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**LA THÈSE A ÉTÉ
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The Effects of Short-Term Cumulative Partial Sleep
Deprivation and Recovery Oversleeping on
Performance Efficiency, Cognitive Processing,
and Subjective Feeling States

by Joel A. Herscovitch

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Abstract

This study examined the effects of 1 and 5 cumulative nights of partial sleep deprivation (PSD) and 1 and 2 nights of subsequent recovery oversleep on performance efficiency, cognitive processing, and subjective feeling states. Seven paid undergraduate volunteers (5 male; 2 female) aged 18-23 who had normal sleep patterns (mean TST = 7.6 hr) participated. They followed a 9 day testing schedule (a.m. and p.m. sessions) interspersed over a 17 day period consisting of a practice day followed by 2 days in each of the experimental conditions: prebaseline, sleep deprivation (-40% TST per night for 5 nights), recovery oversleep (+40%, +20% TST respectively for 2 nights), and postbaseline. Mean all-day performance was significantly impaired on the 1-hr Wilkinson auditory vigilance test and on one (simple RT) of two (also four-choice serial RT) short-duration (10 min) portable cassette recorded reaction time tests. Subjective ratings of sleepiness Stanford Sleepiness Scale (SSS), mood, and energy also indicated negative changes with sleep reduction; SSS ratings, however, did not correlate with performance measures. Quantitative and qualitative all-day changes in cognitive processing were observed on the Wisconsin Card Sorting Test, but not on an anagrams test. These changes were especially pronounced during the period of recovery sleep which otherwise promoted rapid functional restitution in all non-cognitive measures. Time of day effects were also evident on most performance tasks particularly on the days following initial shifts in sleep time. Results were discussed in relation to the objective and subjective consequences of sleep reductions and extensions, the effect of type of task, circadian rhythms, sensitivity of the SSS, cognitive strategies, psychophysiological substrates, and clinical implications.

Curriculum Studiorum

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Introduction

It is certainly a not uncommon social event for individuals to entertain periods of shortened and prolonged sleep. Whether due to insomnia, pleasure, or excessive work load, we all at one time or another receive less than our usual sleep ration; and this we may follow by one or more nights of extended sleep. Perhaps the most prevalent instance of this pattern is the typical work week for many individuals, undersleeping on weekdays and oversleeping on weekends.

Moreover, certain special populations chronically experience disrupted sleep schedules; witness the frequency of insomnia in today's society. Of further practical import are the effects of fluctuations in the sleep period in professions (e.g., medical interns, airline personnel, shift workers) where this may be a regular part of the job, and the intimate connection between psychopathology and aberrant sleep patterns.

It is then of great practical and heuristic interest to ask what are the consequences for the individual of too little and/or too much sleep. Certainly, most sleep-deprived persons will claim that they do not feel up to par, although individuals may vary widely in this respect. We may then ask whether or not these self-perceptions translate into actual functional impairment. If so, under what conditions? Some will maintain that they can effectively "catch up" on lost sleep by subsequent oversleeping, while others will state that this only serves to perpetuate their drowsiness. Can lost sleep be made up? Is "recuperative" sleep indeed recuperative?

Unfortunately, there are no simple answers to such questions. In particular, the effects of moderate sleep curtailments and extensions

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have remained rather elusive, their clear exposition complicated by a number of practical and semantic factors. Most notable among these is the fact that we are conscious and willful beings who, despite subjective feelings of fatigue, must nevertheless meet the demands of our day. The objective delineation of the effects of sleep loss and oversleeping can then be shrouded behind the veil of steady performance backed by grim, conscious effort. This leads logically to the view that a thorough understanding of these events can only be ascertained by examination both of how we feel and how we perform under such conditions.

The present study addresses itself to the investigation of the effects of short-term sleep reductions and extensions in humans. To this end a holistic and integrative approach is favoured in which not only various levels of information processing will be analyzed but also subjective appraisal will be examined and elaborated operationally. Another primary focus is methodological, namely to assess the sensitivity of certain tests and testing paradigms which are particularly suited to research in the field. Finally, what is learned presently will be related to a number of empirical, theoretical, and practical issues so that an overall view of under- and over-sleeping effects, their basis and implications, may emerge.

