This is considered a microanalysis of discourse. The focus for this analysis was on morphological units and lexical classification as well as the (relatively rare) syntactic errors within sentences and aposiopesis, "the abrupt termination of an utterance that leaves a thought incomplete" (Hier, Hagenlocker, & Shindler, 1985, p. 119).

5.232 Morphology

Unit counts were made for all utterances (or written production in the case of the WAB-Picnic Scene - description below), and then separated for all lexical items and all errors, such as number of repetitions, fillers, and stereotypies. Repetitions could be syllable, word, phrase or sentence repetitions. Fillers are sounds that are common in speech that serve to fill a space while processing information or deciding what to say next, e.g. ums and ahs. Stereotypies are words or phrases that are idiosyncratic to the individual, and are repeated frequently in speech. Examples of these words or phrases are; like, so, yeah, I don't know, y'know, etc.

While all data was transcribed and counted for unit total, analysis was conducted only on the first 100 words of speech.

As reported by Haravon, Obler, & Sarno (1994) two general categories (substantives and functors) were used when classifying words into lexical groups. Subcategories were additionally classified within those categories including for substantives; nouns, verbs (main and infinitival), gerunds, adjectives, and adverbs, and for functors; pronouns, auxiliary/copula/modal verbs, conjunctions, articles, prepositions, and remaining words that do not fall into any of the other categories. While every attempt was made to clearly define all words in the computer analysis to ensure objectivity of word classification, some words were classified by the independent raters according to dictionary definitions. Any independent classification was agreed by both judges in discussion. Note in this system any unit could be double or triple classified because this method of analysis allows for numerous analyses (e.g. words can be lexically classified as nouns but also be repeats or stereotypies).

Lexical errors were also classified and these included indefinite words such as "thing", "something", and "anything", any nonwords, or semantic paraphasias (substituting one word for another in the same semantic category, e.g. "chair" for "stool" or "she" for "he").

5.233 Syntax

Syntactic errors were classified as omissions or paragrammatisms. Omissions were charted if a word was left out of a phrase when clearly in Standard English it should be present, e.g. "He falling" where "is" has been left out. Paragrammatisms include misuse of functors, word order errors, and idiom errors. Omissions and paragrammatisms were collapsed together for analysis.

5.234 Pragmatics

Pragmatic errors include aposiopesis, making personal judgements about the scene, making statements of unsureness, apologies, personalisation of the material, and giving names to the characters in the scene. It is interesting to note that pragmatic errors more often occur in the speech of healthy controls than in brain-damaged patients (Haravon, Obler, & Sarno, 1994).

Note: It may be questioned how criteria for conversational speech differs from written speech. It is important to note that transcribed conversational speech is treated as the spoken word (transcription is simply the form in which the spoken word is more easily analysed) while prose writing (which is not written speech) is treated as written text. The criteria for analysis does not differ between conversational speech and prose writing in this study, as microanalysis is based on grammatical structure and word-by-word classification. For further understanding of microanalysis of speech, refer to Haravon, Obler & Sarno (1994) and to the entire book edited by Bloom, Obler, Desanti & Ehrlich (1994) Discourse Analysis and Applications: Studies in Adult Clinical Populations.

5.3 Results

Analysis was conducted using two separate methods. One-way ANOVAs with post hoc Tukey$_a$ comparisons were used for each variable as a conservative measure of changes in response to sleep loss and countermeasures. As a less stringent test, planned comparisons were conducted using t-tests for three separate comparisons: Control vs. 36-h SD, 36-h SD vs. NAP, and 27-h SD vs. 36-h SD. This was done in an attempt to avoid Type II Errors associated with the conservative one-way ANOVA, since a small effect was deemed to be more likely than a large difference in spontaneous language. All six groups were analysed in the one-way ANOVAs. Significance level was set at $\alpha = .05$. Analysis was conducted on all language variables discussed above, including grouped variables, such as; substantive word total and number of errors. Note that in each of the analyses the control group N = 22. This is due to the pooling of the control group results to provide a more accurate representation of 'normal' performance. Means and Standard Deviations for the language production results are reported in Appendix 16.

5.31 Verbal Production (Boston Cookie Theft Picture)

One-way Anova

When comparing the six groups, no differences between mean responses were observed for the following language variables: total number of units spoken, time taken to completion, speech rate, number of nouns, verbs, gerunds, adjectives & adverbs, pronouns, auxiliary verbs, conjunctions, prepositions, number of fillers, indefinite words, stereotypies, personalisations/judgements/unsureness, semantic paraphasias, repetitions, and paragrammatisms, or total number of errors. The only significant difference observed using the one-way ANOVA was on the substantive word total ($F(69, 5) = 2.34$, $p = .05$) (See Figure 5.2). Post-hoc analysis indicated a difference between 27-h SD and 36-h SD groups. Two additional measures were nearly significant using the one-way ANOVA; an error measure, number of fillers

, 5) $= 2.19$, $p = .065$, **ns) (See Figure 5.3), and a functor measure, number of junctions ($F(69, 5) = 2.32$, $p = .053$, **ns) (See Figure 5.4). Number of functors could also be considered an error measurement, since repetitive use of functors (such as 'and' and 'because') is considered poor use of language.

Figure 5.2 Substantive Word Total

Figure 5.3 Error Measure: Number of Fillers (e.g. 'ums', 'ahs')

Figure 5.4 Functor/Error Measure: Number of Conjunctions

A priori Comparisons

1. Control vs. SD

The less stringent a priori t-test comparisons indicated significant differences in a number of other measures between the control and 36-h SD group. They included a difference in the mean time taken to completion (t=2.16, p = .04)(see Figure 5.5). The other differences between the Control and SD groups related to significant differences in their variance and will be discussed under the Variance results below.

Figure 5.5 Difference in Time taken to completion between Control and 36-h SD.

2. SD vs. NAP

Differences in means for the SD vs. NAP group were limited to the number of nouns produced (t = -2.48, p = .023). There were a number of differences between groups for the variance in response (see Variance results below).

3. 27-h SD vs. 36-h SD

T-tests of mean differences between 27-h without sleep and 36-h without sleep indicated a large number of differences in performance. Following 36 hours, SD subjects produced significantly fewer total words (t = 2.19, p = .04) (See Figure 5.6) and took less time (a related measure: t = 3.5, p = .002) (See Figure 5.5) than after 27

hours. In addition, fewer substantive words were spoken ($t = 2.66$, $p = .022$) (See Figure 5.2). Within the substantive word category, fewer nouns ($t = 2.6$, $p = .017$) (See Figure 5.7) and fewer verbs ($t = 2.6$, $p = .016$) (See Figure 5.8) were produced after 36-h than after 27-h without sleep, while the differences between adjectives and adverbs approached significance ($t = 2.06$, $p = .053$, **ns) (See Figure 5.9).

Figure 5.6 Total number of Units Produced

Substantive Words: Subcategories

Figure 5.7 Number of Nouns

Figure 5.8 Number of Verbs

Figure 5.9 Number of Adjectives & Adverbs

Variance

One of the most striking findings in examining the Verbal Production of SD subjects
was the significant difference in variance for a number of the measures. In terms of
time taken, variance decreased with SD (See Figure 5.10 for an illustration of the
variance of time taken). A Levene's test for Equality of Variance indicated Controls
had a significantly higher variance than SD subjects (F = 5.49, p = .026). It is possible
that sleep loss impacts time taken by removing individual differences in speech.
There was a tendency towards shorter response times in sleep deprived individuals.
In addition, Controls had a greater variance in the number of personalisations,
judgements, and statements of unsureness than SD subjects (F = 5.4, p = .027) (See
Figures 5.11 & 5.12 for variance and means charts). The difference in means between
control and SD subjects for the measure of personalisations, judgements, and
unsureness approached significance (t = 1.97, p = .059, **ns). Personalisations,
judgements, and unsureness are measures of pragmatic errors. It is possible the
emotive content of giving names to characters (personalisation), critically analysing
the contents of the picture (judgements), and hesitating before making definitive

statements (unsureness) is inhibited at 36-h of sleep deprivation. Statements of this nature require additional effort, and volunteered information.

Figure 5.10 Variance of Time Taken

Figure 5.11 Variance of Personalisations, Judgements, and Unsureness

Figure 5.12 Illustration of Mean Differences in Personalisation, Judgements, and Unsureness (note: non-significant trend)

In a measure of error, repetitions of words, phrases, and sentences, SD subjects had a significantly higher variance or response than Control subjects ($F = 7.79$, $p = .009$) (See Figure 5.13 for illustration).

Figure 5.13 Variance of Repetition Errors

Differences in variance were apparent between SD and NAP subjects on three error measurements. On all three measures, stereotypies (F = 5.06, p = .037) (See Figure 5.14), repetitions (F = 8.81, p = .008) (See Figure 5.13), and paragrammatisms (F = 8.46, p = .009) (See Figure 5.15), SD subjects had a higher variance than NAP subjects. Differences in number of repetitions was not significant for any measure, even though it approached significance when testing differences between SD and NAP (t = 1.98, p = .064). An illustration of the trend in errors (as measured by number of repetitions) is provided in Figure 5.16.

Figure 5.14 Variance of Stereotypies

Figure 5.15 Variance of Paragrammatisms

Figure 5.16 Illustration of Mean Number of Repetitions (note: non-significant trend)

Only one difference in variance was apparent between 27-h of SD and 36-h of SD, on the measure of Substantive Word Total (For means chart, see Figure 5.2). Levene's test for equality of variance indicated a higher variance for 36-h SD than 27 (F = 16.4, p = .001) (See Figure 5.17). The decrease in mean number of substantive words with an increase in the variance suggests that overall, there is a decline in verbal production with increasing sleep loss, however, individual differences in response to sleep deprivation is increasing the variance in verbal output.

Figure 5.17 Variance of Substantive Word Total

5.32 Written Production (WAB – Picnic Scene)

One-way ANOVA

Analysis of written language production under sleep deprivation conditions suggests that spontaneous writing is much easier than spontaneous speaking for SD individuals. The number of analyses conducted was 10, including Total words spoken, nouns, verbs, gerunds, adjectives & adverbs, pronouns, auxiliary verbs, conjunctions, prepositions, and errors.

Only one measure was significantly different between groups (number of pronouns produced: $F(66, 5) = 2.5$, $p = .039$) in a one-way ANOVA analysis. Post-hoc Tukey analysis indicated 36-h SD subjects used fewer number of pronouns than Control-Caffeine subjects in the written task ($t = -4.2$, $p = .023$) (See Figure 5.18). Trend analysis indicates that for written tasks, the 36-h SD subjects are producing fewer words, but also fewer errors than the control groups. This may indicate the SD subjects are slowing down when writing in order to maintain correct grammatical and lexical structure. Pronouns were used most often to attribute cause to an individual described in the scene, e.g. 'There is a young boy standing by a dog. *He* is waving to a passing sailboat.' Fewer number of pronouns for SD individuals may indicate that they were making statements of presence (e.g. ' There is a couple sitting on a blanket.), rather than making further descriptive comments (e.g. ' They look happy'/ 'He is reading'/'She is pouring a glass of juice').

