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**THE EFFECTS OF SHORT-TERM, TOTAL SLEEP DEPRIVATION
ON COGNITIVE PERFORMANCE IN HUMAN SUBJECTS**

by

FRANK WIMMER, B.A.

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of**

Master of Arts

Department of Psychology

**Carleton University
Ottawa, Ontario
August 22, 1990
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ISBN 0-315-60477-8

**The undersigned recommend to the Faculty of Graduate Studies
and Research acceptance of the thesis**

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ON COGNITIVE PERFORMANCE IN HUMAN SUBJECTS**

**submitted by Frank Wimmer, B.A.
in partial fulfilment of the requirements for
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Thesis Supervisor

Chair, Department of Psychology

Carleton University

Date

Abstract

Twelve subjects were deprived of sleep for one night and performed a series of six cognitive tasks; their performance was compared to the performance of thirteen matched control subjects. Performance measures included a working memory task, a modified Stroop test, a trail making test, a vowel/consonant discrimination task, a letter recognition task, and the Torrance Test of Creative Thinking (Figural Form). Change scores were analyzed for each of the measures to investigate performance improvements and decrements from a baseline measure. Results of a MANOVA on four component measures of the vowel/consonant discrimination task did not reveal any differences in performance between the two groups. Likewise, results of the working memory task did not reveal statistically significant differences between the groups. The completion time on the trail making test was significantly slower for the experimental group on the evening following sleep loss ($p < .02$). A letter recognition task revealed that longer display latency was required for the experimental subjects when the letter presentation rate was paced by the testing computer ($p < .01$), but no differences existed between the groups when subjects were allowed to determine the presentation rate. The modified Stroop test revealed longer completion times for the experimental subjects than control subjects ($p < .002$), with a significant group by trials interaction ($p < .0001$). The performance on the Torrance Test revealed a statistically significant group difference on the Flexibility component ($p < .01$), but no differences were found on the Fluency, Originality, or Elaboration measures. The implications for these findings are presented as a lack of support for the lapse hypothesis and are discussed in terms of changes in attention processes which follow sleep deprivation.

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Acknowledgments

I would like to thank everyone involved in supporting this study. This includes an extensive list: Christine Morel, Judy Niles and Amber Hayward; special thanks to Derek Loewy, Rick Bonato, and Penny McGregor. Thank you all for making my life easier and this thesis possible. I would like to extend a very special thanks to Robert Hoffmann for teaching me so much and for being a friend; thanks to Alan Moffitt for inspiring me to think harder than I sometimes wanted. Thanks also are in order to Anders Kjellberg, James Horne, and Michael Stipe for inspiring me.

Finally, I wish to thank my best friend, wife, and reason for being on this wacky planet, Susan Wimmer. Thank you for being bold enough to venture off to Canada and for tolerating being married to a graduate student.

Introduction

Sleep deprivation studies have been employed by psychologists for over one-hundred years. Most of the sleep deprivation research has been of an applied nature, mainly in vigilance research for military scenarios. Less frequently, sleep deprivation research has been performed in order to discern the need for human sleep. The interest of this study is with the latter; through the course of this paper, we will focus on the cognitive performance in short-term, total sleep deprivation.

First, a survey of the historical findings in the sleep deprivation literature will be presented. This will be followed by a discussion of the foremost hypothesis in the sleep deprivation literature - the "lapse hypothesis." The experiment which follows will be an attempt to expose some of the shortcomings of the lapse hypothesis and to suggest some alternative hypotheses to explain the performance errors found in sleep deprived subjects.

1.1 A History of Sleep Deprivation Research

In 1896, Patrick and Gilbert performed what has since been credited with being the first methodological sleep deprivation experiment (Horne, 1988b). Few consistent conclusions have been drawn from such studies, especially with regard to sleep deprivation of short periods (Horne, 1988b; Naitoh, 1976; Percival, Horne, and Tilley, 1983). Horne (1978) concluded that a review of

Sleep Deprivation...2

sleep deprivation studies provides "little support for any body restitutional role for human sleep." (p. 95). A review of sleep deprivation research by Naitoh (1976) stated:

For some SD researchers, SD has become merely a tool used to change the experimental subject's body and mind. Reporting these changes is a major obsession of some SD studies, leading them to, euphemistically speaking, an empiricism which in fact is to confirm repeatedly a truism: SD makes humans and animals sleepy (p. 54).

Most researchers of sleep deprivation effects (e.g., Angus and Heslegrave, 1985; Horne, 1988b; May and Kline, 1987; Naitoh, 1976) have commented on the paucity of findings; as a result, the human body is reported to be quite resilient to sleep deprivation, particularly when the deprivation period is short (i.e., less than two nights) and when testing is directed at cognitive performance.

A number of psychological changes have been reported following extended sleep deprivation. These problems include increased anxiety (Vein, Dallakyn, Levin and Skakun, 1983), temporal distortions, disorientation, visual illusions and hallucinations (Morris, Williams, and Lubin, 1960; Bliss, Clark, and West, 1959). However, results such as these are rarely reported in sleep loss of less than two nights. Incidents of psychological misperceptions under a single night of sleep loss are most often reported when sleep loss is paired with continuous operation scenarios (e.g., Mullaney, Kripke, Fleck, and Johnson, 1983; Mullaney, Kripke, Fleck, and Okudaira, 1983). Such phenomenological measures have been frequently reported, but have rarely been investigated due to a preoccupation with developing more "objective" measures.

Behavioral changes which occur in conditions of extended sleep loss have proven difficult to quantify. In a series of studies at the Walter Reed Army Hospital, the "Cognitive Disorganization" scale (Morris, Williams, and Lubin, 1960) was created to describe the behavioral changes and deterioration of cognitive abilities in sleep deprived persons (Morris et al., 1960; Williams, Lubin, and Goodnow, 1959). The scale consists of five temporally ordered items to be scored by the experimenter; lower numbered items are arranged to correspond to the behavioral changes first expected, while higher numbered items are intended to correspond to behavioral changes expected to appear in late stages of extensive, long-term sleep deprivation. The list consists mainly of items such as "slurred speech" and "lapses of attention." Results of the Cognitive Disorganization scale suggest that this attention impairment begins after approximately three nights of sleep deprivation. However, due to its subjective nature, the scale is no longer used (Horne, 1988b).

In an attempt to objectify the subjective nature of behavioral and psychological changes, performance measures became heavily emphasized in sleep deprivation studies. One such frequently used format in sleep deprivation testing is reaction-time tasks (e.g., Lisper and Kjellberg, 1972; Wilkinson and Houghton, 1975; Glenville Broughton, Wing and Wilkinson, 1978); these measures can be subdivided into simple reaction-time (e.g., Lisper and Kjellberg, 1972) and serial reaction-time tasks (e.g., Glenville, Broughton, Wing, and Wilkinson, 1978). Simple reaction time uses a single response key, whereas serial reaction-time scenarios implement multiple response keys to multiple levels of a stimulus. In either design, subjects are required to respond, as quickly as possible, to either visual stimuli (Wilkinson and Houghton, 1975; Glenville et al., 1978) or to an auditory tone (Lisper and Kjellberg, 1972).

Results of these reaction-time tasks have indicated that impaired response performance can be detected near the end of a 10-minute testing session when the subject has been deprived of sleep for a single night.

Another frequently used measure for sleep deprivation studies has been vigilance tasks, such as Wilkinson's auditory vigilance task (Wilkinson, 1965). The auditory vigilance task requires participants to discriminate between variable length auditory tones which are presented at a rate of every two seconds. Wilkinson, Edwards, and Haines (1966) used one-hour sessions composed of four 15 minute test blocks. In this test, subjects wearing headphones were required to respond to occasional target auditory tones (375 msec in duration) embedded within a more regular series of longer (500 msec) tones. Subjects were asked to immediately respond to target tones by pressing one of three confidence-interval keys. Wilkinson found that subjects deprived of sleep for a single night missed a significant number of signals after about 30 minutes of testing.

Williams, Lubin and Goodnow (1959) tested auditory vigilance in a series of long-term sleep deprivation studies, demonstrating the linear relationship between performance and length of sleep loss; when subjects were sleep deprived for 72 hours, auditory vigilance was affected after only two minutes. Impaired performance was evident after six minutes following 48 hours of sleep deprivation and remained unaffected at the end of the 10 minute testing session when subjects were deprived of only a single night of sleep.

The results of reaction-time and vigilance studies led Wilkinson (1965) to propose that there are two major factors which influence the sensitivity of a task to sleep deprivation. These two factors are *type of task* and *task duration*. The types of task reported to be most sensitive in sleep deprivation studies are those

which are highly monotonous and low in cognitive demands; furthermore, tasks which are paced by the experimenter are more sensitive to sleep loss than those which are paced by the subject. Regarding task duration, Wilkinson (1968) concluded that, in order to detect performance deficiencies after a single night of sleep loss, experimental tasks should be prolonged to a duration of at least 30 minutes or, preferably, to one hour. By Wilkinson's criteria, reaction-time tasks and vigilance tasks of an extended duration are ideal measures of sleep deprivation. However, the monotonous nature of such a task has also been interpreted as a modifier variable (Johnson, 1982; Kjellberg, 1977).