Chapter I provides a review of the literature and concludes with a statement of the problem and theoretical hypotheses. Chapter II describes the method by which the hypotheses were tested. Chapter III presents the results which are discussed in Chapter IV. Chapter V represents a more general, integrative, and speculative discussion of the principal findings.

Chapter I

REVIEW OF THE LITERATURE

Sleep deprivation research in perspective

Sleep deprivation is one of the principal laboratory means of gathering information concerning the functions of sleep. It can be likened to an organ extirpation study in physiology in which function is inferred from behavioural changes precipitated by removal. The limitations of this analogy, however, represent one of the major criticisms that can be directed towards sleep deprivation research. As Dement (1972) has aptly remarked, sleep and sleep stages are not "things" which can be totally abolished but rather represent confluences of events, aspects of which may "leak" into other periods of the diurnal cycle. Evidence of brief periods of sleep in supposedly awake behaviour following sleep loss (Bjerner, 1949) lends strong support to this contention. This argument aside, much has been learned about the effects of sleep loss since the first reported experimental sleep deprivation study by Patrick and Gilbert (1896).

Sleep deprivation procedures are of three types - total, selective, and partial. Total sleep deprivation is accomplished by abolishing one or more consecutive nights of sleep. Traditionally this has been the most prevalent form of sleep deprivation experiment. With the discovery of sleep stages through electrophysiological recordings, attention shifted to the study of the functions of the component events comprising sleep. In the last 25 years, selective (differential) sleep deprivation, involving

exclusion of specific stages of sleep, has been predominant. The vast majority of experiments have examined the effects of REM-deprivation, although deprivation of slow-wave sleep (stages 3 and/or 4) has recently commanded more attention.

Partial sleep deprivation is reduction of part of one or several nights of sleep. It is certainly the most common form of sleep loss encountered in our daily lives, but has not been extensively studied. Partial sleep loss represents a compounded problem because the inherent organization of sleep stages is such that NREM sleep occupies the majority of the early part of the night whereas REM (and stage 2) predominate in the latter portion. Reduction of usual nocturnal sleep from 8 to 4 hr is therefore effectively differential deprivation in that REM is reduced by about 66% but stage 4 by only 12% (Webb, 1973).

One of the traditional problems that has faced sleep researchers is the difficulty of obtaining reliable and consistent measures of the effects of sleep loss. Certainly loss of sleep is accompanied by subjective changes, yet objective specification of the nature of such changes has been rather elusive. Substantial research effort has therefore been directed towards the application of certain theoretical notions concerning the functions of sleep in order to circumvent the circular conclusion that the main effect of sleep loss is to induce sleepiness. Premature conclusions have had the unfortunate effect of biasing research effort and of excluding alternative lines of reasoning.

The early REM-deprivation literature exemplifies such a trend. The discovery by Aserinsky and Kleitman (1953) of frequent dream reports

following awakening from cyclical periods of REM sleep provided a physiological indicator of dream activity. The later finding (Dement, 1960) that denial of REM sleep resulted in its rebound on subsequent nights signified that there was a "pressure" or need for such sleep. These findings prompted the proliferation of studies directed at testing the Freudian contention that dreaming represented the "safety valve" for mental health and that exclusion of dreams would precipitate psychological disturbance. Early studies supported the hypothesis. In particular, Dement (1960) noted instances of pathological behaviour following REM-deprivation by multiple forced awakenings. The symptoms included anxiety, irritability, and difficulty in concentration all of which could approach acute levels in certain subjects. Dement reported that one subject quit "in a panic" and two others insisted on terminating one night short of the goal of five nights "presumably because the stress was too great" (p. 1707). Subsequent studies using more systematic assessment procedures failed to confirm these findings even for prolonged periods of REM-deprivation (Wyatt, Kupfer, Scott, Robinson, & Snyder, 1969). The accumulation of evidence (cf., reviews by Albert, 1975; Vogel, 1975) is that REM-deprivation is not harmful and may even be beneficial for certain clinical populations. The modern view represents a complete turnabout from that of 20 years ago. REM sleep is now often considered to play a key role in ontogenetic development (Roffwarg, Muzio, & Dement, 1968) but to be dispensable in adults within the limits of individual needs for psychological restoration (Dement, 1965; Hartmann, Baekeland, Zwilling, & Hoy, 1971).