Note the change in subject numbers was a result of a technical error during recording of three subjects. As well, for the Written Production task all error categories were pooled under the heading Errors, due to so few errors in each category. In general, people will produce a much larger number of errors in speech than in writing, possibly due to the speed of speech when compared to the written word. Errors are defined here as utterances or word use that differ from the correct, grammatical construction of the English language. While conventional, conversational speech does deviate from the correct grammatical construction defined in English, that grammatical construction is an excellent baseline for study when classifying work by word discourse.

Figure 5.18 Written production – number of pronouns produced

A priori Comparisons

Planned t-tests between Controls and the PM SD condition indicated the SD group produced significantly fewer total words (t = 3.43, p = .002) (See Figure 5.19), fewer nouns (t = 2.51, p = .018) (See Figure 5.20), fewer pronouns (t = 2.63, p = .014) (see Figure 5.18), and fewer conjunctions (t = 2.74, p = .010) (See Figure 5.21). These measures indicate that the SD group is outputting fewer words, which may indicate they are taking longer to write than the Control group.

Figure 5.19 Written production – number of total words produced

Figure 5.20 Written production – number of nouns produced

Figure 5.21 Written production – number of conjunctions produced

Comparisons between the SD and NAP group indicated a nearly significant trend towards SD producing fewer total words than the NAP group (t = -2.04, p = .058, **ns) (See Figure 5.19). SD subjects produced significantly fewer pronouns than the NAP group (t = -2.48, p = .024) (See Figure 5.18). No other differences were found.

Comparisons between the 27-h SD and 36-h SD groups indicated a nearly significant difference on number of pronouns produced (t = 2.09, p = .058, **ns), and a significant difference in variance for number of pronouns produced (F = 7.66, p = .014) (refer to Figure 5.18 for illustrations of both means and standard deviations).

Both a priori and post-hoc analysis of written production indicate a decrease in output by sleep deprived individuals. Rather than an increase in error, there is slower production in the time limited task. Whether this is defined as a specific or non-specific effect of sleep loss depends on whether language is accepted as an executive functioning task. Invariably, components of the brain malfunction or deteriorate under stress in qualitatively different ways, leading to an overall slowing

down, (Horne, 2000) however this is not evidence of only non-specific effects of sleep loss. Horne has argued that given the great diversity in the structure and function of brain tissue it is reasonable to propose that there are some regions more affected by sleep loss and that these differences might be qualitative, rather than quantitative.

5.4 Discussion

Analysis of mean responses indicates that SD subjects speak for a shorter length of time and use fewer words when giving verbal descriptions. This trend is noticeable after 36 hours without sleep, but not after 27 hours, indicating the critical period of sleep loss sensitivity of verbal language production is sometime between 30-36 hours without sleep. It is anticipated, based on past research (Schein, 1957; Webb, 1986) and the current findings, that language deficits in response to sleep loss will progressively increase beyond 36 hours without sleep. Analysis further indicated a 2-hour Nap opportunity is sufficient to overcome the effects of sleep loss on verbal production.

These findings suggest that the critical period of decline for executive functioning tasks is at 36 hours. It is important to note that while some researchers would argue that speech is not an executive function, I would maintain that there is a basis for speech being included under the executive functioning category. This basis is dependant on human neuropsychological testing to determine localisation of language function in the brain and studies of anthropology. Tests reported by Posner & Raichle (1994) and Damasio & Damasio (1992) indicate frontal lobe activation during speech generation (see neurological discussions on Broca's area and localisation of language for further descriptions. I suggest Kolb & Wishaw (1996) as a good place to start). In addition, comparisons between human and other animals (even our closest genetic relatives, the primates) indicate that speech is the one outstanding, differentiating feature between us and other animals, which would indicate speech is an executive functioning behaviour.

Testing at 27 hours does not reveal decrements in language performance in response to sleep loss. It appears the critical period for declines in executive functioning performance is at 36 hours without sleep. In addition to this, this study also coincided with the reports from Chapter 2 that a 2-hour nap opportunity is a sufficient countermeasure to sleep-loss induced performance decrements at 36 hours without sleep.

A notable finding from this study is the difference in variance between SD individuals and other groups on time taken to completion and on emotive responses (Figures 5.10 & 5.11). This indicates that sleep loss has a generalised effect on maintaining language performance and interest in the subject matter. Interestingly, increases in variance are observed at 36-h without sleep on repetitions, stereotypies and paragrammatisms, all measures of error. It appears that some individuals respond to sleep loss with a larger increase in errors than other individuals. Analysis of potential subgroups in the subject pool did not indicate any specific cause for this variable response to sleep loss (e.g. when looking at gender/age). A striking feature of the error measures, however, is the increase in variability in response to caffeine for both the SD and control groups (refer to Figures 5.13, 5.14, & 5.15 for illustration). Similar to Chapter 2, findings from this study indicate there may be individual language differences in response to sleep loss, which could produce additive effects with individual differences in response to sleep loss. It is important to note however, that I cannot claim that individual differences were really found. In order to find these I would need test-retest correlations, or correlations between deficits in performance on different tests, or a personality factor (e.g. extraversion, locus of control) that correlates with deficits after sleep loss. All that I can claim here is a greater variability of performance on one occasion. I cannot state whether those with the worse performance would do worse on another occasion, or on another test.

This analysis indicates the need to review the appropriateness of using verbal production as a mode of testing other effects of sleep loss (e.g. memory, metacognition, creative thinking, etc.). If sleep loss has an effect on verbal production, as indicated in this study, using speech in testing other higher functions adds a significant confound to tests of sleep loss sensitivity.

Analysis of written output indicated a slowing of output with sleep loss, and only after 36 hours without sleep with no increase in number of errors. The number of errors produced in written production was minimal, regardless of sleep or caffeine condition. This indicates written production may be a more sensible choice when attempting to test higher order functions, however only on tasks where time taken is not limited.

As was suspected, sleep loss does not produce clinical levels of aphasia when examining verbal output however there are noticeable similarities between the effects of sleep loss and symptoms of some types of aphasia. These similarities include a slowing down of production, time taken to respond, a lower variability of responses when compared to control groups on time taken to completion & emotive responses and trends towards decreases in substantive word use. See Haravon, Obler & Sarno (1994), Obler, Au, Kugler et al. (1994) and Kolb & Wishaw (1996) for further discussion on aphasic symptoms and gradients of decline on language ability.

5.41 *Evaluating Language Performance*

Frontal lobe function has been implicated in many aspects of language, including speech production and comprehension. Neuropsychological tests on language function involve assessing patients with language impairments and comparing similar symptomology to location of lesions. Included in the classification of language impairments is the multi-faceted disorder of aphasia.

Aphasia refers to a disorder of language observed in writing, reading, or speech, occurring after brain injury to the relevant areas (Kolb & Wishaw, 1996). Symptoms of language disorder include: poor auditory comprehension, poor visual comprehension, poor articulation, word-finding deficit, unintended words or phrases, loss of grammar and syntax, inability to repeat aurally presented material, low verbal fluency, inability to write and loss of tone of voice. Many of these symptoms have been identified in sleep loss subjects. Morris, Williams & Lubin (1959) noted subjects were increasingly difficult to understand, made more speech errors, repetitions, mispronunciations, and sentences trailed off without endings during the period of sleep deprivation. Schein (1957) reported subjects lost voice tone, frequently paused and interrupted speech, enunciated poorly, mispronounced word, and repeated words or phrases. The similarities between the language deficits of frontal lobe patients and the language effects observed in the literature and the pilot study (Chapter 4) prompted this investigation.

While different types of aphasia are difficult to categorise due to the relatively few cases and the wide assortment of symptoms, attempts have been made to classify specific cases. Transcortical aphasia, also termed isolation syndrome, shows a

remarkable similarity to the language deficits observed in SD individuals. In Transcortical aphasia, patients can repeat and understand words and name objects, but have a marked tendency to reduction of spontaneous speech and inertia (Kolb & Wishaw, 1996). Comprehension could be poor due to a failure of words to arouse associations and production of meaningful speech could be poor because the production of words is not associated with other cognitive activities in the brain. In addition to this, symptoms characteristic of mild Broca's aphasia are characteristic of SD tendencies in language production. There are slight but obvious articulatory disorders, phonemic paraphasias with anomia, agrammatism, and dysprosody. For example, anomia was shown by SD individuals, when describing the Boston Cookie Theft Picture, calling the stool 'a chair' and the window 'a door', or a plate 'a pot'.

The critical period for this decline in functioning in speech is hypothesised as occurring around 36 hours without sleep and progressively increasing beyond 36 hours, to the times tested by Schein (1957) and Morris, Williams & Lubin (1959) (approximately 50 hours without sleep). This hypothesis will be further discussed in Chapter 6.

This study attempted to draw on two types of language skill used in real-world tasks to systematically study language in sleep deprived individuals. While the short duration of the sleep deprivation did not allow fine measures of changes in language function during sleep loss, it did help to define the period of decline. It does appear that any effect sleep deprivation has on language and communication ability occurs near to, or after, 36-h of sleep deprivation, and has a variable effect depending on the individual. It is hypothesised that any indication of language changes during sleep loss before 36-h is an effect of generalised sleepiness and not of specific frontal lobe impairments. However, the time of testing reported by Bard (1996), May & Kline, (1987) and Schein (1957), and comparisons of the sleep literature to the aphasia literature indicates possible specific frontal lobe effects on language skill following sleep loss. The question of whether generalised sleepiness could possibly increase after 36-hours to give the effects is one that needs clarification given that in order to test specific effects of sleep loss, it is important to first removed generalised sleepiness because the effects of generalised sleepiness are so strong they mask any

specific effects. I am not disputing in this thesis that generalised sleepiness has a debilitating effect on SD individuals.

Figure 5.22 Answering the Research Questions

Attempting to Understand the Role of Language as a Tool and as an Executive Functioning Task

• The use of verbal production as a mode for studying effects of sleep loss on executive functioning is inadvisable because sleep loss appears to have an effect on verbal production. Sleep loss has variable effects on sleep deprived individuals, owing to individual responses to sleep loss. The significant effects observed using verbal production were not present when using written production, making written production the more suitable method for testing, when not under time constraints.

• Sleep loss appears to have relatively little effect on language skill up to 36 hours without sleep. At this time, the critical period, more specific effects of language deterioration are observed, including decrease in substantive words and increases in errors. Substantive words indicate a specific effect otherwise, there would be a decrease in all words. This finding suggests a specific effect of sleep loss on language skill, which begins to be observable at approx. 36 hours. Observations reported in the literature indicate findings of specific effects are exacerbated with increasing sleep loss.