According to Johnson (1982), extended task duration and tasks with low cognitive demands are merely modifier variables which lead to quicker loss of motivation by the subject. By increasing the length of a task and making the task less interesting, the experimenter is merely creating lowered motivation and, as a result, increased boredom. This observation is strengthened by the fact that the effects of reaction-time tasks and vigilance tasks have been removed following short-term sleep loss when the subject is offered a performance incentive such as knowledge of results (Williams, Lubin, and Goodnow, 1959; Wilkinson, 1961) or money (Horne and Pettitt, 1985). Deprivation effects have also been removed when tasks are highly interesting to the subject, such as video games (Wilkinson, 1964). In order to avoid excessive de-motivation of sleep deprived subjects, Horne (1988a) has recommended that sleep researchers use measures which are more cognitively challenging and interesting to experimental subjects; otherwise, Horne argues, sleep loss studies cannot address cognitive changes in sleep loss beyond decreased motivation.

Research by Angus and Heslegrave (1985) has suggested that performance measures of a cognitive nature warrant further examination; previous cognitive measures, which have appeared insensitive to sleep loss in former studies, may not have been demanding enough to detect the performance limits of sleep deprived subjects. When highly demanding cognitive tasks such as logical reasoning of complex sentences (Haslam, 1982; Angus and Heslegrave, 1985), encoding and decoding (Angus and Heslegrave, 1985), and a complex subtraction task were used, performance decrements were detected following only a single night of sleep loss. A study by Horne (1988a) further emphasizes the problem of ceiling effects in sleep deprivation measures.

Utilizing the Thurston Word Fluency Test (Pendleton, Heaton, Lehman, and Hulihan, 1982) as a performance measure, Horne (1988a) found that the structure of the task may cause the task to appear insensitive to sleep loss. Initially, subjects were instructed to generate all of the four letter words they could think of which begins with a given letter. Under such conditions, no differences were evident between a control group and a group which was sleep deprived for one night. However, when subjects were asked to generate as many responses as they could containing an open-ended number of letters, experimental subjects generated significantly less words than a control group. Horne also noted that sleep deprived subjects perseverated on responses, often crossing through words they had recorded earlier in their list. In an object usage test, Webb (1985) found no differences in the number of responses generated by control and experimental subjects; Horne suggested that this was case where the task parameters reduced performance differences, that two minutes were insufficient to reveal the limits of the sleep deprived group; after

using a similar task, Horne (1988a) stated that the first minute of the object usage task was used by both control and experimental subjects just to "collect their thoughts" (p. 535).

Angus and Heslegrave (1985) have pointed to another methodological shortcoming in many sleep deprivation studies. They have argued that infrequent, intermittent testing can result in low frequencies of data which may not produce sufficient measures to accurately reflect subject performance; it is further cited that infrequent measures will overlook the circadian aspects of human performance. These circadian aspects of human performance present a methodological difficulty in sleep deprivation studies, resulting in large variability within subjects over repeated measures. Thayer (1989) reports that due to the "morning" and "evening" personality type variations, nearly 50% of individuals function better in either early or late day, while the remaining 50% perform best at some mid-point.

In addition to the circadian rhythms of human performance, performance measures are further complicated by the introduction of a 90-minute ultradian cycle, also known as the basic rest-activity cycle (Kleitman, 1963). It has been proposed that the BRAC is due to an alternating activation between the left and right cerebral hemispheres (Broughton, 1975). In turn, this 90-minute rhythm appears to be linked to variations in cognitive performance, notably perception and vigilance, as well as physiological cycles in heart rate, hormonal levels and urine flow (see Armitage, 1986). These circadian and ultradian rhythms both act together to result in an underestimate of performance changes by increasing the performance variance of subjects.

1.2 The Lapse Hypothesis

In explaining performance deficits resulting from sleep deprivation, few hypotheses have been offered by sleep researchers. Hypotheses have focused mainly on predicting the missed responses found in reaction-time and vigilance tasks; to date, the most accepted hypothesis to explain such findings is the "lapse hypothesis."

Williams, Lubin, and Goodnow (1959) noted that sleep deprived persons experience periodic "lapses of attention" which result in missed intake of information and missed responses (Williams et al., 1959; Wilkinson, 1968). These lapses were later proposed to be the result of "microsleeps" (Dement, 1972) - rapid, fragmented sleep occurrences resulting from sleep loss. According to Dement, total sleep deprivation is not possible - our attempts to deprive a subject of sleep merely break up the individual's sleep into a series of stage one sleeps.

While many sleep researchers have accepted the lapse hypothesis as an ample explanation for the performance deficits associated with sleep loss, others have pointed to the inadequacies of the hypothesis. Naitoh (1976) has insisted that, although Dement's advice is a helpful reminder against "methodological naivete" in sleep research, studies have consistently demonstrated that even hundreds of microsleeps are inadequate in deterring fatigue and sleepiness (see Webb and Ross, 1972). Furthermore, microsleeps consist only of stage 1 sleep; after three nights of sleep deprivation, the total amount of microsleeps occurring in a 24-hour period would be expected to total no more than 20 minutes (Horne,

1988b). While the lapse hypothesis may explain some performance loss which results from sleep deprivation, it seems unable to account for most sleep loss effects (see Dinges and Powell, 1988; Dinges and Powell, 1989; Kjellberg, 1972).

1.3 Inadequacies of the Lapse Hypothesis

Most sleep deprivation research has utilized the types of tasks recommended by Wilkinson (1968). The tasks used in the past have been long in duration, with very low cognitive demands (e.g., vigilance tasks and simple reaction time tasks). Tasks which were considered cognitively demanding have only recently begun to appear in the literature; formerly, such tasks were not considered sensitive to one night of sleep loss (see Horne, 1988a; Angus and Hesgrave, 1985). As a result, the body of sleep deprivation literature appears to support the lapse hypothesis.

Kjellberg (1977) noted two major shortcomings of the lapse hypothesis. First, Kjellberg states that we cannot be certain that attention lapses are purely the effects of sleep loss and not modifier variables of the experiment; for example, microsleeps appear more frequently as the task is made more tedious or as the participant becomes habituated to the task. Secondly, Kjellberg points out that "lapses" do not appear as discrete units as do Dement's "microsleeps," but rather over a period of time - until, finally, a performance decrement occurs.

Limitations to the lapse hypothesis are further evident in studies of visual attention under sleep deprivation (Hockey, 1970b; Sanders and Reitsma, 1982). In one instance (Sanders and Reitsma, 1982), two groups were tested for

responses to visual stimuli. The first group was sleep deprived for a single night; the second group consisted of non-deprived controls. Light stimuli were presented to a position in either the peripheral or central visual field. For peripheral stimuli, missed signalling and lowered response time was significantly greater for the experimental group. Such a result cannot be explained by the lapse hypothesis. An attention lapse that is merely the result of a "microsleep" would be uniformly altered - a decrement in response performance should be equal for both central and peripheral visual stimuli. Sanders and Reitsma interpreted the findings of their study as evidence for a change in the mental capacity to process information which follows extended sleep loss.

An interpretation of attention as provided by Sanders and Reitsma (1982) may be helpful in explaining the variety of findings found in sleep deprivation studies. Sanders and Reitsma suggest that there is a narrowing of attention which occurs in conditions of sleep loss; a view which is consistent with the results of their study. Sanders and Reitsma interpreted their findings as evidence that cognitive resources are depleted as a result of sleep loss. Since less attention capacity is available, attention becomes centralized as an adaptive function. Research by Horne (1988a), using divergent thinking tasks in sleep deprivation, seem to further implicate a narrowing of attention resources.

Horne (1988a) found that tests which involved a flexible thinking style and the ability to focus on a large number of goals at the same time were problematic for subjects who had experienced total sleep loss of a single night: An experimental group and a non-deprived control group were administered the Torrance Test of Creative Thinking. The test is composed of two parts - figural and verbal. Responses are scored on the basis of originality, flexibility, elaboration, and response fluency.

Horne also administered a test of non-verbal planning (Shallice, 1982). This test, the Tower of London problem, was created in order to establish impairment of planning abilities in persons with attention disorders; in particular, for persons with frontal lobe dysfunctions. The puzzle is similar to the Tower of Hanoi problem, but is different in that there are a number of increasingly difficult problems, each requiring an increasing number of moves to reach problem resolution. The puzzle employs three posts on a wooden base and three colored, wooden beads. The beads (one red, one green, and one blue) are threaded on the posts in one of a variety of combinations. The problem requires the subject to maneuver the beads from the current formation to a different, pre-assigned configuration (i.e., the beads situated in a particular organization on the posts) in as few moves as possible. The difficulty introduced in the Tower of London problem is that, without careful planning immediate goals can impede resolution of the final goal. Using this task, Horne (1988a) found that planning time significantly increased for sleep deprived subjects. Horne suggests that Shallice's test is an exceptionally good measure, because it is found to be highly interesting to the participants and requires only a short time for each session (approximately 7-10 minutes).