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It was in the area of performance rather than clinical aspects of behaviour that the effects of sleep loss began to be specified in a manner which ultimately proved reliable and consistent. This work came from research projects conducted by Harold Williams and co-workers at the Walter Reed Hospital and Robert Wilkinson at Cambridge, England. Remarkably, this did not occur until the late 1950's, 60 years after the first sleep deprivation experiment.

Beginning in 1956, the Walter Reed group undertook a series of studies designed to evaluate tests for their sensitivity to sleep loss. Borrowing a concept from earlier studies of fatigue (notably Bills, 1931), Williams, Lubin, and Goodnow (1959) demonstrated that absence of responses, not the emitted responses, represented the critical feature of performance after sleep loss. Further, the periods of no-response were shown by EEG recordings to be associated with brief periods of Stage 1 sleep. Their findings were formalized into the "lapse hypothesis" which stated that sleep-deprived performance is characterized by brief periods of response omission which increase in frequency and duration as hours of sleep loss increase. Implicit in this hypothesis is that even acutely sleep-deprived individuals can continue to perform accurately: performance is rendered progressively uneven, however, due to lapses into brief periods of microsleep. Further investigations of Williams et al. (1959) involved classification of tests in terms of demands on the subject, patterns of deficit, and analysis of the factors which counteract the effects of acute sleep loss.

Wilkinson's major contribution has been the development of sensitive tests and appropriate experimental paradigms through systematic

investigation of those factors which influence the detectability of sleep loss effects. Principal among these are the effects of motivational factors. A long standing problem for sleep deprivation researchers had been the tendency for sleep-deprived individuals to react to sleep loss as a challenge and thereby exert compensatory effort towards bettering their performance. This had the unfortunate effect of rendering performance impairment precipitated by sleep loss very difficult to detect. Wilkinson (1961, 1969) successfully demonstrated that tasks become increasingly sensitive as a function of the number of times they are administered within each testing day and the number of times subjects have experienced the period of sleep deprivation. Presumably, the effect of repetition removes the challenge by fostering habituation to the familiar event or situation.

Not only should all aspects of the testing situation be such as to minimize the effects of motivation, but the tasks themselves should also be as devoid as possible of interest value. This was demonstrated most poignantly in a study (Wilkinson, 1964) showing that after 50 hr of sleep deprivation subjects could perform for an hour without degradation on a complex and interesting "battle game". Whereas performance suffered increasingly with greater complexity on other tasks involving choice, the stimulating nature of battle simulation offset these effects. Addition of incentive through other means, such as providing knowledge of results, can also act to reverse the decrement precipitated by total sleep loss (Wilkinson, 1961, 1962, 1963b). Summarizing his findings, Wilkinson (1969) concluded that in order for sleep loss effects to become evident, performance tasks must be unstimulating in nature: and to this end they must incorporate the necessary ingredients of being prolonged "for a period

of at least thirty minutes and preferably one hour" (p. 33), monotonous, and lacking in incentive. The sensitivity of tasks incorporating these features, notably the 1-hr Wilkinson auditory vigilance and addition tests and Leonard's (1959) 30-min five-choice serial reaction time test, have been amply documented by Wilkinson amongst many others, and such tests have become the virtual sine qua non of researchers in the area of sleep loss and performance.