Theorising the Answer to the Specific vs. Non-Specific Question of Sleep Loss

• The findings from Chapter 2 and Chapter 5 indicate *both* non-specific and specific effects of sleep loss, which are observable over different periods in the sleep loss time course. See Chapter 6 for further

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Chapter 6
Discussion

6.0 Discussion

This thesis intended to examine the effects of sleep loss and countermeasures on executive functioning tasks and to conduct a systematic analysis of the effects of sleep loss on language and communication. Through examinations of executive functioning performance following 27-h and 36-h without sleep, using 200mg of caffeine and a 2-hour nap opportunity as separate countermeasures, the effects of sleep loss on executive functioning were further documented. There appears to be very minor effects of sleep loss at 27-h without sleep, and these effects can be overcome by 200 mg of caffeine. There also appears to be a critical point near to 36-h without sleep at which point executive functioning performance deteriorates. A 2-h nap opportunity is sufficient to overcome this decline in performance.

A microanalysis of language skill, both verbal and written production, was conducted to systematically analyse the effects of sleep on language. This analysis indicated that there is no significant deterioration in language skill at 27-h without sleep, but there are definite changes in verbal production at 36-h without sleep. These changes include a decrease in output, a decrease in emotive content of spontaneous speech, and an increase in the variability of errors. The changes observed with verbal production were not mimicked by written production. Changes in verbal output were not systematically affected by caffeine intake, however a 2-h nap opportunity was sufficient to overcome the decrements in performance associated with 36-h of sleep loss. It is notable that all effects observed in these experiments were relatively minor, and their statistical significance dependent on the conservative nature of the statistical test chosen.

The initial hypothesis that there would be increasing decline in performance with increasing sleep loss was not substantiated by the data. Instead, the findings proved to be nonlinear with respect to decline in functioning, with the surprising discovery of the critical period at 36-h without sleep. The hypothesis that caffeine would not have an effect on executive functioning performance at 27 –h without sleep loss, as was reported by Harrison et al. (1999) at 36-h, was also not supported by the data. The findings with relation to caffeine were complicated and difficult to interpret,

particularly as a secondary issue to the main research question of the effects of sleep loss. While it was an unexpected finding, the most important point to be made about the cumulative research in this thesis is the detection of the critical period for decline in executive functioning.

The collective findings of this thesis allow for further speculation on the Specific vs. NonSpecific Effects of sleep loss.

6.1 Executive Functioning during Sleep Loss

As was mentioned in Chapter 1, the term 'cognition' can be given a number of different meanings. Examination of the current literature on cognitive functioning and sleep loss provides a vast number of varied psychological tasks used to evaluate the effects of sleep loss on cognitive skill, yet categorising these varied tests into groups proves difficult. Different studies use different tests of sleep loss sensitivity and within each of these tasks there are various factors that can effect performance during sleep loss (Johnson, 1982). These include:

- Level of Generalised Sleepiness,
- Task Variables such as;
    - Duration
    - Knowledge of results
    - Difficulty of task
    - Task pacing
    - Proficiency level
    - Task Complexity
    - Memory requirements
- Non-task Factors
    - Psychological - high interest, motivation, personality, repeated experiences,
    - Situational Factors - exercise, noise, temperature, drugs, breathing atmosphere
- Circadian Rhythms

As is evident by the above list, sleep deprivation studies are labour intensive for both subjects and experiments. Considering the number of variables that must be controlled or manipulated, it is not surprising that it is difficult to find comparable reports in the past literature to new sleep deprivation experiments.

In order to have a comparable basis, the tasks used in this thesis were modelled after those used by Wimmer, Hoffmann, Bonato, & Moffitt (1992) and Harrison & Horne (1997, 1998a, b, 1999a, b, c) in support of the claim that executive functioning cognition, also termed 'higher' cognition, is sensitive to sleep loss. The ideas proposed by Harrison & Horne were contrary to previous statements made about the effects of sleep loss on cognitive performance (Dinges & Kribbs, 1991; Dinges, Kribbs, Steinberg, & Powell, 1992, Dinges, Pack, Williams et al., 1997), and as such, represented a radical, new approach to sleep deprivation research. I felt justified in modelling the tasks of this thesis after the work by Harrison & Horne for a number of reasons:

1) they provided substantial evidence and an intriguing theory about why executive functioning tasks are sensitive to sleep loss;

2) they provided contradictory evidence to the claim that reaction time and vigilance tests are sensitive, when these tasks are administered in a novel, stimulating situation, and over a short duration;

3) they provided a basis against which countermeasures to sleep loss could be tested for executive functioning;

4) they provided a benchmark for untested tasks suspected as being divergent in nature (e.g. Pelshenke, 1983), and;

5) the tasks they used had strong language components.

Many of the previous 'cognitive performance and sleep loss' research can be classified under the heading vigilance and reaction time. Krueger (1989) summarised the issues relating to sustained work, fatigue, and sleep loss by stating that sleep loss appears to have a deleterious effect on reaction time, decreased vigilance, perceptual and cognitive distortions, and changes in mood. Cognitive performance was once again defined as including vigilance and reaction time. While various aspects of executive functioning were discussed as being sensitive to sleep loss, including memory, learning, complex verbal processing and decision making, these results were from sustained performance studies by military researchers (Babkoff, Thorne, Sing et al., 1985; Englund & Krueger, 1985; Haslam & Abraham , 1987), and qualified as dependent upon task duration, knowledge of results, difficulty of task, task pacing, proficiency, complexity and memory load. While the military papers are very good at raising issues related to sleep loss and applied performance, and discuss aspects of

executive functioning during that performance, they fail to specifically address types of executive functioning. They also fail to address how each aspect of executive functioning (e.g. memory or speech) is affected, and to what degree, by sleep loss.

It is important to note, as stated in Chapter 5, that while some researchers would argue that speech is not an executive function, I would maintain that there is a basis for speech being included under the executive functioning category. This basis is dependant on human neuropsychological testing to determine localisation of language function in the brain and studies of anthropology. Tests reported by Posner & Raichle (1994) and Damasio & Damasio (1992) indicate frontal lobe activation during speech generation (see neurological discussions on Broca's area and localisation of language for further descriptions. I suggest Kolb & Wishaw (1996) as a good place to start). In addition, comparisons between human and other animals (even our closest genetic relatives, the primates) indicate that speech is the one outstanding, differentiating feature between us and other animals, which would indicate speech is an executive functioning behaviour.

Often, the military studies involve multiple psychological measures intermingled with physical performance and emotive content, which does not allow for extrapolation of the material to a theoretical level. This being said, the military researchers should be applauded (in addition to the above, research by Heslegrave & Angus, 1985; Mikulincer, Babkoff, Caspy, & Sing, 1989; & Mikulincer, Babkoff, Caspy & Weiss, 1990 is noted) for their efforts and advancement of sustained work research of an applied nature.

Similar to the military research, David Dinges and colleagues at Pennsylvania University can be highly commended for their extensive research on the effects of experimentally-induced sleepiness, particularly on attention tasks, such as vigilance and reaction time (e.g. Dinges & Powell, 1988; 1989; Dinges, 1989; Dinges & Kribbs, 1991). In their review of sleep deprivation research, Dinges & Kribbs (1991) stressed that 'cognitive lesions' were not the cause of decrements in performance during sleep loss, but rather, generalised sleepiness was to blame for all declines in performance. They suggested lapsing, cognitive slowing, memory problems, accelerated vigilance decrement, and optimum response shifts are basic feature of performance decrements

during sleep loss, all of which can be attributed to attentional deficits. The views put forward by Dinges & Kribbs (1991) are strongly in support of the NonSpecific Effect theory of sleep loss, that is that all decrements in performance during sleep deprivation can be attributed to generalised sleepiness. This sleepiness can be overcome by countermeasures such as caffeine and motivation up to a certain period without sleep (approx. 48 hours) but beyond that time, the countermeasures are useless, and the pressure to sleep steadily increases. They further suggested that the performance changes brought about by sleep deprivation are "insipid [uninteresting] and temporally complex, involving degradation of cognitive functioning overall rather than a dramatic loss of functional capability in circumscribed higher cognitive functions." (pg. 117). It will be argued later that it is not an either/or issue of generalised sleepiness versus specific functional incapacity, but rather an interrelated combination of both Specific and NonSpecific effects that are temporally dependent.

6.2 Period of Decline

There were indications in the studies discussed in this thesis that there is a decline in executive functioning performance between 27-h and 36-h without sleep. This decline in performance was specific to prefrontal cortical (PFC) tasks, (see Chapter 1 & 2 for definitions) and indicated a critical period of performance degradation on cognitive functioning between 30-36 hours. It is very difficult to indicate where in that time period the critical period lies, however due to lack of large experimental effects, (e.g. no effect on the Haylings Sentence Completion task or Temporal Memory as was previously reported in the sleep literature), the critical period is hypothesised as being near to 36-h. The difficulty in addressing more precisely the time period of degradation relates to the afternoon circadian dip, which exacerbates generalised sleepiness at that time. This specific period of decline has not previously been noted, mainly due to repeated measures testing. During repeated measures testing, sleep deprived subjects are usually tested at regular intervals during interim nights and throughout the second, and often third day without sleep. The repeated testing procedure promotes 'generalised sleepiness/fatigue' (Krueger, 1989), thereby masking the specific effects of sleep loss. In addition to this, it is a rare occasion for prefrontal-oriented tasks to be used in sleep deprivation research.

6.3 Caffeine as a Countermeasure

Caffeine was initially introduced into this study as a countermeasure to generalised sleepiness, similar to the methodological manipulations of making the tasks short, novel and interesting in order to promote alertness. Caffeine was given to a control group in order to maintain consistency and abide by statistical procedure, although no effects were expected on these tasks. Therefore, it was surprising to discover the variable effects of caffeine, depending on sleep condition and on individual differences. Penetar, McCann, Thorne et al. (1993) reported that caffeine reversed the effects of sleep deprivation on alertness and mood by administering 150 - 600 mg doses. Harrison et al. (1999) reported caffeine had no effect on sleep deprived, executive functioning performance at 36-h without sleep, although they failed to test a caffeine control group in their study. Based on these reports, and other applied sleep deprivation literature (e.g. driving) caffeine was expected to have a positive effect on generalised sleepiness, and therefore mood, but no effect on executive functioning performance. The findings reported in Chapter 2 differed from those reported by Harrison et al (1999) for the same tasks, however there was one major difference in the two studies. The Harrison & Horne study was conducted at 36-h without sleep while the caffeine study reported in Chapter 2 was conducted at 27-h. It is hypothesised that the beneficial effects of caffeine observed in this study of executive functioning was related to a reversal of the generalised sleepiness present at 27-h. A review by James (1991) indicated the reports of caffeine's effect on healthy, alert individual's cognitive performance is far from uniform. Similar to the problems of comparing procedure in sleep deprivation research, James suggested that there is difficulty in gauging the comparability of procedures and tasks used in the caffeine literature. Reports of caffeine's effects include contradictory findings on what appear to be similar measures. James suggested the effects of caffeine on cognitive function are mediated by arousal, which is believed to be influenced by: personality, time of day, cognitive resources that are required to perform the task, gender, and hormonal balance. These variables, particularly when combined with the experimental manipulation of sleep loss, make conclusions from the experimental findings difficult and questionable. The most important finding from the caffeine effects in the Chapter 2 study is that 200 mg of caffeine is sufficient to overcome the generalised sleepiness associated with 27-h without sleep, indicating that specific effects on executive

functions is not present at that time. A secondary recommendation from the findings is that caffeine should not be used as a procedure for promoting alertness in basic sleep research because its effects are not fully understood.