Norton's study (1970) of attention selection processes following sleep loss demonstrated the attention problems which had been only casually noted by one-hundred years of sleep research. Norton placed varying amounts of information on a series of cards. Subjects were required to separate the cards in stacks according to alphabetic characters printed on the cards. Norton found that as the amount of irrelevant information printed on the cards increased, sleep deprived subjects required increasingly more time to sort the cards. However, the irrelevant information did not significantly affect the performance of control

subjects. Based partly on these results, Kjellberg (1977) stated that lowered performance in sleep deprived conditions seems to result, in part, from impaired attention resources.

Attention impairment is a frequently cited problem in earlier studies (e.g., Patrick and Gilbert, 1896; Morris, Williams, and Lubin, 1959; Wilkinson, 1965; Norton, 1970). In such studies, experimenters noted attention problems only as a passing observation. Very few experimenters have looked directly at attention in sleep deprivation studies (e.g., Norton, 1970; Fisher, 1980; Sanders and Reitsma, 1982). Kjellberg emphasized the lack of research into these reported attention problems which follow sleep loss. However, since Kjellberg's review, only two attention related sleep deprivation studies have appeared in the psychology literature (i.e., Fisher, 1980; Sanders and Reitsma, 1982). One reason for the apparent disinterest with this issue may be the lack of consensus about the nature of attention (Baddeley, 1986).

Posner and Klein (1973) proposed a three-part concept of attention composed of alertness, selection, and processing capacity: Alertness readies the system for incoming information; selection determines the appropriateness of material being processed; processing capacity is some finite limit which determines the amount of information which will be processed. By considering this three-part view of attention and the general lapses of "attention" reported in the sleep deprivation literature, future directions for studies in sleep deprivation are apparent.

The term "attention" is very broad; a hypothesis which merely states that sleep deprivation results in lapses of attention tells us little about the nature of sleep. Although a single definition of "attention" remains controversial within psychology, conceptualizing attention in the smaller units suggested by Posner

and Klein (1973) may be helpful in understanding the cognitive effects of sleep loss. Given that attention involves the components of alertness, selection, and processing capacity, the lapse hypothesis addresses only the alertness component of attentio... Research such as the study by Norton (1970) and that by Sanders and Reitsma (1982) suggests that changes in selection processes occur after sleep deprivation. High-level cognitive tasks (Angus and Heslegrave, 1985; Horne, 1988a) suggest that changes in processing capacity also occur following short-term sleep loss.

1.4 The Current Study

The purpose of this study is to expose the inability of the lapse hypothesis to predict certain effects of short-term sleep deprivation. Although the lapse hypothesis was once capable of explaining the results of measures being used in sleep deprivation studies (e.g., reaction-time tasks and vigilance tasks), more recent studies (e.g., Horne, 1988a; Angus and Heslegrave, 1985; Sanders and Reitsma, 1982; Norton, 1970) have presented data which are not amenable to the lapse hypothesis.

The original conception of the lapse hypothesis (Williams, Lubin, and Goodnow, 1959) merely regarded "lapses of attention" to be the cause of performance errors. Dement (1972) extended the hypothesis by attributing these lapses as drifts into stage one sleep (microsleeps). Since that time, "microsleeps" have been accepted as the cause of the attention lapses in the lapse hypothesis.

Kjellberg (1977) argued strongly against the lapse hypothesis. Although Kjellberg agrees with Williams, Lubin, and Goodnow (1959) that performance errors occur from attention problems during sleep deprivation, he disagrees that

the cause of these attention failures are due to sleep onset. Unfortunately, few studies regarding attention processes and sleep deprivation have been performed since Kjellberg's writing.

Perhaps the greatest reason for the lack of follow-up to Kjellberg's work is that reaction-time tasks and vigilance tasks had accurately established the attention problems which follow sleep deprivation. Performance on tasks not of a reaction-time or vigilance nature were found to be insensitive to one night of sleep loss. However, recently it has been demonstrated that studies which use complex or high-level cognitive processes are sensitive to only a single night of sleep loss (Horne, 1988a; Horne, 1988b, Angus and Heslegrave, 1985). For Kjellberg, such tasks could also be viewed as those which are more attention demanding. In response to the suggestions of Kjellberg, six tasks which focus on attention processes have been chosen for this study.

One task which will be used in the study is the Torrance Test of Creative Thinking (Figural Form). This measure was used by Horne (1988a) in a sleep deprivation paradigm. This task proved to be sensitive to sleep deprivation of only one night and does not conform to the results predicted by the lapse hypothesis. Horne explained the results of his study in terms of task demands on divergent thinking processes. The distinction between convergent and divergent thinking skills can also be conceived as a difference in attention requirements necessary for task performance. Convergent tasks, such as IQ tests (Percival et al., 1983), require attention selection from a linear flow or single piece of information; however, divergent processes require the processing of multiple units of information and alternating attention selection between these units. Due to attention impairment following one night of sleep deprivation (Norton, 1970;

Sanders and Reitsma, 1982; Kjellberg, 1977), results of the figural form of the Torrance Test of Creativity are expected to replicate those of Horne (1988a).

According to Baddeley (1986), working memory is an important component of attention processes. Working memory is a cognitive store which holds current rules, concepts, and items necessary to manipulate a mental problem (e.g., multiplication, logical reasoning). For Baddeley, dysfunctions of working memory should lead to a reduction in the processing capacity of attention. A variation on the Dobbs-Rule working memory task (Dobbs and Rule, 1989) was used to assess working memory. A working memory task will be used in the current study to examine possible processing capacity limitations of attention following sleep deprivation. The task was created for the purpose of investigating working memory limits; it has yet to be used in a sleep deprivation paradigm. The results of the working memory test are expected to reveal more errors for the sleep deprived subjects than for control subjects. Such a hypothesis is based on an assumption that working memory is one component of attention which is affected by sleep loss and that the memory task used here is an adequate measure of working memory.

A trail making test will be administered to investigate possible attention impairment following sleep deprivation. Shallice (1986) reports that the trail making test has been successful in detecting impairment of attention processes, particularly for persons with frontal lobe deficits. The trail making test is effective in detecting organizational problems, particularly perseveration of thought. Persons with attention deficits, such as frontal lobe patients, make more order errors and require longer completion times than a normal population. The results of a modified trail making test in this study are expected to be consistent with the findings of Norton (1970). The test incorporates varying

amounts of irrelevant stimuli, which are expected to increase completion time and errors in sleep deprived persons (relative to a control group). Trail sheets with irrelevant information are expected to significantly impair the performance of the experimental group; in this case, pages with squares and circles should interfere with the performance of the sleep deprived group. In order to avoid "lapsing," task duration will remain less than five minutes.

A vowel/consonant discrimination task will be administered; this task involves two concurrent tasks. The dual nature of the task and the establishing of task priorities is similar to the study by Fisher (1980). The earlier study, however, did not analyze differences in response times between control and experimental subjects, but rather the proportion of time spent on each of the two tasks. In the current study, the concurrent tasks will be used to examine the selection and capacity limitations of attention following sleep deprivation. The vowel/consonant discrimination task alone is not expected to yield differences. However, the pairing of a secondary task is expected to reveal decreased attention resources. By designating a vowel/consonant identification task to be the "primary task" and response to an auditory tone to be a "secondary task," sleep deprived subjects are expected to perform equal to control subjects on the main task, but have less reserve attention resources to perform a concurrent task; this could also be explained as a "narrowing of attention" as indicated by Sanders and Reitsma (1982). The lapse hypothesis cannot explain such results; lapsing which causes poorer performance on one task component should equally impair performance on a secondary task.

Two versions of a letter recognition task will be administered in order to investigate differences in pacing; one version of the task will be paced by the experimenter, a second version will be paced by the subject. Wilkinson (1965)

found that tasks which are paced by the experimenter are more sensitive to sleep deprivation than tasks which are paced by the subject. The task is designed to examine narrowing of attention following sleep deprivation, as noted by Sanders and Reitsma (1982). In line with this work, letter recognition latencies of the experimental group are expected to be longer for both versions of the task. However, the experimenter paced (or "auto-paced") version of the task is expected to be more sensitive to sleep deprivation.

A modified version of the Stroop Color and Word Test (Stroop, 1935) will be administered. Based on the findings of Norton (1970), which demonstrated that irrelevant stimuli interfere with efficient processing following extended sleep loss, subjects deprived of sleep for a single night are expected to perform significantly more poorly on the Stroop test than non-deprived control subjects. Impaired performance should be reflected in the completion times of the experimental group. The task duration will be held to a minimum in order to avoid "lapsing."

Method

Subjects

Twenty-five participants were obtained for the study; all subjects were selected from the student population at Carleton University. Subjects were between 17 and 27 years of age. Criteria for these participants included male, right-handed, nonsmokers of good health. Participants were also required to have no problem with color-blindness, to have 20/20 or corrected vision, and reported sleeping an average of 7.5-8.5 hours per night. Persons who worked nights were not accepted as subjects. Subjects were informed that they could withdraw from the experiment at any time; however, those successfully completing the study were paid one-hundred dollars for their participation.

Apparatus

During active testing periods, two-way communication was maintained between the experimenter and participant. An Uher microphone was connected to a Pioneer SA-7500 amplifier which was linked to an Acoustic Research 2ax model speaker located in the testing room. An additional microphone was amplified by a Pioneer SA-7500 unit, then coupled to an Audiovox speaker for vocal contact with the experimenter.