Recently, however, it has been found that certain tests of short-duration prove sensitive to similar amounts of sleep loss. These new tests were developed at the Applied Psychology Research Unit, Cambridge and are a four-choice serial reaction time test and a simple visual reaction time test. Because they are brief (10 min), portable, and cassette-recorded, they have the particular methodological advantage of being suitable for research outside the laboratory.

The four-choice serial reaction time test is a modified version of Leonard's (1959) 30-min five-choice test. This newer test has been shown to reflect general deterioration in performance within 5 min (Wilkinson & Houghton, 1975). The visual simple reaction time test is based on the auditory prototype developed by Lisper and Kjellberg (1972) which was shown by these authors to be sensitive to the effects of 24-hr of total sleep deprivation (TSD).

Both the four-choice serial reaction time test and the simple reaction time test have recently been found to be sensitive to 24 hr of TSD

(Glenville, Broughton, Wing, & Wilkinson, 1978). The recent success of these tests certainly demonstrates that tasks sensitive to total sleep loss need not be as prolonged as previously thought.

The seminal contributions of the Walter Reed and Cambridge studies have set the course for research relating sleep loss and performance for the past 20 years. Moreover, their mutual findings have interacted in a complementary fashion: Whereas Williams and co-workers described the kinds of deficits to be expected, Wilkinson outlined the procedures necessary for these to become readily apparent without resorting to more extreme sleep loss procedures. In particular, the monotony inherent in Wilkinson's vigilance-type tasks provided an ideal context in which lapses in performance would be most likely to occur. At least for total sleep deprivation then, the nature of performance deficits on sensitive tasks is now largely understood, theoretically interpretable, and easily replicable. The findings for more modest sleep reductions, such as partial sleep deprivation, are, however, neither as consistent nor as clear.

Partial sleep deprivation

The effects of partial sleep deprivation (PSD) on performance have not been extensively studied and our knowledge in this area is incomplete. This is at least partially due to the traditional difficulties encountered in reliable detection of performance deficits following more severe sleep loss and the lack of a strong theoretical impetus such as that which sparked the proliferation of REM-deprivation studies. It is also a function of the presence of a number of powerful "nuisance" variables which

contribute strongly to ambiguity of interpretation of PSD findings and which may render proper execution of such studies rather laborious. These certainly are related to the inconsistency of findings in this area (cf., review by Johnson & Naitoh, 1974; Kleitman, 1963).

Unlike other forms of sleep deprivation, reduction of sleep comprises a virtually infinite range of possibilities. In any PSD study, early decisions must be made as to the amount of sleep reduction, the duration of sleep reduction over days, and whether to reduce sleep by delaying time of retiring or advancing time of arising. Differences among these factors across various studies militate against their comparison and obscure the emergence of general trends.

The influence of circadian rhythms is a most potent contaminating factor in PSD studies. Because reducing sleep length necessarily involves changes in the time of retiring or arising, partial sleep loss also alters the timing of the usual sleep-wakefulness cycle. There always exists, therefore, the strong possibility that performance deficits following PSD may have been due to disruption of normal body rhythms irrespective of loss of sleep. Evidence to this effect has been presented by Taub and Berger (1973, 1976 a, b). In their experiments it was shown that 3-hr advances and delays in the timing of sleep without shortening the sleep period resulted in performance deficits equivalent to that for 3-hr sleep reduction. Moreover, performance degradation was most pronounced in the early morning, and exaggerated time of day differences are widely interpreted as reflective of biorhythmic disruption (Lubin, 1967; Taub & Berger, 1973, 1976 b; Wilkinson, 1962, 1963 a). These findings suggest the potentiating influence of shifts in the phase of sleep for one night on natural body rhythms.

A related finding (Hartley, 1974) implicates the effects of diurnal changes with cumulative sleep reduction. Hartley found that the equivalent of half a night's sleep distributed throughout the course of the day for three days upset performance less than the same ration taken in single blocks. The author interpreted this to mean that the duration of time between awakening and testing represents a crucial factor in sleep reduction experiments.