6.4 Napping as a Countermeasure

A 2-h nap opportunity in the afternoon of the second day without sleep was sufficient to overcome the decrements associated with sleep loss on executive functioning tasks and on language skill. While the effects of a nap are widely reported in the sleep loss literature for lower order cognitive tasks, such as visual/auditory monitoring, reaction time and sustained performance (e.g. Angus, Pigeau, & Heslegrave, 1992; Mullaney, Kripke, Fleck, & Johnson, 1983; Rosa, Bonnet, & Warm, 1983; Naitoh, 1981; Lubin, Hord, Tracy, & Johnson, 1976; Bonnet, 1991), none have address the effects of a nap on executive functioning performance. The study discussed in this thesis is an elaboration on the nap literature to date and reports similar findings of beneficial effects of a nap following a period of sleep loss. The testing time in this study was approximately 2 hours post awakening and therefore, sufficient to overcome any effects of sleep inertia (see Chapter 1 for definition). Further research in this area is necessary to determine if a 2-hour nap will be sufficient to overcome specific effects of sleep loss later in the sleep loss period, e.g. after 48/72 hours. However, for the purposes of addressing the main research questions in this thesis, testing at 36-h allowed for the conclusion that a first cycle nap is sufficient to overcome the deterioration in performance associated with sleep loss at 36-h for short duration tasks. It is not known if beneficial effects of a nap would be observed for tasks of longer duration. The beneficial effects of the nap were observed 2-3 hours after the nap had ended, suggesting that positive effects of a nap are observable at least until 3 hours post nap. The period of time the improved performance could be sustained is not known, however the literature suggests that a nap taken early in a period of sustained wakefulness will be beneficial even up to 54 hours without sleep (Bonnet, 1991; Dinges et al., 1987; Gilberg, 1974). Dinges et al. (1987) reported beneficial effects of a nap wherever it was placed in a 54-h period, however naps after 42 hours without sleep did not improve RT time but did prevent additional lengthening of reaction time when compared to no nap controls for three hours post nap. In general, naps typically reduce but do not reverse the full effects of sleep loss. It can be

speculated that improved performance during testing beyond 36-h would be in a dose response relationship with increasing length of nap linearly improving performance, as indicated by simple cognitive performance and mood scales reported by Bonnet (1991). At 36 hours, however, the decrements in executive functioning performance are not extensive and a two-hour nap was sufficient to reverse the effects of sleep-loss related decline.

6.5 Language

The findings from the microanalysis of language mimicked the findings of the executive functioning (see discussion on pg. 165 – language as an executive function) in that the effects were observed at 36-h, but not at 27-h without sleep. The 2-h nap opportunity served to recuperate language performance. The biggest changes with respect to language were the increased variability in the errors produced by sleep deprived subjects, the decrease total word output, and the decrease in emotive content (as measured by personalisations, judgements, and unsureness). Specific changes in the content of language were less profound than the generalised findings, such that total word counts and error measures proved to be significant more often than changes in nouns, verbs, conjunctions, pronouns, etc. The verbal effect was much more profound than the written effect.

This analysis of language is difficult to compare with previous reports of language changes in the literature, because the tasks used here were specifically testing language skill, as opposed to reading ability, or memory. One notable difference between the literature on language and sleep loss and the study reported in Chapter 5 is the time of testing. Previous reports by Schein (1957), Webb (1986) tested subjects at approximately 50 hours and tested comprehension of verbal or written instructions rather than production. Whitemore & Fisher (1996) and Harrison & Horne (1997) examined other aspects of linguistics such as acoustical characteristics of vocal changes, emotional level of phonetics, and verbal fluency as measured by short tasks. In contrast, the study reported here is one of spontaneous, continuous speech and writing.

Findings from this study, particularly in comparison to the Schein (1957) and Webb (1986) qualitative reports, indicate that 36-h is the beginning of language deterioration in the sleep loss time scale. While language use promotes metabolic activity in the prefrontal cortex (McCarthy, Blamire, Rothman et al., 1993), language as an executive function does not appear to show deterioration until approximately 36 hours without sleep. Decrements in performance before that time are minimal and can be attributed to generalised sleepiness.

6.6 Theoretical Discussion: Specific vs. NonSpecific Effects

NonSpecific Effects or generalised sleepiness has also been previously defined as 'generalised fatigue' (Krueger, 1989). In his review paper on sustained work and performance Krueger referred to generalised or mental fatigue as "the subjective feeling of weariness which accompanies repeated performance of almost any nonphysical task." (pg. 131).

Wimmer, Hoffmann, Bonato, & Moffitt (1992) outlined the need for further testing of cognitive measures following sleep deprivation in a report of negative effects of sleep loss on divergent thinking and attention processes. They suggested their results supported the hypothesis that sleep serves a function of cognitive restitution, particularly in the maintenance of attentional mechanisms. This suggestion is in line with the separate views put forth by Dinges & Kribbs (1991) (attentional processes) and by Horne (1988) (divergent thinking), and provides further support for the hypothesis proposed here that sleep deprivation causes interrelated Specific and NonSpecific Effects that are temporally dependent. (See Figure 6.1). Sleep Loss may show effects of additive Specific and NonSpecific effects, depending on time awake.

Figure 6.1 Hypothetical Specific and NonSpecific Effects of Sleep Loss

Figure 6.1 is the graphical representation of a possible theory about Specific vs. NonSpecific effects. As is demonstrated in the graph, NonSpecific Effects or generalised sleepiness is proposed to be influenced by circadian rhythms and shows an increasing decline in performance over time, particularly over the second night without sleep. While the experiments of this thesis did not test beyond 36 hours, the reports in the literature, particularly from the Dinges - Pennsylvania research group, indicate a steady decline in performance. Horne & Pettitt (1985) reported an inability of subjects to maintain performance, even with strong incentives as a countermeasure, beyond 48 hours. It is hypothesised that the NonSpecific Effects can be partially overcome by countermeasures throughout the sleep loss period, however countermeasures are expected to have a steady state effect, i.e. they will positively counteract NonSpecific effects to a level equal to n throughout the sleep loss period, even though NonSpecific effects cause larger decrements over time. This steady state hypothesis would help to account for the literature reports that naps help to prevent further decline, rather than reverse the effects of sleep loss, particularly into the second night without sleep. The effectiveness of the countermeasures is expected to be inversely proportional to the function of NonSpecific effects multiplied by the steady state of the countermeasure, n. The following formula is the proposed relationship, where E = Effectiveness of the countermeasure, n = the combined steady state level of improvement given by countermeasures, f(t) = function of NonSpecific effects over time, and t = time:

$$E = \frac{n}{f(t)}$$

Specific Effects are hypothesised as maintaining at baseline until approximately 32 hours without sleep, at which point there is a rapid decline in performance and an inability to recuperate performance, even with waking countermeasures such as incentive, novelty, and caffeine. From observations in the studies reported in Chapter 2 and Chapter 5, it is hypothesised that countermeasures do not have any effect on Specific Effects of sleep loss.

The view proposed by Horne (1988) and furthered by Wimmer et al. (1992) that previous sleep deprivation cognitive research failed to show results because the cognitive demand was to low, or the methodology was not sufficient to correctly test for cognitive performance, is supported here. However, the Specific effects of sleep deprivation on individual higher order/executive functioning components have not yet been adequately addressed. The time course of these effects needs to be documented, and the tests used need to be carefully chosen in order to differentiate related executive functions (e.g. memory, language, and attention are frequently tested together, making specific statements about the effects of sleep loss on any one of them impossible). I would like to emphasise here that executive functions, such as memory and language) have been grouped in this thesis on the basis of their localisation in brain mapping studies, i.e. frontal-lobe functioning. It is important to note that my references throughout the thesis to executive functioning or memory differ from the cognitive psychology principle of the central executive, which is distinct from visuospatial sketchpad and articulatory loop. I, at no time throughout this thesis, am intending to make a statement about Baddeley's (1986) theories of working memory which differentiate a central executive from the set of slave systems it controls (a visiospatial sketchpad and an articulatory loop, both used for rehearsing material). I hope it has been clear that my focus has been more on localised brain function, as determine by various neuroimaging techniques (refer to Chapter 1 for further discussion) in determining executive functioning tasks. Within neuropsychology and sleep research, since it is difficult to differentiate memory and attention, for instance, tasks should be chosen which doubly dissociate the executive functioning components.

6.7 Areas for Future Research

6.71 Individual Differences

Individual differences in sleep habits and response to sleep loss are an important factor in considering the functions of sleep and the effects of sleep loss. Individual differences affecting sleep need or sensitivity to sleep loss could include age, gender, personality, health, and sleep architecture. While some research has commented upon individual differences in sleep factors (Rutenfranz & Colquhoun, 1979; Morgan,

Winne & Dugan, 1980; Smith & Maben, 1993) none have examined the possibility of individual differences in brain EEG activity during sleep associated with differential response to sleep deprivation. The increased variability in responses observed in the language study, as a response to sleep deprivation, highlights the need for future research into individual differences.

6.72 *Systematic Analysis of Other Higher Order Executive Functions*

This thesis included a systematic analysis of verbal and written language production during spontaneous speech at 27 and 36 hours. This research could be expanded to include language analysis at 48/72 hours and other aspects of language could be tested (e.g. verbal and written comprehension). In addition to this, other executive functions such as memory and learning, with their many subcomponents, need to be systematically analysed to further the knowledge of sleep loss effects on executive functioning, in order to further our understanding of why we sleep. By studying the effects of sleep loss on executive functioning in order to discover the answer to the elusive question of 'Why we sleep', we are using a method of ablation, a common practice in neuropsychology. It is common practice to study the need for something by removing/preventing it and studying the subsequent changes in behaviour. It falls within the classical scientific strategies discussed by Rechtschaffen (1998) including description, stimulation (experimentation), correlation and deprivation. "Ideally, sleep deprivation would reveal what goes wrong without sleep" (pg. 361), thereby indicating why we sleep.

6.8 Implications of this Research

Following submission of this thesis, a number of questions have been raised regarding the implications of this research. These questions have been addressed throughout the thesis at specific points and under the following sections.

6.81 *What are the implications for sleep function?*

Allan Rechtschaffen (1998) challenged sleep researchers to make strides forward in defining the answer to that elusive question: Why we sleep? . The answer to the question has been eluding sleep researchers for decades. While our understanding of sleep function is still quite uncertain (Reschtschaffen, 1998), this thesis has attempted

to address some components of that question. The main implications for sleep function are around the effect sleep loss has on performance, suggesting sleep is necessary to perform creative and complex thinking. Generalised sleepiness appears to be nature's way of promoting sleep before sleep loss extends to specific deterioration in complex cognitive processing. Rechtschaffen (1998) pointed out that while sleep does not appear to have a physiological effect on sleepiness, sleep studies to date have not attempted to push humans beyond a short timeframe, for obvious ethical reasons. Generalised sleepiness may be a way to inhibit psychological deterioration in advance of physiological deterioration.