Computer tests were conducted on a Zenith MS-DOS XT compatible microcomputer with a EGA graphics card, Zenith color monitor, 640k RAM, and a 40 megabyte hard disk drive for data storage. A Microsoft mouse was attached for manual input in the letter recognition task. Practice sessions were performed on a Packard-Bell MS-DOS AT compatible microcomputer with EGA graphics card, Zenith color monitor, 4 megabytes of RAM, and 80-megabyte hard disk drive; a Logitech mouse was attached for manual input.

Several of the tasks were administered on a computer; these included the letter recognition task, the vowel/consonant task, the Stroop Color and Word Test, and the working memory test. The letter recognition task and vowel/consonant tasks were created for the purpose of this study. The computerized Stroop test was based on the paper test developed by Stroop (1935). The working memory test was a variation of the working memory task created by Dobbs and Rule (Dobbs and Rule, 1989). All of the computer tasks were written in Borland's Turbo Pascal programming language (Borland International, 1987).

In addition to the four computer tasks, two paper tests were used. Forms A and B of the figural component of the Torrance Test of Creativity were administered (Torrance, 1974). Three sets of three forms of a modified trail making test were administered on paper; placement of letters and numbers were inversions and mirrored images of a single set in order to maintain character distance for all forms, to establish equal difficulty between test sessions.

Responses to the computer tasks and Stroop test completion time were recorded by the testing computer. Trail making test completion times were manually recorded by the experimenter.

An additional Packard Bell MS-DOS AT compatible computer was implemented at the experimenter's location. This system was equipped with a Hercules graphics card and Tatung color monitor, then linked to the testing computer by null modem cable. The system was used to monitor the performance of the experimental subject.

Procedure

Participants were solicited by notices posted around the Carleton University campus. Subjects meeting experimental criteria were instructed to be in bed by 2300h on the four nights prior to their experimental participation; participants were contacted by telephone four nights before their experimental date in order to remind them of this curfew and were further instructed to awaken at 0800h on the morning of the experiment; they were also told to refrain from alcohol and caffeine on the day of the experiment.

The twenty-five subjects who participated in the study were assigned, at random, as either control or experimental subjects. The control group consisted of 13 subjects, while the remaining 12 were in the experimental group. Participants were not informed whether they would be control or experimental subjects until the morning of the experiment. All of the subjects were tested on an individual basis.

On the morning of the experiment, subjects were contacted by telephone between 0800h and 0815h to assure that they were awake; at this time they were instructed to remain awake and reminded to not have alcohol or caffeine for the remainder of the day. Otherwise, they were encouraged to continue their day as

usual, until they arrived at the sleep laboratory at 1900h. Subjects assigned to the control group were encouraged to bring their own pillow and sleeping attire in order to enhance their comfort in a new sleeping environment.

The 12 experimental subjects and 13 control subjects were administered the same hourly tests. Hourly test sessions included the Stroop Color and Word test, the vowel/consonant discrimination task, and the letter recognition task. In order to accelerate asymptotic performance levels, subjects received two training and practice sessions prior to actual testing. Testing sessions took place each hour from 2200h on the first night until 2100h on the following evening. Hourly testing sessions were identical for both control and experimental subjects; however, control subjects ceased hourly testing following the 2300h session and did not resume until 0900 the following morning. As a result, the three hourly tests were administered to control subjects 15 times and to experimental subjects 24 times. The order of the tasks in the hourly sessions was presented to both groups as follows: (1) Vowel/consonant discrimination; (2) Letter recognition; (3) Stroop; (4) Letter recognition (e.g., self-paced if auto-paced presented formerly or auto-paced if self-paced presented formerly). The administration times and order for all tasks is shown in Figure 1.

In addition to the three hourly tasks, both groups were administered a modified trail making test and a working memory test; they were also administered two forms (A and B) of the Figural component of the Torrance Test of Creative Thinking. The working memory test was administered to experimental subjects at 2330h, 530h and 2230h and to control subjects at 2330h, 0800h and 2230h. The trail making test was administered to experimental subjects at 2345h, 545h and 2245h and to control subjects at 2345h, 0845h, and 2245h. The Torrance test was administered to both groups at 2030h and again at

Figure 1. Testing schedule for experimental and control subjects.

2130h the following evening. Order of the trail making tests remained the same for both groups, while the order of the Torrance test forms was counterbalanced within the groups.

Hourly Tasks

2.1 Vowel/consonant discrimination task.

Each subject was seated at the computer in a sound-attenuated room and allowed to determine his own comfortable viewing distance from the display monitor. The experimenter then left the subject alone in the room; after that time the subject initiated the first task by pressing either mouse button. After the task had begun, the subject used the computer mouse to respond to visual stimuli and the space-bar on the keyboard to respond to auditory stimuli.

In each session of this task, a series of 150 alphabetic characters appeared serially on the screen; these characters appeared randomly at any one of the 1920 possible character locations allowed by a standard EGA graphics card display (i.e., 24 rows by 80 columns). The subject was instructed to press a given mouse button when he detected a vowel on the screen and the other button when he detected a consonant (in order to avoid confusion, the letter "Y" was not used). Once a letter appeared on the screen, it remained there until the subject made a decision with the mouse. The subject was instructed that his performance would be judged for both speed and accuracy. The target mouse button for vowels and consonants was counterbalanced on one trial, the right button was used to respond to a vowel, the left for a consonant. On the following trial, the left button indicated a vowel, while the right indicated a consonant.

A secondary stimuli also occurred: a tone was presented five times during the testing sessions. These tones occurred at random points within the session. The subject was instructed to respond to the tone as quickly as possible by pressing the space bar on the computer keyboard. Once the tone sounded, it continued until the subject responded.

In a former study using a dual-task paradigm (Fisher, 1980), sleep deprived subjects were found to maintain task priority better than control subjects. For the current study, subjects were instructed that the vowel/consonant discrimination was their primary task, while response to the tone was a secondary task.

2.2 Letter recognition task.

There were two versions of this task; both required participants to identify letters presented on the computer screen. These letters were presented for a brief period of time, then masked by a small rectangle in order to prevent participants from reading their retinal afterimage. Initially, the character was displayed for a duration of 360 msec, then the participant responded by entering the letter which he believed he had seen. If his first response was correct, the display duration was decreased for the next presentation; conversely, if the response was incorrect, the display duration was increased for the next letter. In other words, the first letter was displayed for 360 msec; if this character was identified correctly, the second display was presented for 350 msec, or for 370 msec if the first response was incorrect. The sequence continued through the

presentation of 100 letters. The responses for the last ten letters in the series were then averaged in order to obtain the presentation interval necessary for letter recognition.

The two versions of the task were identical in design, except that one version dictated the letter presentation onset, while a second version allowed the subject to initiate the presentation of each letter. In the case of the automatically-paced (or "work-paced") task, letters were presented at a rate of one letter every three seconds. For the self-paced (or "subject-paced") version of the task, subjects were instructed to press the carriage return key on the computer when they were ready for the next letter. The two versions of the task were counterbalanced across subjects and trials.

For the letter presentation of the task, the standard PC courier font was used. This was displayed in uppercase in a 3x3 array; the central position of this array was marked on-screen as a fixation target. The letter stimuli appeared randomly in any of the eight positions immediately surrounding the target; this display area constituted a visual field of 1.5 degrees so that all letters were presented foveally to the participant. The target block appeared in green on a black background; letter stimuli were presented in white.

2.3 Stroop test.

In this computer version of the original Stroop test (Stroop, 1935), subjects were in the same setting as for the letter discrimination task. When the subject was ready to begin the task, he pressed the carriage return on the computer keyboard. A screen of 70 color names appeared on the computer monitor; these were presented in five columns on the screen, with 14 color

names per column. These words appeared in random order and included four possible words; these were the names "red, blue, green," and "yellow." Additionally, these four color names were printed in either red, blue, green, or yellow; however, the computer presented these words so that printed color always conflicted with the color name. These colors were also randomized by the computer and appeared in bold-type, capital letters.

Subjects were instructed to name the color that the words were printed in, while ignoring the actual words. Subjects were informed that both speed and accuracy were important and that, if they were aware of making a mistake, they should correct themselves before continuing.

Once subjects completed the first screen of color words, they pressed the carriage return key. At this time a second screen of color words appeared, which the subject completed in a similar manner to the first screen. Subjects were instructed to speak loudly so that the experimenter could record their progress.

At the end of each hourly set of computer tasks, subjects were instructed to close their eyes and remain still for four minutes. This was implemented in order to alleviate possible eye fatigue.

Additional Tasks

2.4 Working memory task.

The working memory test was administered on the same computer used for the hourly tasks. However, for this test the experimenter remained with the participant. The subject was presented with a series of single digits on the

computer screen. Presentation proceeded in a serial fashion, at a rate of approximately one digit every two seconds. Six levels of the test were given in each session, increasing in difficulty throughout the six levels.