These findings demonstrate the necessity for consideration of the role played by diurnal changes in PSD experiments. They certainly show that results may vary widely depending on the time periods selected for testing of subjects. Because sleep reduction and circadian shifts are inextricably linked, study of the pattern of performance across different times of day may provide an important clue to their disentanglement. Of particular interest is whether or not diurnal fluctuations, evident following abrupt shifts in the circadian cycle, are gradually tolerated, as might be suggested from studies showing adaptation to long-term sleep curtailment. Analysis of interaction between time of day and term of restricted sleep, absent in previous studies of cumulative PSD, is worthy of fuller consideration.

Another complication derives from individual differences in sleep requirement. It is well known that persons may vary widely in this respect as evidenced most dramatically from studies of short sleepers who function without impairment on as little as 1-3 hr sleep per night (Jones & Oswald, 1968; Meddis, Pearson & Langford, 1973; Stuss & Broughton, 1978). Only the subject of Stuss and Broughton was tested under conditions of both PSD and oversleeping and therefore was proved to be obtaining his optimal amount of sleep (about 2 hr). This condition of natural short sleep aside,

individual needs for sleep may encompass a wide range, and short and long sleepers may display profound differences in personality (Hartmann, Baekeland, & Zwilling, 1972; Monroe, 1967). Moreover, variations in sleep requirement may occur within the same individual (variable sleepers), the demand for sleep increasing with psychological disturbance and decreasing when "things are going well" (Hartmann, 1973). Subtraction of a fixed amount of sleep may therefore exert disproportionate consequences for individuals varying in sleep requirements, as shown by Taub and Berger (1976 a), and even for the same individual depending on current psychological status. This would also be the case among individuals of different ages as sleep need is known to be age-related (e.g., Webb, 1972). Thus a fundamental control in sleep-deprivation studies is to insure to the greatest extent possible that subjects chosen for study are homogeneous with respect to sleep requirement.

Finally, individuals may also differ with respect to habitual diurnal patterns of rest-activity. Time periods selected for sleep and for subsequent testing must take into account differences between morning-active "larks" and evening-active "owls" (Johnson & Naitoh, 1974). To the extent that individuals differ on any of these dimensions, within group variability is increased and the saliency of principal effects thereby diluted.

Failure to control for many of these factors may account for much of the diversity of findings in the sleep reduction literature. This is certainly the case for the early PSD studies (1916-1934) which were further hindered by small sample size, unsystematic observations, and lack of sensitive tests. These studies, concentrating mainly on the effects

of partial sleep loss on memory, motor responses, and cognition yielded no consistent findings; and the effects of PSD on performance could not be inferred (cf., review in Kleitman, 1963).

Between the mid-1930's and early 1960's the literature is silent on sleep limitation. With the resurgence of sleep research based upon EEG monitoring, there was a renewed interest in the effects of partial sleep loss. Since 1965, 10 studies have investigated the effects of PSD on performance. Profound differences in findings between short- and long-term studies suggest that these be grouped according to duration of the restricted sleep schedules.

Studies of prolonged limitation of sleep length over periods ranging from 2 to 8 months report relatively modest effects even though supposedly sensitive tasks were used. According to Webb and Agnew (1974), the principal effect of 60 days of 5.5 hr sleep per night is on subjects' motivation. The authors noted that a slight but steady decline in correct detections on the Wilkinson auditory vigilance task was accompanied by a steady decline in false positive rate, thus indicating that deterioration in performance was most likely due to an increasing unwillingness to report signals.

Studies of gradual curtailment of sleep time over much more extended periods have shown that subjects can adapt to such schedules. Johnson and MacLeod (1973) had two subjects reduce their sleep time downward to 4.5-5.5 hr per night over a period of eight months. Limited changes in mood and performance become apparent after eight weeks (5.5 hr total sleep time per night), but these were neither marked nor consistent. An eight-month follow-up report indicated that both subjects had maintained a sleep schedule of 1 to 2 hr below their previous baseline.