6.82 Which effects are based on lack of effort, which on non-specific decline in arousal, and which are specific effects?

It is impossible to determine which of the effects discussed in this thesis are based on lack of effort, which are on non-specific decline in arousal and which are on specific effects because it is impossible to accurately determine if there was lack of effort, non-specific decline in arousal or specific decline in arousal. In order to compensate for this, measures were taken to combat lack of effort (i.e. motivation and reward) and non-specific decline in arousal (i.e. testing outside circadian dips, providing caffeine and motivation as a stimulant). In previous reports of sleep loss studies using motivation and stimulation, successful reversal of non-specific declines of arousal implies that employing these measures in this research will have the same effect.

6.83 What are the implications for theories of arousal?

It is assumed that 'theories of arousal' focus on hyper-arousal, a topic outside the scope of the current research. The Yerkes-Dobson hypothesis has been addressed in Chapter 2, following unusual results in response to caffeine. This thesis does not attempt to make a statement of any implications on the theories of arousal, preferring instead to address theories of sleep loss.

6.84 What of Dinges' claim that non-significant findings mean the wrong task, or measurement, has been used?

Some researchers who favour the non-specific theory of generalised sleepiness have contested significant findings with the nebulous argument that non-significant findings simply mean that the wrong task, or measurement, has been used. I would

counter with the question 'what defines the right task for measuring the effects of sleep loss?'. If sleep researchers limit themselves to tasks which indicate significant findings of sleepiness, they are purposefully ignoring tasks which do not show significance, and which may confound their theories of sleep function. Is it reasonable to assume that humans will continually perform well on complex cognitive tasks and that only tasks which indicate generalised sleepiness should be used in sleep deprivation studies? If one only uses tasks which indicate significant findings, what are their studies truly contributing to our understanding of why we sleep?

6.85 What of Webb's claim that performance and learning are confounded in many sleep loss studies?

I agree that performance and learning are confounded in many sleep loss studies because if practice is provided for tasks, it is difficult to measure whether enough practice has been given to sufficiently ingrain the learning such that further learning does not take place during the period of deprivation. I would argue, however, that in studies using short, novel tasks, where novelty is necessary to make the tasks interesting for the subject learning is not as much of a confound as in studies where extensive practice is used in advance of the study. In any task where practice is used in advance of testing, implies that learning may not be consolidated in advance of the sleep loss stress, prompting forgetting. In this thesis, the language tasks chosen for study relied on subjects' naïve understanding of the tasks before testing, and the tests novelty.

6.86 Could different aspects of divergent thinking be susceptible to sleep loss, and other components not susceptible?

It is possible that different aspects of divergent thinking may be susceptible to sleep loss and other components not susceptible, which implies specific effects of sleep loss. In order to determine if this is the case, it is necessary to break down the divergent thinking tests into their sub-components. Unfortunately, by breaking down divergent thinking tasks into their sub-components, their complex nature is lost. In this thesis, the focus was on complex cognitive tasks. I challenge further researchers to look at the components of divergent thinking to determine the exact components which are susceptible to sleep loss.

6.87 Does this thesis go beyond what Wilkinson said about sleep loss and complex or interesting tasks?'

This thesis certainly goes beyond what Wilkinson said about sleep loss and complex/interesting tasks, i.e. tasks which are complex/interesting are not sensitive to the effects of sleep loss. This thesis addresses the timing of the decline in executive functioning, the effects of caffeine and a nap as a countermeasure to sleep loss, and the effects of sleep loss on language skill. This research has furthered the work previously reported by Harrison & Horne on sleep loss's effects on frontal-type tasks and will hopefully be used as a benchmark for further research in these areas.

6.9 Summary

As is shown in this thesis, the studies conducted provide a new development in sleep loss research of the critical period of executive functioning declines in performance, and the beneficial effects of a nap on executive functioning. It is important to note that not all executive functioning tasks showed a significant effect following sleep loss: refer to Chapter 2 and Chapter 5 for specific examples and discussion of findings. In addition to this, the effects of sleep loss on language skill has now been documented and will provide a benchmark for further research on sleep loss and language, as well as for any sleep loss research that relies on the comprehension and production of language in performance testing. The following section summarises the main conclusions from the thesis:

Furthering the Knowledge of Executive Functioning during Sleep Loss

- A 90-min nap is an effective countermeasure for counteracting the effects of sleep loss on executive functioning performance. This may be due to the high levels of SWS expected during the first 90-min cycle.

- While some aspects of executive functioning appear to be starting a decline after 27 hours without sleep (such as increases in errors), the Specific effects of decrements in executive functioning are hypothesised as occurring sometime after 30 hours. In fact, the critical period may be sometime after 36 hours, as indicated by the lack of difference between SD and Control performance at 36 hours. Boredom effects, and the NonSpecific effects of sleep loss have a profound effect on subjects ability to function, and should not be underestimated when attempting

to assess Specific Effects of Sleep Loss. It is proposed that these boredom effects contributed to positive findings in previous reports of executive functioning sensitivity to sleep loss.

- Caffeine is an appropriate countermeasure for sleep loss on executive functioning tasks at 27 hours without sleep.

Questioning the Robustness of Executive Functioning Sensitivity to Sleep Loss

- Important components of executive functioning tasks appear to be inhibition of unnecessary information, verbal fluency, and memory.

- Not all tasks that are labelled divergent thinking in the aptitude literature display sensitivity to sleep loss. Tasks that have components of inhibition, verbal fluency, and memory load are more likely to display sensitivity to sleep loss.

Attempting to Understand the Role of Language as a Tool and as an Executive Functioning Task

- The use of verbal production as a mode for studying effects of sleep loss on executive functioning is inadvisable because sleep loss appears to have an effect on verbal production. Sleep loss has variable effects on sleep deprived individuals, owing to individual responses to sleep loss. The significant effects observed using verbal production were not present when using written production, making written production the more suitable method for testing, when not under time constraints.

- Sleep loss appears to have relatively little effect on language skill up to 36 hours without sleep. At this time, the critical period, more specific effects of language deterioration are observed, including decrease in substantive words and increases in errors. Substantive words indicate a specific effect otherwise, there would be a decrease in all words. This finding suggests a specific effect of sleep loss on language skill, which begins to be observable at approx. 36 hours. Observations reported in the literature indicate findings of specific effects are exacerbated with increasing sleep loss.

Theorising the Answer to the Specific vs. NonSpecific Question of Sleep Loss

- The findings from Chapter 2 and Chapter 5 indicate *both* NonSpecific and Specific effects of sleep loss, which are observable over different periods in the sleep

loss time course. It is hypothesised that NonSpecific effects of sleep loss, or generalised sleepiness increases with increased time awake. This generalised sleepiness increases the pressure to sleep and is exacerbated by circadian dips. The generalised sleepiness can be countered using external manipulations such as motivation and caffeine. It is further hypothesised that the countermeasures act on generalised sleepiness to the same extent during the time course without sleep, however are not easily observable beyond 36-h due to the increased pressure to sleep at that time. In comparison to the pressure to sleep, the effect of the countermeasures is presumed to be minimal at 48 hours and beyond.

- It is hypothesised that Specific effects of sleep loss on various executive functions are not behaviourally observable until approximately 36 hours without sleep, even though they may be metabolically observable in PET studies. The behavioural manifestation of Specific sleep loss effects is dependent on the executive function. It is worth noting that executive tasks may be more interesting and hence more sleep loss is needed to find deficits, which is why executive functions were only beginning to show deficit at 36 hours.

- Language skills begin to be affected at 36 hours without sleep. The time course of effect on other executive functions, such as memory and attention, is not yet known.

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Appendices

HEALTH SCREEN FOR STUDY VOLUNTEERS

Name or Number :.................

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:
   - (a) on medication, prescribed or otherwise..............................Yes ☐   No ☐
   - (b) attending your general practitioner......................................Yes ☐   No ☐
   - (c) on a hospital waiting list...Yes ☐   No ☐

2. **In the past two years,** have you had any illness which require you to:
   - (a) consult your GP ....Yes ☐   No ☐
   - (b) attend a hospital outpatient department..............................Yes ☐   No ☐
   - (c) be admitted to hospital ....Yes ☐   No ☐

3. **Have you ever** had any of the following:
   - (a) Convulsions/epilepsy...Yes ☐   No ☐
   - (b) Asthma..Yes ☐   No ☐
   - (c) Eczema..Yes ☐   No ☐
   - (d) Diabetes ....Yes ☐   No ☐
   - (e) A blood disorder ....Yes ☐   No ☐
   - (f) Head injury ....Yes ☐   No ☐
   - (g) Digestive problems ....Yes ☐   No ☐
   - (h) Heart problems..Yes ☐   No ☐
   - (i) Problems with bones or joints ....Yes ☐   No ☐
   - (j) Disturbance of balance/coordination..................................Yes ☐   No ☐
   - (k) Numbness in hands or feet..Yes ☐   No ☐
   - (l) Disturbance of vision...Yes ☐   No ☐
   - (m) Ear / hearing problems..Yes ☐   No ☐
   - (n) Thyroid problems..Yes ☐   No ☐
   - (o) Kidney or liver problems..Yes ☐   No ☐

If YES to any question, please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.) ....

Additional questions for female participants
   - (a) are your periods normal/regular?..Yes ☐   No ☐
   - (b) are you on "the pill"?..Yes ☐   No ☐
   - (c) could you be pregnant? ....Yes ☐   No ☐
   - (d) are you taking hormone replacement therapy (HRT)?   Yes ☐   No ☐

Name: _____   Date: _____

Health Questionnaire

The following items are designed to assess your general level of health. Please circle the appropriate answers.

1. In the last six months, have you consulted any health professional
(e.g. physician, psychiatrist, or psychologist) for help with psychological   Yes/ No
problems?

2. Have you ever suffered from a psychiatric illness?   Yes/ No

3. Do you suffer from any physical conditions which interfere with your
daily functioning and, therefore, may make your participation in the present   Yes/ No
study difficult?