The task required the subject to enter a series of numbers (between "0"- "9") on the keyboard in the same order that they were presented on the screen. Subjects were allowed to use either the standard "qwerty" keyboard keys or the alphanumeric keypad for entering digits. On the first level, the subject was simply instructed to enter each digit as it appeared on the screen. On the following level, the subject was required to hesitate for one number before entering the first number in the series; this delay continued so that he was required to always remember one number previous in the sequence. On the third level, the subject entered the digit which appeared two numbers earlier in the sequence. This scenario continued until, on the final level, the subject was required to remember numbers which appeared five digits earlier in the sequence.

The subject attempted each level twice before continuing to the next level. When the subject had entered 10 digits in a level, he continued to the next series. The beginning of each level was initiated by the subject, so that a short break could be taken if desired. On the average, a test period of the working memory task required 10-15 minutes.

2.5 Trail making test.

Subjects were seated at a desk and supplied with a pencil, while the experimenter was situated next to the subject with a stopwatch. The subject was given a sheet of paper with letters and numbers printed at various locations on

the page, then instructed to draw a continuous trail, as quickly as possible, which connected the numbers and letters in an alternating fashion (1,A,2,B,3,C,4,D...). The subject was given the sheet and told to find the number "1" (labeled with "begin"); when this position was located on the page the subject was told to start as the experimenter began timing. Timing stopped when the subject reached the final character (marked "end") on the sheet.

Following the first page, two more pages were administered. The initial sheet contained 13 characters (6 letters and 7 numbers), the second and third sheets contained 25 characters (12 letters and 13 numbers). Each character on the first two sheets was enclosed in a circle. On the third sheet, half of the characters were enclosed in circles, while half were enclosed in squares.

2.6 Torrance Test of Creative Thinking (Figural Form).

The figural component of the Torrance Test of Creative Thinking is composed of three activities: picture construction, picture completion, and "lines" (form A) or "circles" (form B). Each activity allows ten minutes for subjects to generate as many responses as possible.

Subjects were seated at a desk and were read instructions as developed by Torrance; however, since the test instructions were composed to allow group administrations, minor revisions were made to change plural verbal instructions to singular forms. After the experimenter was comfortable that the individual understood the instructions, the subject was left to complete the section alone. The experimenter re-entered at the end of each 10 minute session to inform the subject of the procedures for the upcoming section. Subjects were aware of the 10 minute time restriction for each section prior to testing.

In general, test instructions directed the subject to draw figures to elaborate upon the figures and partial figures printed on each page. Subjects were instructed to make their responses as different from anyone else as they could and to make it tell as complete a story as possible; they were further instructed to write in titles for their completed pictures.

The Torrance Test is scored on four components: Fluency, Flexibility, Originality, and Elaboration. These scores are intended to be objective in nature; the scoring manual was based on the responses of 500 individuals who ranged in age from kindergarten to college students (Torrance, 1974). In preparing the scoring manual, higher originality points were assigned to figures which appeared less frequently. Higher flexibility scores are assigned for a lower incidence of identical figures. Fluency is based upon number of responses. Elaboration is scored by the amount of detailing that appears in each figure.

When hourly testing was underway, testing occupied approximately 25 minutes of the participant's time per hour; when the subject was not being tested, he was free to read, play games, listen to music, or engage in whatever activity he preferred. The subject was given access to a number of computer games and a portable stereo. Students were also provided with their own office desk so that they could read or work on school work if they preferred.

Subjects' meals were supplied for the duration of their time in the experiment. Control subjects were fed at 0730h, 1230h, and 1830h; experimental subjects were fed at the same hours, with an additional snack at 0230h.

Results

To remind the reader, the tasks can be categorized by the number of administrations; the Torrance Test, being administered only twice will show only the effects of a single night of sleep loss, with 24 hours between testing sessions. Both the working memory task and the trail making tests were administered three times; the evening measures will indicate performance loss one day after the initial test, while the middle test will indicate potential intermediate performance changes. The hourly letter recognition task, vowel/consonant task, and Stroop test were performed hourly; these measures are sensitive to trends in performance. Results will be reported in the aforementioned order.

During the course of the study, only one subject withdrew; this experimental subject had great difficulty staying awake and withdrew at 0800h on the morning following sleep deprivation.

3.1 The Torrance Tests of Creative Thinking (Figural Form)

An analysis of variance (ANOVA) was performed on each of the four difference measures (Fluency, Flexibility, Originality, and Elaboration) between the first and second tests. A Bonferroni procedure was used to correct for type 1 statistical error: the standard .05 alpha value was divided by the four planned analyses in this measure. As a result, an alpha level of .0125 was held for each measure. The analyses revealed that the two groups were significantly different on the Flexibility measure of the test, $F(1,23) = 7.731$, $p < .01$, indicating that

control subjects scored higher than experimental subjects on the second administration of the test, relative to first session performance. The control group mean improved by 3 points on the Flexibility measure, whereas the performance of the experimental group declined by -1.83 points. This resulted in a mean group difference of -4.83.

No statistically significant differences were found on the Fluency, Originality, or Elaboration measures. Figure 2 shows the performance change from session one to session two for the two groups on each of the four measures. On the Fluency measure, performance of the control group improved slightly, with a mean change of 2.61 points; experimental subjects had a mean score change of -3.33 points. Performance on the Originality measure improved slightly from trial one to trial two, in both control and experimental conditions: Control scores improved by a mean of 1.31; the experimental groups mean improved by 0.17. On the Elaboration measure of the test, a mean change of 11.77 was found in the control group, while the mean change of the experimental group changed by -4.58. Although this difference in Elaboration means is large, a great degree of variance was found in this measure within both the experimental ($SD=32.71$) and the control groups ($SD=43.87$).

A smaller sample of ten tests (five from the first session and five from the second session) were scored by a second rater in order to examine inter-rater reliability. This revealed adequate Pearson product-moment correlations on each of the four test measures: Fluency, $r(10) = .782$; Flexibility, $r(10) = .812$; Originality, $r(10) = .721$; Elaboration, $r(10) = .769$.

**Figure 2. Torrance Test difference scores:
Changes in group means from session one to
session two.**

3.2 Working Memory Task

An unpaired t-test (2-tailed, $p < .05$) was performed on the difference scores for total errors between the first and third sessions and on the difference scores between the first and second sessions. Neither of the analyses indicated statistically significant differences between experimental and control groups.

3.3 Trail Making Test

On the trail making test, data for one experimental subject could not be used; the tests for the subject were administered in improper order and, as a result, were removed. Completion times for both groups were faster on the third session, relative to session one; the completion time for the experimental group changed by a mean of -3.3 seconds, while the completion time for the control group changed by a mean of -10.59 seconds. Difference scores on the test completion times for the 11 experimental subjects and 13 control subjects were analyzed first by an unpaired t-test (2-tailed, $p < .05$) on the performance change from session one to session three. As indicated in Figure 3, this t-test revealed significant group differences, $t(22) = 2.45$, $p < .02$, with the experimental group requiring more time than controls for test completion.

An unpaired t-test (2-tailed, $p < .05$) was performed on the change scores for session two of the trail making test. Both the control group completion time difference ($\bar{M}$ change = -8.79) and the experimental group completion time difference ($\bar{M}$ change = -2.39) improved slightly from baseline. However, these improvement differences between the two groups were not statistically significant.

Figure 3. Trail making test mean completion times per page: Performance change from session one to session two and session one to session three. Experimental vs. control subjects.

3.4 Vowel/Consonant Discrimination Task

The vowel/consonant discrimination task was administered hourly. A repeated measures multivariate analysis of variance (MANOVA) was used to analyze the 14 corresponding difference scores of the two groups. Four dependent variables of the task were analyzed: percentage of wrong vowels; reaction time to tones; reaction time to correct vowels; and reaction time to correct consonants. No main effect for groups was found on the task. Likewise, there was no significant effect due to trial or to group by trial interaction.

3.5 Letter Recognition Task

Auto-Paced

The auto-paced letter recognition task was administered hourly, then 14 corresponding difference scores were derived from the 15 trials. Due to equipment failures on the task, data for two of the control subjects could not be used. The difference scores for the remaining 11 control subjects and 12 experimental subjects were analyzed by a repeated measures ANOVA. Results indicated significant group differences, $F(1,21) = 6.99$, $p < .01$, with control subjects requiring less display time for letter recognition (see Figure 4). There was no significant effect due to trial or to group by trial interaction.

The performance of the control group remained relatively unchanged throughout most of the experiment. Relative to baseline performance, the control group recognition latencies decreased until 1100h (M change = -118.85 msec). After the 1100h session, the control group performance remained within

**Figure 4. Auto-paced letter recognition:
Mean change from session one. Experimental
vs. control subjects.**

100 to 110 msec better than baseline. In the final hours of the experiment, the recognition times decreased slightly at 2000h ($\underline{M}$ change = -78.35 msec) and at 2100h ($\underline{M}$ change = -98.23 msec).

The letter recognition latencies of the experimental group varied greatly throughout the experiment; the recognition latencies remained unchanged between 1100h and 1500h. However, performance of the experimental subjects in the late afternoon was noticeably less consistent; recognition latencies were much higher than baseline performance, with peaks at 1600h ($\underline{M}$ change = 128.79 msec), at 1800h ($\underline{M}$ change = 72.27 msec), and at 2000h ($\underline{M}$ change = 89.69 msec).