4. Have you ever suffered from epilepsy or diabetes?   Yes/ No

5. Do you suffer from any hearing impairment?   Yes/ No

6. Are you currently taking any prescription or non-prescription medications?   Yes/ No

7. Have you ever suffered from migraines?   Yes/ No

8. How would you describe your general level of health   Excellent / Fair / Poor

Everyday Activities

1. Do you smoke cigarettes?   Yes/ No
    If so, how many per day on average?_____

2. Do you drink coffee, tea or caffeinated beverages (e.g. cola)?   Yes/ No
    If so, how many cups a day on average? _____

Sleep Pattern Questionnaire

1. How long do you usually take to go to sleep (in minutes)?   _____

2. How many times per week do you fall asleep within 5 minutes?   _____

3. How many times per week does it take more than 30 minutes to
   fall asleep?   _____

4. How many nights per week do you awaken during the night?   _____

5. How many times per night do you wake up?   _____

6. How many times per month do you wake up and are unable to go
   back to sleep?   _____

7. When you are awake, how difficult is it to go back to sleep?

No difficulty	_____
Considerable difficulty	_____
Usually not able to	_____
Never able to	_____

8. How much difficulty do you have in falling asleep initially?

No difficulty	_____
Considerable difficulty	_____
Usually not able to	_____
Never able to	_____

9. How rested do you feel in the morning?

Very rested	_____
Moderately rested	_____
Not very rested	_____
Not rested at all	_____

10. How much do you enjoy sleep?

Much enjoyment	_____
Moderate enjoyment	_____
Little enjoyment	_____
No enjoyment	_____

Karolinska Sleepiness Scale (Akerstedt & Gillberg, 1990)

Listed below are a set of feelings which reflect various degrees of Alertness & Drowsiness. They are graded from 1 to 9. Read them carefully and indicate your present state by writing the appropriate number on the flip side of this sheet.

☐	1	EXTREMELY ALERT
☐	2	
☐	3	ALERT
☐	4	
☐	5	NEITHER ALERT NOR SLEEPY
☐	6	
☐	7	SLEEPY BUT NOT FIGHTING SLEEP
☐	8	
☐	9	EXTREMELY SLEEPY, FIGHTING SLEEP, EFFORT TO STAY AWAKE

Epworth Sleepiness Scale

(Johns 1991)

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently, try to work out how they would have affected you. Use the following scale to choose the *most appropriate number* for each situation.

> 0 = would *never* doze
> 1 = *slight* chance of dozing
> 2 = *moderate* chance of dozing
> 3 = *high* chance of dozing

Sitting and reading   _____

Watching TV   _____

Sitting inactive in public place (e.g. a theatre or meeting)   _____

As a passenger in a car for an hour without a break   _____

Lying down to rest in the afternoon when circumstances permit   _____

Sitting and talking to someone   _____

Sitting quietly after a lunch without alcohol   _____

In a car while stopped for a few minutes in the traffic   _____

In situations where there was a risk to you or others   _____
    Give examples:

Nap Sleep Questionnaire

1. How long did it take you to go to sleep (in minutes)? _____

4. Did you awaken during the nap period? _____

5. If so, how many times did you wake up? _____

6. Did you wake up and found yourself unable to go
   back to sleep? _____

7. How difficult was it to go back to sleep, if you woke up?

   No difficulty _____
   Considerable difficulty _____
   Not able to _____

8. How much difficulty was it falling asleep initially?

   No difficulty _____
   Considerable difficulty _____
   Not able to _____

9. How rested do you feel now?

   Very rested _____
   Moderately rested _____
   Not very rested _____
   Not rested at all _____

10. How much did you enjoy the nap sleep?

    Much enjoyment _____
    Moderate enjoyment _____
    Little enjoyment _____
    No enjoyment _____

Time Asleep (Esitmated hours and minutes): _____

Trail Making Task

In the list below are different animals. They are to be put into sensible groups of three. Make up groups of three and write the appropriate generic term next to the groups.   Example: pen, paper, pencil: tools for writing

cheetah	partridge	chicken
parrot	eagle	boa constrictor
hawk	linx	hippo
ostrich	rattlesnake	mouse
trout	turkey	hog
horse	magpie	sparrow
tiger	bull	duck
raven	salmon	crab
puma	swan	lizzard
donkey	dove	crane

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               oOOo-( )-oOOo
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W e s t   **t s a E**   **South**


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                        Ooooo
     -oooooO------(     )------
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Sign

1. Does the sign man part his hair on the right or the left (from his Point of View)?

2. Does he have eyebrows?

3. Can you see his thumbs?

4. Are nostrils shown?

5. How many fingers does the running figure have?

6. How many directional signs are shown?

7. How many crosses (+) are there altogether?

8. How many hairs are on the sign mans head?

9. What direction is the running figure going?

10. How many toes does the sign man have?

Families

A house containing four families has two flats on the ground floor and two upstairs. In the house lives three married couples, some of whom have children.

Fred Burns, a 50 year old milkman lives with his wife, Kathy. Mr and Mrs Burns have two sons and a daughter. Fred and Kathy live in the upstairs right flat. Kathy is a 42 year old nurse.

In the upstairs left flat lives Mr and Mrs McDonald. Stuart McDonald is a 30 year old carpenter and his 26 year old wife, Melinda is a housewife. Melinda and Stuart are expecting a child in 4 months.

Below the Burns', live Margaret and Harriet Pernault. The Pernault sisters are 28 years old. Margaret is an accountant and Harriet is a fashion designer.

The McDonalds live above the James'. Mr and Mrs James are 56 and 59 years old respectively. Ken and Sylvie James have two daughters, and work out of their flat as architects. Their daughters do not live with them. The children of the Burns live with their parents.

Family Facts Score Sheet

1. House - 4 Flats
2. Two Up
3. Two Down
4. 3 Married Couples
5. Some have children
6. Burns - up right
7. man - Fred
8. woman - Kathy
9. Fred is 50
10. Kathy is 42
11. Fred is a milkman
12. Kathy is a nurse
13. Burns have children
14. Burns - two sons
15. Burns - 1 daughter
16. Children live with them
17. McDonalds - up Left
18. Man - Stuart
19. Woman - Melinday
20. Stuart is 30
21. Melinda is 26
22. Stuart is a carpenter
23. Melinda is a housewife
24. McD - no children
25. McD - expecting a child
26. McD - expecting in 4 months
27. Pernaults - lower Right
28. Pernaults are sisters
29. One is Margaret
30. One is Harriet
31. They are 28
32. Margaret is accountant
33. Harrient is fashion designer

34. James - Lower Left
35. Man is Ken
36. Woman is Sylvie
37. Ken is 56
38. Sylvie is 59
39. They are architects
40. They work in the flat
41. They have children
42. Have daughters
43. Daughters don't live with them