Self-Paced

Recognition latencies were also analyzed for the self-paced version of the letter recognition task. A repeated measures ANOVA was performed on 14 difference scores. This analysis revealed no effects due to sleep deprivation. For purposes of comparison, performance on the self-paced version of this task is shown in Figure 5.

Although significant group differences were found on the auto-paced version of the letter recognition task, this was not true in the self-paced condition. In the auto-paced test, both control and experimental subjects were required to complete the task in the same time; however, the self-paced version of the task allowed subjects to complete the task in without external time constraints. In order to examine the possibility that the time spent by each group on the self-paced task accounted similar group performance in that condition, an additional analysis was performed; a repeated measures ANOVA was performed

**Figure 5. Self-paced letter recognition:
Mean change from session one. Experimental
vs. control subjects.**

on the completion times of the self-paced task. The experimental group performed the task slightly more quickly than the control group; however, there was no statistically significant group differences on completion time.

3.6 Stroop Test

A repeated measures ANOVA was performed on the difference scores for the completion times of the Stroop tests. This revealed a significant main effect for groups, $F(1,23) = 12.32$, $p < .002$, significant effect of trials $F(1,13) = 2.78$, $p < .001$, and significant group by trials interaction, $F(1,13) = 3.74$, $p < .0001$, as seen in Figure 6.

Both groups completed the word lists slightly more quickly on the second test session. However, immediately following the experimental night (at 0900h), the completion time of the experimental subjects had slowed by almost one second from baseline performance ($\underline{M}$ change = 0.9), whereas the completion time of the control subjects improved by seven seconds ($\underline{M}$ change = -6.92).

The completion time of the control subjects peaked at 1000h ($\underline{M}$ change = -7.21); following this session, control improvement remained at approximately five seconds less than baseline performance until the testing session at 1700h ($\underline{M}$ change = -3.73). As of the 1700h testing, performance suffered slightly relative to the group's early morning performance. Completion time continued to be slower than in the morning session until the final session at 2100h ($\underline{M}$ change = -3.0).

Figure 6. Stroop test: Mean completion time change from session one. Experimental vs. control subjects.

As demonstrated in Figure 6, the completion times of the experimental group increased through the noon session ($\bar{M}$ change = 2.4), with a sharp peak at 1300h ($\bar{M}$ change = 4.93). The performance was between four and five seconds longer than baseline completion times, showing the poorest completion times at 1900h ($\bar{M}$ change = 6.22) and 2000h ($\bar{M}$ change = 7.95).

During the experiment, control subjects slept while testing of the experimental subjects continued each hour; this resulted in a total of 15 hourly trials for the control subjects and 24 hourly trials for the experimental subjects. Therefore, 9 trials of the experimental group occurred during the sleep of the control subjects; in the prior repeated measure ANOVA, these trials were removed. In order to address the issue of these differing numbers of treatments between the two groups, an additional repeated measures ANOVA was performed on the first 15 sessions for each of the two groups. As in the former analysis, significant effects were found for the main effect for group, $F(1,23) = 4.36$, $p < .05$, for trials, $F(1,13) = 2.381$, $p < .005$, and for group by trials interaction, $F(1,13) = 1.99$, $p < .02$.

Discussion

4.1 The Torrance Tests of Creative Thinking (Figural Form)

In contrast to the results of Horne (1988a), the Figural Form of the Torrance Test of Creative Thinking revealed no group differences in performance on three of the four categories. Of the four categories on the test (Fluency, Flexibility, Originality, and Elaboration), only the Flexibility measure was negatively affected by one night of sleep loss (as depicted in Figure 2). Horne reported statistically significant group differences on performance on all four components of the test. It had been hypothesized that the current study would replicate the results of Horne; however, this was not the case.

Methodologically, the current study was very similar to the study by Horne (1988a). Horne employed a group of 12 control subjects and a group of 12 experimental subjects, with 24 hours between testing periods; the current study utilized a control group of 13 and an experimental group of 12 subjects, with a between tests interval of 24 hours. The schedule for the administration of the Torrance test was also very similar for both studies.

One explanation for the discrepancy between Horne's results and those of the current study is a difference in the statistical procedures used to evaluate the respective data. Horne used the control group's change in performance between the first and second test sessions as a predictor of what the experimental subjects' performance should be for the second session; first, a regression analysis on the change in performance of the control group data was performed. This

regression equation was then applied to the first test scores of the experimental group to derive predicted performance scores for each individual. Finally, a one-way analysis of variance was performed on the scores of the two new "groups": i.e., the actual experimental group data and the predicted experimental group data for the second test session.

It is of considerable interest that, in the current study, no effect of sleep loss was found on the Fluency and Elaboration components of the test. Based on previous sleep deprivation studies, these are the two measures we would expect to be most affected by sleep loss; according to the lapse hypothesis, the sleep deprived group should have generated less responses due to drifting into stage 1 sleep. These fewer responses would have been reflected in the Fluency and Elaboration scores: Fluency is a measure of total item numbers completed in the time limit, Elaboration is a measure of number of responses within each item.

As stated earlier, the only score which suffered noticeably from sleep deprivation was the Flexibility measure. The Flexibility measure reflects changes between response categories. In scoring of the test items, objects drawn by respondents are first assigned to categories (e.g., Sports, Animals, Cars, etc.). The Flexibility score is obtained by subtracting the number of repeated categories from the total number of responses; for example, a subject completing three separate figures as an airplane, a hang-glider, and a dirigible would receive a Flexibility score of one, while a subject responding with a leaf, a television, and a horse would receive a Flexibility score of three.

This lowered Flexibility score following sleep deprivation reflects thought perseveration in the experimental subjects. This is an effect of sleep loss not directly noted in the literature prior to Horne's 1988 study. Horne found perseveration of thought in sleep deprived subjects on two tasks, the Thurston

Word Fluency Test and Tower of London puzzle. Thought perseveration is a classic symptom of attention deficits, particularly in persons with frontal lobe damage (Shallice, 1986).

When Horne's statistical procedure was applied to the current data for comparison to Horne's study, significant group differences are found for the Flexibility and Fluency measures of the Torrance test. This analysis was performed only for purposes of comparison of Horne's results and the current results. The procedure used by Horne is, in some cases, more sensitive.

A final explanation for the differing results of Horne from those of the current study may be variations in scoring procedures. In the scoring manual for the Torrance Test, several options are offered for scoring protocol. For example, each of the two forms of the test are divided into three sections. The third section of both forms (forms A and B) include either circles (form B) or pairs of vertical parallel lines (form A) to be completed as objects. On both of these forms, participants are encouraged to add to each figure to make a series of different objects from each item. They are further instructed to add titles to each object they have completed. On the pairs of lines in form A, numbered blanks are provided below each line pair for titles; however, these blanks are not provided for the circles. This tends to break up the 30 line pairs of form A into distinct items, while groups of circles in section three of form B are more likely to be used as a single item. In the current study, 92% of the completed form B test versions contained the circles in groups as a single completed item (e.g., using two circles as tires on a bicycle or drawing a large square around four circles and titling the object as a game die), while only 12% of the form A tests revealed the usage of multiple line pairs as combined objects. This discrepancy in presentation of the final section of the two forms also suggested order effects

of the two test forms; all subjects who used multiple line pairs as single objects on form A had all received form B previously; no subjects who received form A on the first session used multiple line pairs of section 3 as combined response.

When several circles or line pairs are used in the same drawing, the scoring manual states that bonus points may be awarded to the Originality score. Such a usage of the objects is considered to show exceptional creativity. However, an individual that completes the section by collectively using the line pairs or circles as single objects tends to score lower on all four measures of the test, since the number of scorable items is reduced. For example, for a set of twelve circles on a single page, if an individual uses all twelve of the circles as the dots on a domino, he can only receive a Fluency score of one and a Flexibility score of one for that page; an individual who completes the page as twelve separate objects can receive a Fluency score of twelve and a Flexibility score of twelve for the same page. As the number of completed items are reduced, the Originality and Elaboration scores tend to be reduced as there are fewer items to be awarded these scores. The scoring manual reports that the usage of several items as single objects can be awarded bonus points for Originality. However, by using such a scoring strategy, the scores of the remaining three measures will be abnormally low. In the current study, bonus points were not awarded; it is unclear whether Horne chose such a scoring strategy.

Although the two forms were counterbalanced between the two groups, the problems inherent in the third section of the test could result in an abnormal amount of variance between the two forms. These problems appear to have been noticed by the makers of the test; a new revised version of the test has been announced for 1990, but was not yet available at the time of this study.

4.2 Working Memory Task

Performance on the working memory test did not change over the course of the three testing sessions. This suggests that the capacity of working memory is not altered by sleep deprivation of a single night. The task has been successfully used in detecting changes in working memory capacity of elderly populations (Dobbs, personal communication, March 26, 1990; Grandmaison and Tombaugh, 1990). However, this is the first time that the task has been used in a sleep deprivation study. Minor changes in working memory capacity may occur after sleep deprivation of one night, but are not substantive enough to be detected by the current task.

Baddeley has argued that working memory is an important component of attention. The working memory store acts as a buffer where information is maintained regarding stimuli to be attended to. When a number of tasks are present, the working memory is the store for these competing tasks. In theory, perseveration of thought could be due to a dysfunction of the working memory store. Deterioration of information from working memory could leave fewer available responses, resulting in less flexible thinking. However, based on the results of the working memory task, reduced working memory storage does not appear to be the cause of the attentional problems associated with extended sleep loss.

4.3 Trail Making Test

While there were no group differences at the time of the second trail making test session, the third test indicated that the sleep deprived group required significantly more time in completing the test. This result could be explained by a lapsing hypothesis; however, this would indicate that lapsing occurs earlier within testing sessions than indicated in previous studies. Testing of all three forms in a session generally required between two and four minutes. Once again, the lapse hypothesis has been used to explain lowered reaction time near the end of a ten minute session. Furthermore, the pace of the task was not monotonous as in reaction-time and vigilance tasks; in both reaction-time and vigilance tasks, the sessions are endured for a fixed time period determined by the experimenter. In the case of the trail making test, subjects were aware that they were racing against a stop-watch. The task duration was based solely upon the subject's own completion time for each sheet.

No difference in number of errors was found. However, this is not surprising, since errors were discouraged during task instruction; accuracy was emphasized and as a result, actual errors were rare. Although these results could be attributed to lapsing, except that each session was approximately only three minutes in duration; a more probable explanation is that performance deteriorated as a result of thought perseveration. After a night of sleep deprivation, experimental subjects had greater trouble alternating between the letters and numbers. This ability to alternate between the two forms of characters is the premise upon which the task is based. Shallice (1986) reports

that persons with attentional disorders tend to require longer completion times and make more errors, often responding with a steady succession of either numbers or letters (e.g., "1,A,2,B,3,4,5,6").

A further analysis of the test versions within each session revealed no statistically significant differences in performance between the three versions. It had been hypothesized that the additional irrelevant information (the addition of circles and squares enclosing the characters, rather than only circles) would lead to decreased performance by the experimental group following sleep deprivation.

Norton (1970) found that irrelevant information decreased the time performance of a sleep deprived group in a card sorting task. Norton had an increasing number irrelevant items printed on cards. When the two groups were instructed to sort the cards into two stacks (such as letters versus numerals), more time was required following sleep deprivation; the irrelevant information served as more of a distraction to the experimental subjects than to control subjects.

The difference between the effects of the irrelevant information on Norton's card sorting task and the current trail making task is most likely due to the degree of stimulus "irrelevancy." In Norton's task, the added volume of stimuli printed on the cards increased the search time for the sleep deprived subjects. In the current task, the number of search items remained the same on the second and third versions of the test, while the distracting information (squares) was added only to the third page. In other words, Norton's effects were found when the number of items necessary to search was increased. In the current study, although irrelevant information was added only between the second and third test versions, the number of search items was stable.

The results of the trail making test appear to be attributable to two major effects of sleep deprivation: (1) lack of flexibility in thinking processes and (2) increased visual search time. Perseveration tendencies following sleep loss have been noted in the study by Horne. Angus and Heslegrave (1985) used a task which suggests further evidence for increased visual search time following sleep loss. When using a complex coding and decoding task requiring subjects to look up and decode letter combinations, completion times were increased following sleep deprivation.

While reaction time tasks have been regarded as the most sensitive tasks to sleep deprivation, repeated research with such tests has indicated that, in most cases, 30 minutes of testing is required before decreased performance is found in subjects deprived of sleep for one night (Williams et al., 1959; Wilkinson, Edwards, and Haines, 1966). Even in the shortest periods, at least ten-minute testing sessions have been required before lapsing was apparent (Lisper and Kjellberg, 1972; Wilkinson and Houghton, 1975; Dinges and Powell, 1985). In the current case, following one night of sleep deprivation, decreased performance was apparent following task duration of approximately three minutes. If lapsing is the cause for performance deterioration, it is apparent much earlier in this task than formerly found in tasks regarded to be the most sensitive to sleep loss. It is highly unlikely that lapsing into stage one sleep could be the cause of lowered performance on this task. It has been established that task monotony and length increase lapsing; the trail making test is neither monotonous nor lengthy, relative to either reaction time tasks or vigilance tasks.

4.4 Vowel/Consonant Discrimination Task

The main purpose of the vowel/consonant task was to see if sleep deprivation affected performance on a secondary task in a dual task scenario. One component of the task (the vowel/consonant discrimination) was designated as being the primary task; performance on the secondary task (tone reaction time) was hypothesized to suffer following sleep loss. It was anticipated that greater attentional resources would be allocated to the primary task, leaving reduced resources for the sleep deprived subjects to successfully complete the concurrent task. However, the results of this task revealed no effects in the sleep deprivation condition.

The hypothesis of reduced attention resource leading to poorer performance on the secondary task was not supported by this task. The most parsimonious interpretation of the finding is that there is no change in resource capacity. However, it is also possible the task was not demanding enough to tax the potential capacity limits of the experimental group. Angus and Heslegrave (1985) have argued that floor effects in tasks have led to an underestimation of the effects of sleep deprivation in the past.

Another explanation for the results of the task may be due to the tone presentation. When the tone sounded, it remained on until the subject responded. This constant tone tended to act as a distractor for the primary task. A less demanding tone (e.g., one that sounds briefly, then stops) may be more sensitive to sleep loss; a less intrusive secondary task may allow the subject to allocate more attention resources to the primary task.

4.5 Letter Recognition Task

Sleep deprivation did have a significant effect upon performance in letter recognition when letters were automatically presented by the computer. However, this was not the case when subjects controlled the presentation of the letters. These results are consistent with the findings of Wilkinson (1965) with regard to sleep deprivation effects on subject-paced and work-paced tasks; Wilkinson noted that sleep-deprived persons perform better on self-paced tasks than on tasks paced by the experimenter.

The results of this task are not supportive of a lapsing hypothesis. If lapsing or drifting into stage one sleep was the source of errors for the sleep deprived group, we would expect a longer completion time for these subjects on the self-paced version of the task; this was not the case. While there was not a significant group difference on the total completion time, the trend was actually for the experimental subjects to complete the sessions more quickly than the control group.

Two factors are responsible for the degraded performance of the experimental group on the auto-paced letter recognition task. One is a narrowing of visual attention. In a former study of visual attention (i.e., Sanders and Reitsma, 1982), sleep deprived persons have performed equally well in responding to centrally located visual stimuli, while missing significantly more peripheral displays than non-deprived persons. However, a narrowing of visual attention alone would not be an adequate explanation, since the performance of the sleep deprived group did not suffer markedly on the self-paced version of the task.

Considering the difference in performance between the two tasks, response readiness appears to be a factor affected by short-term sleep loss. Even though the letter presentation rate was standardized, sleep deprived subjects appeared to have difficulty estimating the onset of the display. Although a letter was presented once every three seconds, the sleep deprived subjects may have had difficulty maintaining this rhythm; this could be associated with poor time estimation, as cited in former studies (e.g., Morris, Williams, and Lubin, 1960; Bliss, Clark, and West, 1959).

It is also noteworthy that during the course of the experiment, sleep deprived subjects remarked having difficulty discerning similar letters such as "Q" and "O" or "U" and "V." This suggests that the sleep deprived subjects were seeing the letters, but that these letters were sometimes being mistaken for similar letters. Conversely, lapses into stage one sleep would result in total misses of the letter presentations.

4.6 Stroop Test

As predicted, sleep deprivation had a negative effect on color naming of the color words. The interference of the word names was enhanced following sleep loss. These results are consistent with the findings of Norton (1970). Norton concluded from his card sorting task that irrelevant information becomes more difficult to ignore following sleep deprivation. This appears to be a reason for the results of the Stroop task; i.e., the competing information (conflicting color) becomes more difficult to ignore.

The increased time of the experimental group for test completion does not appear to be due to lapsing. The current Stroop test was exceptionally short in testing duration; completion times ranged from a low group average of 87.71 seconds for one session to a high average of 105.8 seconds. Even during the slowest completion times, the test was well under two minutes in duration, far shorter than the ten minute testing minimum expected for lapsing. Furthermore, according to the lapse hypothesis, effects due to lapsing should become more pronounced as a task progresses. This was not the case for the Stroop task. The test consisted of two screens of color words; completion times were recorded for each of the two screens individually, but completion times for the experimental group did not differ between the first and second screens.

For this test, since the control group was allowed to sleep while the experimental group continued testing, differing numbers of testing session were administered to each group. Two potential problems which could arise from this situation are: (1) positive performance effects due to increased practice and (2) negative performance effects due to lowered motivation. Practice effects appear to be the most problematic effect of repeated testing in sleep deprivation research. Horne (1988a) proposed that practice effects have caused the negative effects of sleep deprivation to be underestimated in past research, particularly since many past sleep deprivation studies have lacked control groups for comparison. Practice effects of additional testing in the experimental condition would lead to an underestimate of negative performance effects from sleep loss, reducing the difference between the two groups. However, even with the potential advantage of additional practice, the experimental group performs significantly poorer than their control counterparts.

In order to address potential motivation effects, a post-hoc repeated measures analysis of variance was performed on the first fifteen sessions for each of the two groups. Therefore, in this analysis, there was no discrepancy in the number of testing sessions for the groups. The results of this analysis was consistent with the original analysis (which omitted the nine overnight trials of the experimental group, comparing only the fifteen trials occurring at equal hours for the two groups). These results suggest that lowered motivation was not the cause of performance decrements in the sleep deprived condition.