Incorrect Facts

Incorrect

Correct

Total Number

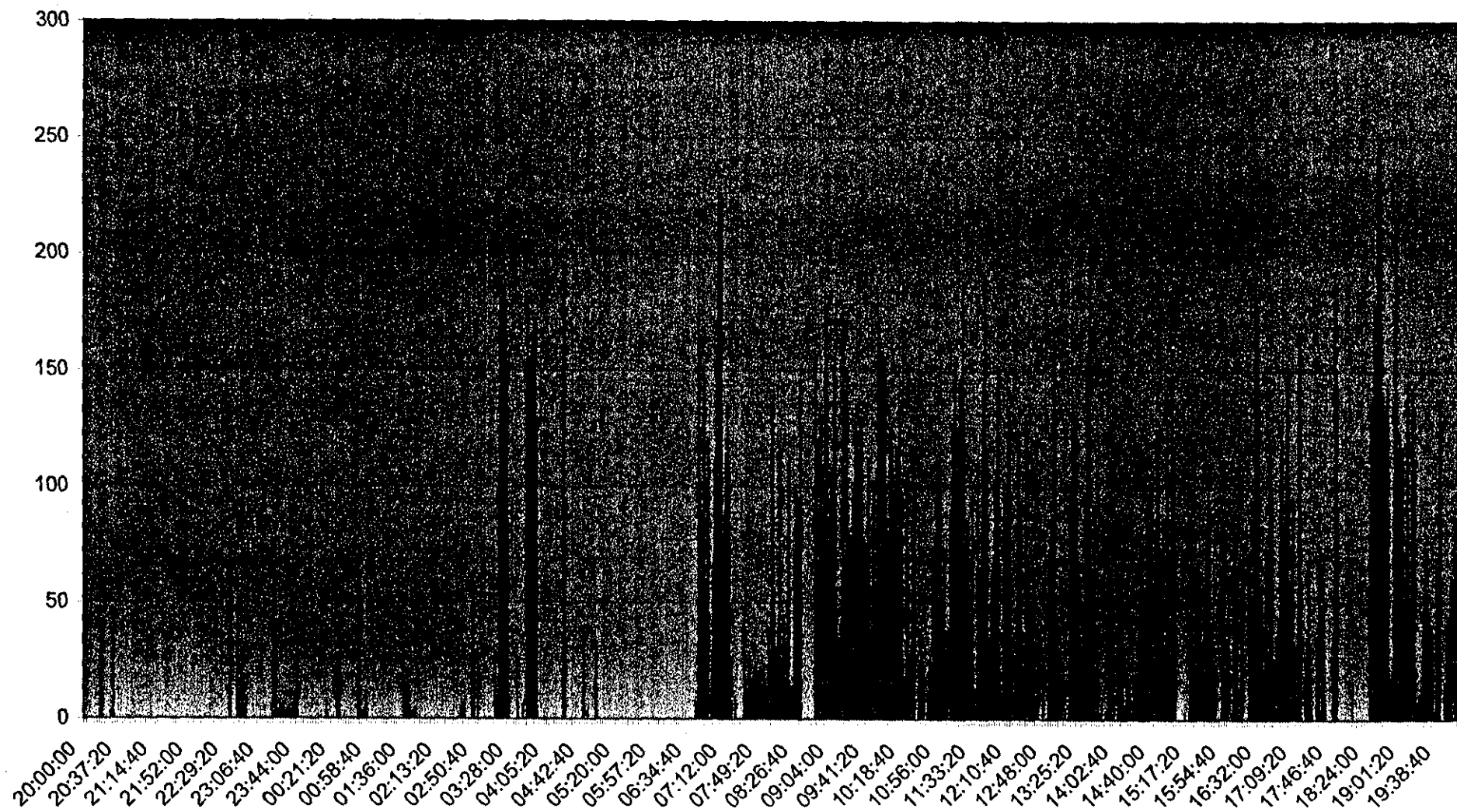# Wooden Pencil

Car Tire

Eyeglasses
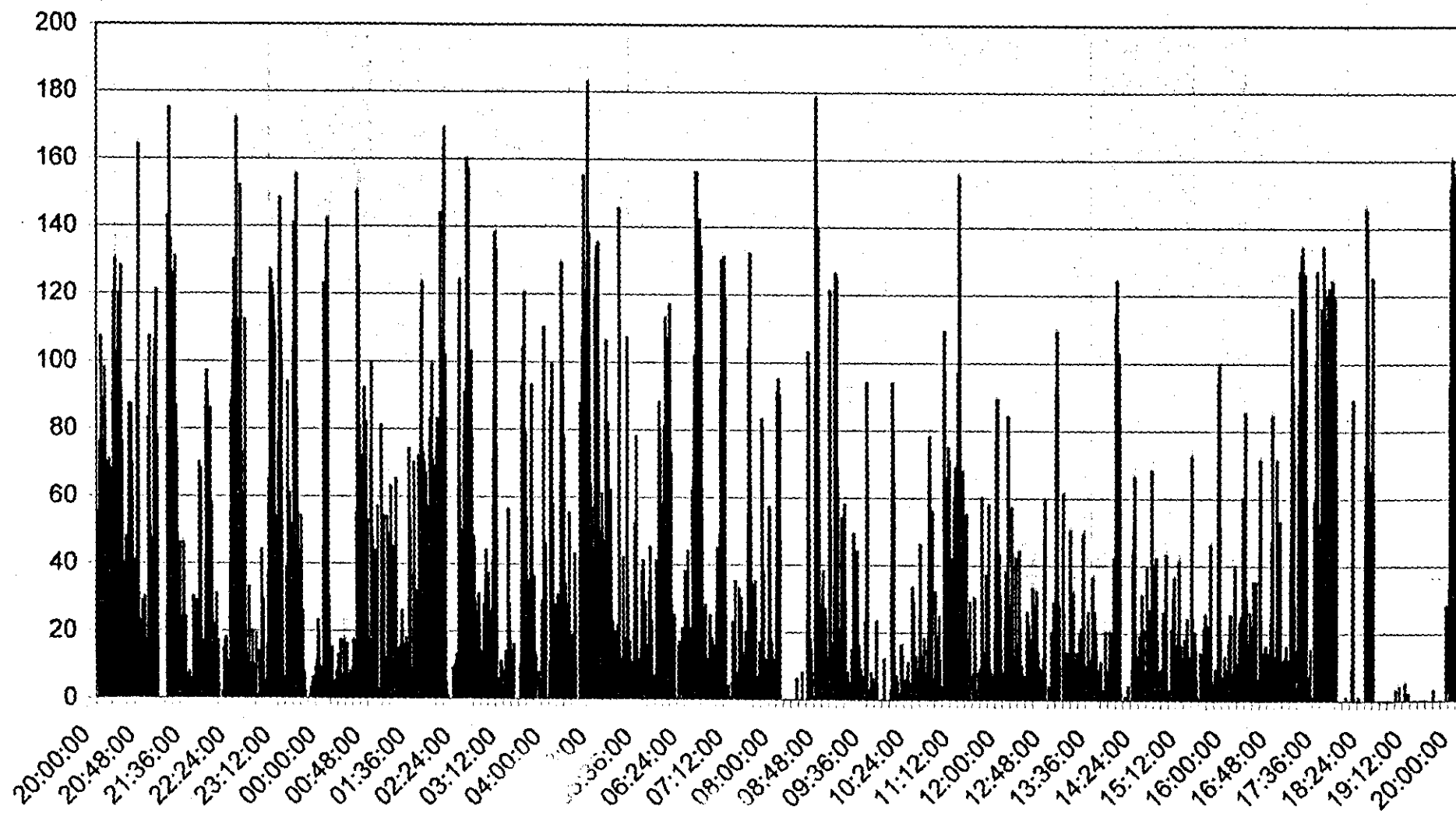

Shoe

Key

Button

Actimeter graph example - Control Subject

Actimeter graph example - Sleep Deprived Subject

Actimeter graph example - Nap Subject

Western Aphasia Battery (Kertesz, 1982)

1

Boston Cookie Theft Picture - Means and Standard Deviations
Means and Standard Deviations for Language Production

		Control	Ct-Caffeine	SD-Caffeine	Condition 27-h SD	36-h SD	Nap
Unit Total	Mean	128.7	113.3	109.3	110.2	78.9	101.1
	St.Dev.	115.9	54.3	68.6	22.7	40.9	36
Time (sec)	Mean	48.5	45.1	45.9	46.4	31.4	45.3
	St.Dev.	34.4	17.1	23.6	10	9.4	23
speech rate	Mean	2.5	2.5	2.3	2.4	2.4	2.3
	St.Dev.	0.6	0.5	0.3	0.4	0.5	0.5
substantive wd total	Mean	63	69.9	67.9	75.8	57.8	72.1
	St.Dev.	15.5	11.1	11.5	7.3	20.3	16.4
errors	Mean	6.5	9.9	7.2	9	6.2	5
	St.Dev.	3.3	6.1	5.3	4.1	5	2.6
substantive proporti(	Mean	0.67	0.7	0.73	0.71	0.78	0.74
	St.Dev.	0.23	0.19	0.2	0.11	0.11	0.13
error proportion	Mean	0.07	0.1	0.07	0.08	0.07	0.05
	St.Dev.	0.04	0.07	0.04	0.04	0.03	0.03
nouns (#)	Mean	15.6	16.1	14.7	17.2	12.8	17.6
	St.Dev.	4.7	5.1	3.1	3.6	4.1	4.5
verbs (#)	Mean	4.1	4.6	4.1	6.3	3.5	5.5
	St.Dev.	2.8	3.6	2.7	2.4	2.4	3.2
gerunds (#)	Mean	7.2	8.8	7.6	8	8.5	8.1
	St.Dev.	2.3	1.9	1.3	2.8	3.3	3
adj & adv (#)	Mean	17.7	17.5	16.5	20.6	15	20.1
	St.Dev.	4.7	5.1	4.8	6.4	6.1	5.8
pronouns (#)	Mean	6.3	9.5	9	8.6	6.4	6.7
	St.Dev.	3.9	3.7	2	3.4	5.6	4.1
auxilliary verbs (#)	Mean	9	9.6	10.2	10.8	8.3	9.5
	St.Dev.	3.3	3.5	3.3	3	4.7	2.6
conjunctions (#)	Mean	3.1	3.7	5.7	4.3	3.3	4.6
	St.Dev.	2.2	1.4	1.7	2.2	2.8	3
prepositions (#)	Mean	15	14.6	14.2	14.5	13.9	16.2
	St.Dev.	4.9	5.9	6.1	4.9	4.3	5.1
fillers (#)	Mean	2.2	4.3	2.1	3.5	1.6	2.2
	St.Dev.	1.8	3.7	2.3	2.6	1.6	1.6
indefinite words (#)	Mean	0.6	0.7	0.6	0.8	0.7	0.6
	St.Dev.	0.7	1.1	0.9	1	0.8	0.5
stereotypies (#)	Mean	0.1	0.1	0.6	0.4	0.3	0
	St.Dev.	0.4	0.3	1.3	0.5	0.9	0
personalisations etc.	Mean	1.3	1.4	0.9	1	0.4	1.2
	St.Dev.	1.8	2.4	1.1	1.4	0.7	1.6
semantic paraphasia	Mean	0.3	0.9	0.9	0.3	0.5	0.4
	St.Dev.	0.6	0.8	1.4	0.5	0.7	0.5
repetitions (#)	Mean	1.1	1.6	1.4	1.6	1.9	0.3
	St.Dev.	1.1	1.8	1.4	1.6	2.5	0.7
paragrammatisms	Mean	0.8	0.9	0.6	1.4	0.8	0.3
	St.Dev.	0.9	1.1	1	1	0.9	0.5

Wab Picnic Scene - Means and Standard Deviations
Means and Standard Deviations for Language Production

		Control	Ct-Caffeine	SD-Caffeine	Condition 27-h SD	36-h SD	Nap
Unit Total	Mean	98.6	86.5	87.4	91.1	76.4	95.6
	St.Dev.	14.9	27.6	18.5	14.2	19.6	21.2
Nouns	Mean	24.4	22.2	23.4	21.4	20.3	23.3
	St.Dev.	3.8	2.8	4.7	5.8	4.6	4.1
Verbs	Mean	2.7	4.5	4.1	3.4	3.2	3.5
	St.Dev.	2.9	2.9	3.1	2.9	3.6	3.8
Gerunds	Mean	7.6	6.6	7.1	7.7	6.2	7
	St.Dev.	3.2	3	3.2	2.5	2.2	2.5
Adj & Advs	Mean	26.5	22.6	23	23.8	22.7	25
	St.Dev.	4.8	4.4	5.2	5.4	6.4	4.8
Pronouns	Mean	5.1	6.7	5.7	6.3	2.6	5
	St.Dev.	2.6	3.4	4	2.9	2	2.3
Auxilliary Verbs	Mean	9.1	7	6.6	8	7.3	7.3
	St.Dev.	3	2.9	1.9	2.2	2.6	3
Conjunctions	Mean	3.5	3.1	2.6	4	1.9	2.6
	St.Dev.	1.2	2.5	1.2	2.1	1.9	1.2
Prepositions	Mean	13.7	13.5	13.1	13.6	11.3	14.6
	St.Dev.	2.9	2.9	3.3	2.6	3.9	5.5
Errors	Mean	1.59	1.73	0.44	0.55	0.67	1.5
	St.Dev.	3.29	2.49	0.73	1.21	1.12	2.01

Sleep Loss, Language Skills, and Attention Tasks
Information Sheet

Sleep Research Laboratory, Department of Human Sciences, Loughborough University

This purpose of this study is to examine the effects of sleep loss on performance. You will be asked to complete a confidential Health Questionnaire and Sleep Pattern Questionnaire. If, based on these questionnaires, you are selected as a participant you will be assigned to an experimental session based on your preferential choice. In particular on the health questionnaire, we are screening for epilepsy and a history of psychiatric illness.

You will be asked to arrive at the laboratory (Towers Bungalow 5) the afternoon before your test session to be fitted with the Actimeter recorders and instructions for your experimental condition. Depending on the experimental condition to which you are assigned, you may be required to remain awake overnight in the presence of at least one other person, and will be required to make half hourly phone calls to the sleep laboratory to ensure your compliance with this protocol. Alternatively, you may be required to go to bed at 2300h and to arise at 0700h the following morning. You will then be asked to return to the laboratory the following morning at your specified testing time. Drink will be provided during the time in the laboratory. At the completion of the study, you will be escorted home, or to your next destination for your own safety. You will also be asked to sign a document stating you will refrain from driving a vehicle, riding a bicycle, and operating heavy machinery until you have slept.

The testing session will involve short performance tasks introduced according to your own participant schedule.

Other requests: please keep a regular sleep schedule (a consistent bedtime between 2300-0100h and a consistent waking time between 0700-0900h) for two nights prior to the beginning of the study, please refrain from using alcohol or any other drugs for 48 hours prior to the session and please limit caffeine intake to a moderate amount for 24 hours prior to the experimental sessions.

All of the data collected in this study will be encoded such that you will remain anonymous and only those directly involved in this research will have access to the data. If for any reason you do not wish to continue your participation, you are free to withdraw at any time during the course of the study.

If you have any questions or concerns, please contact Terri-Lee Weeks (Ph: 223021 or email: T.L.Weeks@lboro.ac.uk). If you have further questions that should be addressed by a member of the department, contact Prof Jim Horne, Department of Human Sciences (Ph. 223091 or email: J.A.Horne@lboro.ac.uk).

Alternate Uses - Instructions for Scoring

For each use given, please deem correct all answers that adhere to the following criteria:

The use must be a conceivable use.
The use must be different from the common use stated by the experimenter.
The use must be different than the other uses given.

Total all 'correct' responses for the six prompts per subject.

Verb Generation - Instruction for Scoring

For each answer given, please deem correct all answers that adhere to the following criteria:

The answer must be a verb.
The verb must be related to the known prompt in a conceivable way.