4.7 Conclusions

The current research was performed as a result of the predominance of the lapse hypothesis in the sleep deprivation literature. The lapse hypothesis is the most cited, most accepted "explanation" of sleep deprivation effects. However, no one has yet demonstrated a "microsleep" co-occurring with performance errors; electrophysiological measures have never been used to validate the existence of microsleeps. As a result, the supposition that performance errors occur due to stage one sleep onset has only been hypothesized; this assertion that microsleeps are the source of "lapsing" has been accepted for nearly 20 years (i.e., Dement, 1972) with no supporting empirical evidence.

Due to its circular reasoning, the lapse hypothesis is of little value to sleep research. Merely stating that sleep deprived persons make errors because they fall asleep says nothing about a possible function served by sleep; it asserts only that the purpose of human sleep is to keep humans from becoming sleepy. Furthermore, it does not explain the discrepancy in performance of experimental

subjects on various types of tasks. As Johnson has pointed out, in tasks with very low cognitive demands (such as reaction-time tasks and vigilance tasks), individuals not deprived of sleep eventually begin to "lapse" and make performance errors. Additionally, the lapse hypothesis cannot account for the performance errors found in short-duration tasks and highly demanding tasks. These problems of the lapse hypothesis should lead researchers to question what purpose the lapse hypothesis now serves. The results of this study, in combination with other research (e.g., Horne, 1988a; Angus and Heslegrave, 1985; Norton, 1970; Sanders and Reitsma, 1982), present an anomaly for the lapse hypothesis which sleep researchers can no longer ignore (see Kuhn, 1970).

In summary, while lapses could explain some of the effects of total, short-term sleep deprivation, they are incapable of predicting many of the results obtained in the current study. Previous research has indicated that, following one night of sleep deprivation, lapsing does not occur until after 30 minutes of testing. Even in the earliest lapses reported, performance has been unaltered for the first ten minutes of testing. The longest continuous task used in this research was the Working Memory Task; this task required between 10-15 minutes for completion. Interestingly, although this task was the longest, it did not reveal performance differences between the two groups. The Torrance Test of Creative Thinking required 30 minutes for completion of an entire test (10 minutes for each of three sections). Lapsing during this test would have resulted in lowered performance after sleep deprivation on the Fluency and Elaboration components of the test (due to fewer responses within the time limits of the test); however, the only significant performance decrease in the experimental condition was on Flexibility, which cannot be predicted by the lapse hypothesis.

One great difficulty encountered in sleep deprivation studies is that of over-generalization; researchers are often looking for a singular process which is responsible for performance errors following sleep deprivation; this is clearly the case for the lapse hypothesis. There are undoubtedly a number of cognitive and physiological processes which are affected by sleep loss. An assertion that attention is affected by sleep loss is still quite general, given that there is so little consensus about the nature of "attention."

The lapse hypothesis arose from the initial insight that sleep deprivation results in attention problems (Morris et al., 1962). However, still other researchers have commented on the attention problems from deprivation without subscribing to the lapse hypothesis (e.g., Kjellberg, 1972; Dinges and Whitehouse, 1988). The three component parts of Posner and Klein's attention framework - alertness, selection, and processing capacity - is helpful in prompting us to examine the attention processes which are affected by short-term sleep loss.

The lapse hypothesis, in its current incarnation, addresses only an alertness component of attention; once again, the lapse hypothesis proposes that this lowered arousal is a result of stage one sleep onset. Although decreased arousal is consistent with some of the results of this study, the supposition that stage one sleep onset is the cause of arousal changes is not supported. The lapse hypothesis should predict longer completion times for experimental subjects in a self-paced letter recognition task; this was not the case in the present study. No statistically significant differences were found between the completion times of the two groups. For the Torrance Test of Creative Thinking, the lapse

hypothesis would predict lowered Fluency and Elaboration scores following sleep deprivation; conversely, there was no statistically significant group difference in these two measures.

Selection processes, like arousal, appear to be altered by sleep deprivation, but are not addressed by the lapse hypothesis. Selection errors seem to be the cause of decreased completion time on the trail making test in the experimental condition. Additionally, selection errors are the most parsimonious explanation for the increased completion time on the Stroop test; for the sleep deprived individual, selection criteria for naming the word colors appears less resistant to the influence of the lexical content of the color names. The results of the card sorting task used by Norton (1970) is also consistent with a hypothesis of impaired selection processes following sleep loss.

Stimulus novelty in sleep deprivation conditions is another indicator of impairment of selection process in attention. Lowered performance to novel stimuli has often been noted in sleep deprivation studies. Familiar events are performed better after sleep loss; however, this is true only to a degree. Lack of novel events also means a higher amount of redundancy of stimuli. Redundant stimuli is known to enhance fatigue effects. Highly redundant material results in lowered performance after sleep deprivation. For this reason, shift-workers are frequently rotated through job operations (i.e., to reduce the likelihood of operator accidents due to fatigue).

With regard to Posner and Klein's third component of attention, a change in resource capacity, the current study is inconclusive. The vowel/consonant discrimination task was expected to reveal capacity limitations by the incorporation of a primary task and a concurrent secondary task; however, no

statistically significant group differences were found. Likewise, the working memory task revealed no change in resource capacity following sleep deprivation.

Conceptualizing a continuum of stimulus redundancy/novelty is helpful in demonstrating the performance errors found following sleep deprivation: At one end of the continuum, tasks which are very simple and familiar to the individual increase performance redundancy and are not performed well; at the other extreme, tasks which are complex or contain very novel components are not performed well either. The first type of tasks (i.e., tasks which are slow-paced and highly redundant) are problematic due to decreased alertness; the second form of tasks (i.e., tasks which contain a high degree of stimulus novelty) are problematic due to deficiencies in selection processes.

This notion of extremes in the continuum is consistent with the cumulative results of research to date in short-term sleep loss. Earlier research has demonstrated deteriorated performance of sleep deprived persons in extremely simple, repetitive tasks. More recent research has focussed primarily on performance errors in highly complex tasks. Tasks which are neither too simple nor too complex are the tasks which are not sensitive to a single night of sleep.

The effects of sleep deprivation on performance can be attributed to two mechanisms related to the alertness and selection processes components of attention. With regard to selection mechanisms, highly complex tasks (tasks which increase stimulus novelty and selection) are impaired by deficiencies in frontal lobe operations. Tasks which require complex planning processes, and highly novel processing of information (e.g., over-riding "automatic" processes such as ignoring color names in the Stroop test) can be considered "complex" tasks.

Secondly, extremely simple, highly-focussed, routine tasks may exhaust sensory input. Heavily redundant information appears to deteriorate processing facilities, similar to the manner in which persistent non-changing visual stimuli becomes ineffective through fatiguing of visual receptors. Singular highly-focussed, repetitive attention can lead to performance errors by fatiguing attentional input processes, in turn, enhancing the need for sleep.

In the case of "complex" tasks, sleep deprivation reduces the ability to alternate between problems. In the case of "simple" tasks, it reduces the ability to sustain attention. This, in turn, suggests that task sensitivity to sleep deprivation is not simply an issue of task complexity, but rather the tasks demands on focussing of attention and the selection processes.

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Sleep Deprivation...68

Appendix A:

Subject Briefing

The study that you will be participating in is a study in sleep deprivation. We are interested in the different ways that different amounts of sleep effect an individual's performance on different types of tests.

You will be tested hourly with a variety of tasks. Some of these will be repeated more than others; to familiarize you with these tests, you will be given an opportunity to practice some of the tasks before we actually begin the study. During your stay here, you will find that your performance may improve on some tests, but not on others - this is to be expected. We just want you to do as well as you can at all times. If you have questions about a test at any time, feel free to ask the experimenter.

As you have been told, you will not be allowed to have caffiene while you are here. However, if you should have trouble staying awake, let me know - I'll be glad to keep you company, give you some music to listen to, or show you how to use the computer for computer games.

In one of the tests, you will be asked questions, then you will be instructed to lie or tell the truth; all of these questions will be mundane, none will be personal or embarassing to you in any way. To assure you of this, you will be given a list of these questions to review before you actually begin the study.

Before we begin tonight, we will place electrodes¹ on your scalp in order to measure your brain activity during your stay. The electrodes are simply attached with a special kind of glue. This will not be painful, but you may feel a little stinging when the glue is applied. If an electrode should accidentally come loose during your stay, it's no problem, just let me know and I'll re-attach it.

Once you are in the testing area, feel free to make yourself at home. If you should need anything, just call for me - you have a microphone in your testing area for contacting me.

¹Electrophysiological measures were assessed for a concurrent study and were not used for this research.

Sleep Deprivation...70

Appendix B:

Trail Making Test

Sleep Deprivation...71

Sleep Deprivation...73

Sleep Deprivation...75

Sleep Deprivation...78

E

End

13

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B

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L

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10

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H

J

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F

11

K

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C

I

A

Begin

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D

2

G

Sleep Deprivation...79

END

1|2|0|4|9|1

FIN