Please deem incorrect:
Any nonwords.
Any nonverbs.
Any repeated verbs.
Any verbs not related to the noun prompt.

Please total the correct and incorrect answers for all four noun prompts per subject.

Letter Prompt Word Fluency - Scoring Instructions

<u>L Prompt</u>

Score incorrect every word beginning with the letter L, that falls into the falling categories:

The word 'letter'
Any proper words/names such as London, Leicester, Lisa, etc.
Any repeated words (e.g. light twice)
Any nonwords.
Any words repeated with a different ending; e.g. live, living, lives, lived (the first word is correct, the others are wrong because they are repeats).

Score correct every other word beginning with the letter L.

<u>P Prompt</u>

Score incorrect every word beginning with the letter P, that falls into the falling categories:

The word 'pineapple'
Any proper words/names such as Peterborough, Peter etc.
Any repeated words (e.g. pine twice)
Any nonwords.
Any words repeated with a different ending; e.g. play, playing, played, player (the first word is correct, the others are wrong because they are repeats).

Score correct every other word beginning with the letter P.

Boston Cookie Theft Picture & WAB Picnic Scene- Scoring Instructions

<u>WORD CLASS</u>
All words must be classified into a category. The categories are classified by colour or altered font.

Nouns (man, woman, boy, girl, etc.) are printed in red.
Verbs (fall, reach, pour, etc.) are underlined in black.
Gerunds (noun ending in -ing when used distinctly as part of a verb (e.g. is washing) are in blue.
Adjectives and adverbs (e.g. little, the, words ending in -ly) are in pink.
Pronouns (we, they, he, she, it, who, what, which etc) end in dark yellow.
Auxilliary, copula, or modal verbs (is, want) end in turquoise.
Conjunctions (because, as, so, therefore, however) are in dark green.
All others/miscellaneous including prepositions are in dark red (eg. No, not, still, yes, maybe, up, behind, into etc).

Count the various colours and enter your count total in the appropriate box on the score sheet.

For the words that are not coloured, decide which category they fall under and add them to the total for that category.

<u>LEXICAL PROBLEMS</u>
There are parts of speech which are not grammatically correct and we code these as errors. There are a few different types of errors, some of which have been classified already.

Fillers - (um, ah) have a strikethrough.
Indefinite words (something, anything, thing) are in italics.
Stereotypies - word use which is idiosyncratic to the individual (eg. Like, y'know, ok).
Semantic paraphasias: when a word replaces the more appropriate word. Eg.
Individual says chair rather than stool.

Repetitions - if a syllable, word, or phrase is repeated.
Sentence Repetitions - if a sentence is repeated.
Paragrammatism (misuse of functors, word order errors, involving who words). Count as one (1) every instance of a paragrammatism.
Ommisions (eg. That bad is an ommision of the word is).
Aposiopesis is 'the abrupt termination of an utterance that leaves a thought incomplete.' If a sentence begins and abruptly trails off while a new thought begins this is classified as one aposiopesis.
Pragmatics are classified as judgements (eg. She is a bad woman, this must be America), statements of unsureness, apology, personalisation (referring to 'I'), giving names to characters (Mary, John, Mrs Jones).

Language Task: Example of Computerised Scoring

REC9 time: 26.1 sec   Wd: 84

Ah There's a young man who's ah climbing <u>out</u> <u>of</u> the cupboard <u>to</u> get himself <u>out</u> <u>of</u> the cupboard a plate <u>of</u> food by the <u>looks</u> <u>of</u> it or a cookie and he's um passing it <u>down</u> <u>to</u> his sister but he's falling <u>off</u> the back <u>of</u> his chair. Mum's washing <u>up</u> and the washing seems <u>to</u> be overflowing and it <u>looks</u> like quite a nice day outside. Ah there a <u>few</u> pots and pans <u>on</u> the side which <u>need</u> washing <u>up</u>. Um...

REC13   Time: 23.5 sec   Wd: 64

K, there's two children <u>in</u> the kitchen. The boy <u>on</u> the stood <u>on</u> the stool. It's <u>about</u> <u>to</u> <u>fall</u> <u>over</u>. He's trying <u>to</u> <u>grab</u> <u>some</u> food or <u>some</u> biscuits <u>out</u> <u>of</u> the cookiejar <u>on</u> the top cupboard. Um there a woman washing <u>up</u>. Um she's got the taps <u>on</u>. Um the water's overspilling <u>onto</u> the floor and she's getting her feet wet. Um...

REC16   Time: 24.3 sec   Wd: 42

The lady's washing <u>up</u>. The water's going all <u>over</u> the floor. The kid's <u>about</u> <u>to</u> <u>fall</u> <u>off</u> the chair and crack his head open. The kids are eating biscuits. A nice view <u>out</u> the window. The window's open. The curtains look nice.

REC5 27 sec   Wd: 50

The boy is reaching <u>up</u> <u>into</u> the cupboard. The stool slips and he's <u>about</u> <u>to</u> <u>fall</u> <u>off</u> and the woman's <u>to</u> across the sink which is overflowing, carrying a plate. As she walks she slips, falls <u>over</u>, and the plate smashes. The little girl then has <u>to</u> run for help.

adj. *n.* *n.* *pro.* *adv.* +Judged
Language Task: Example of Computerised Scoring
gerund

REC9 time: 26.1 sec   Wd: 84

V.
Ah There's a young man who's ah climbing out of the cupboard to get himself out of

pron. *conj.*
the cupboard a plate of food by the looks of it or a cookie and he's um passing it down

pron. *n.* *n.*
to his sister but he's falling off the back of his chair. Mum's washing up and the

V. V. *pron. adj.*
washing seems to be overflowing and it looks like quite a nice day outside. Ah there

a few pots and pans on the side which need washing up. Um...

REC13   Time: 23.5 sec   Wd: 64   Rep.

Stereo.
K, there's two children in the kitchen. The boy on the stood on the stool. It's about to

conj.
fall over. He's trying to grab some food or some biscuits out of the cookiejar on the

aux.
top cupboard. Um there a woman washing up. Um she's got the taps on. Um the

adj.
water's overspilling onto the floor and she's getting her feet wet Um...
gerund   gerund

REC16   Time: 24.3 sec   Wd: 42

pron. *n.*
The lady's washing up. The water's going all over the floor. The kid's about to fall

n. V. *n.*
off the chair and crack his head open. The kids are eating biscuits. A nice view out
                                              gerund
aux.
the window. The window's open. The curtains look nice.

REC5 27 sec   Wd: 50

V.
The boy is reaching up into the cupboard. The stool slips and he's about to fall off

pro. gerund
and the woman's to across the sink which is overflowing, carrying a plate. As she

V. V. V. V. *pro.* V. *pro.*
walks she slips, falls over, and the plate smashes. The little girl then has to run for

n.
help.

Language Tasks Coding Sheet
(based on Haravon, Obler, Sarno, 1994 example)

Time to first prompt: _____sec

A. Morphology

_____1. Unit Total   _____ Units to First Prompt   _____Narrative Time

_____2. Total Repetitions

_____Syllable Repetitions

_____Word Repetitions   _____ literal   _____ nonliteral

_____Phrase Repetitions   _____ literal   _____ nonliteral

_____Sentence Repetitions   _____ literal   _____ nonliteral

_____3. Filler Total   _____4. Jargon

_____5. Word Total   _____6. Stereotypies

_____7. Total Substantives

_____Nouns   _____definite   _____ questionable

_____Main Verbs   _____definite   _____questionable

_____Adjectives   _____definite   _____questionable

_____Adverbs   _____definite   _____questionable

_____8. Total Functors

_____Pronouns   _____definite   _____questionable

    [_____Pronouns without antecedent (do not add)]

_____Auxiliary Verbs   _____definite   _____questionable

_____Conjunctions Total   _____ "and"   _____all other conj.

_____All other functors   _____definite   _____questionable

_____9. Indefinite Words

_____10. Neologisms   _____definite   _____questionable

_____ 11. Paraphasias

_____ Literal   _____ definite   _____ questionable

_____ Semantic   _____ definite   _____ questionable

_____ Verbal   _____ definite   _____ questionable

B. Syntax

_____ Paragrammatisms

_____ Unbound

_____ Bound

_____ Omissions

_____ Aposiopesis

C. Semantics

_____ Total   _____ first story item

_____ 1 mother/woman/lady

_____ 2. Washing/wiping/drying/doing dishes

_____ 3. Water overflowing out of sink

_____ 4. Boy/kids

_____ 5. Stealing/reaching for cookies

_____ 6 stoop tipping/boy falling off stool

_____ 7. Girl/sister

_____ 8.mother not paying attention/oblivious

linkage: _____ 8a. First connector: Mother doesn't notice children

_____ 8b. Second connector: Mother doesn't notice sink overflowing

D. Pragmatics

_____ Judgement   _____ Unsureness   _____ Apology

_____ Personalisation   _____ Giving Names   _____ Other

Written Task Instructions

Word Grouping Task (Animal task)
When you are instructed, you have 3 and a half minutes to read the passage and answer its directive. The 3 columns of words are all part of the same list. You have 3 and a half minutes to complete this task. Please begin now. (TIMED)

Sign Task
- You have 30 seconds to study this figure. You may begin now. (TIMED)
- You have 90 seconds to answer the questions. Please begin now. (TIMED)

Fact Recall Task (Family Fact Recall)
- You have 1 minute to read this passage. Please begin now.
- Please turn the sheet over. At the cue please write down every fact you can remember from the passage. You have 2 minutes to complete this task. You may begin now.

Faces T:
- Plea   sider the following faces. This is list A.
- Plea.   sider the following faces. This is list B.
- Pleas   iy the sheet. You will be shown another list of faces. For each face you must decide wheth   r not you've seen it before, if so, in what list, and how confident you are about that judgement.

RECENCY JUDGmt SCORE SHEET	Yes/No		LIST?	A	B	100%	very	quite	not very	guessing
HAVE YOU SEEN THIS FACE BEFORE?			IF YES WHICH			HOW CONFIDENT are you of this LIST?				
No.1										
2										
3										
4										
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48										

| RECENCY JUDGmt SCORE SHEET | TEMPLATE FOR SCORING | | | | | | | | |

HAVE YOU SEEN THIS FACE BEFORE?	Yes/No	IF YES WHICH LIST?	A	B	HOW CONFIDENT are you of this LIST? 100%	very	quite	not very	guessing
No.1									
2									
3									
4									
5	▓		▓						
6									
7	▓			▓					
8	▓			▓					
9									
10	▓		▓						
11									
12									
13									
14	▓			▓					
15									
16	▓			▓					
17									
18	▓		▓						
19	▓		▓						
20	▓		▓						
21									
22	▓		▓						
23	▓			▓					
24									
25									
26	▓			▓					
27									
28	▓		▓						
29	▓		▓						
30	▓		▓						
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37	▓		▓						
38									
39	▓			▓					
40	▓			▓					
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42	▓			▓					
43									
44	▓			▓					
45	▓		▓						
46	▓		▓						
47									
48	▓			▓					