In a more comprehensive extension of the above study (Friedmann, Globus, Huntley, Mullaney, Naitoh, & Johnson, 1977), four young adult collegiate couples volunteered to curtail habitual sleep amount by 30 min intervals until they did not wish to reduce sleep further. Although subjects began to verbally complain of discomfort between 6.5-6.0 hr of sleep, all were able to maintain the restricted schedule over an eight month period by which time they were sleeping 4.5-5.5 hr per night. Moreover, performance on such sensitive tasks as the Wilkinson auditory vigilance task, the Wilkinson addition task, and a modified Williams Word Memory task showed no significant impairment. Follow-up reports revealed that total sleep time decreased by 1.0-2.5 hr below baseline was maintained voluntarily for at least one more year.

As suggested by the authors, there is some plasticity with respect to sleep length when it is reduced gradually over a long period of time. Quite a different picture is obtained, however, from studies involving abrupt reductions in sleep duration over periods ranging from 1 to 8 days.

Much of what we do know of the nature of performance deficit subsequent to short-term PSD comes from the work of Wilkinson and co-workers. Emphasizing the necessity of repeated administration of prolonged and monotonous vigilance tasks, Wilkinson et al. have demonstrated in detail the effects of short-term partial sleep loss on performance on the 1-hr Wilkinson auditory vigilance task and the 1-hr Wilkinson addition task. In the first of two related studies (Wilkinson, Edwards, & Haines, 1966; Hamilton, Wilkinson, & Edwards, 1972), six subjects followed a schedule of 0, 1, 2, 3, 5, and 7.5 hr of sleep on two consecutive nights in each of 6 weeks, counterbalanced so that each subject

received each of the sleep treatments at a time different from the others. Subjects were required to spend virtually the entire testing day on calculation and vigilance tasks. Decrements in performance occurred when sleep was reduced to one hour or no sleep was allowed at all, for 1 night, or where 3 hr of sleep (or less) were permitted over 2 consecutive nights. Utilizing a signal detection theory analysis (Tanner & Swets, 1954) on the vigilance data, Wilkinson (1969) later concluded that signal detectability (as indexed by d') was impaired when curtailment of sleep time intruded upon slow-wave sleep (Stages 3 and 4), whereas willingness to respond (as inferred from β) declined with less severe restrictions infringing mainly on REM sleep periods.

In an extension of this study, Hamilton, Wilkinson, and Edwards (1972) examined performance following 7.5, 6, and 4 hr of sleep per night for four consecutive nights in each condition, and observed a significant decrease in correct detections and number of sums added at the 4-hr level. Moreover, the 4-hr ration showed a cumulative deterioration effect over the 4-day period. For the vigilance task, this was ascribed to a levelling off of the intrinsic capacity to detect signals (d') which otherwise showed substantial improvement with practice. In sum then, the findings of the Cambridge studies suggest that degradation in performance is a definite consequence of short-term PSD. Such changes however are not readily apparent and require rigorous experimental procedures to facilitate their detection.

Other studies of short-term PSD have produced mixed findings. Independent confirmation of the Cambridge studies has been reported by Frazier, Benignus, Every and Parker (1971) utilising a visual detection

task. These authors found a deterioration in percent detections and response latencies across 3 days of a 3-hr regime. Conversely, Sampson (1966) found only modest deficits in six subjects when sleep was reduced to 2.5 hr for 3 consecutive nights. The tasks in this study, however, were digit span and a complex serial subtraction task, and being stimulating and of short-duration, are not of the type generally acknowledged to be sensitive to sleep loss effects. A study by Webb and Agnew (1965) revealed no uniform or consistent changes over the first 6 days of an 8-day schedule of 3 hr sleep per night. Only after the last two nights of sleep reduction were deficits apparent on such sensitive tasks as auditory and visual vigilance and paced addition. In direct contrast, the above mentioned works of Taub and Berger (1973, 1976 b) and Hartley (1974), although stressing the importance of circadian upset, present definite evidence that reduction of half of one night's sleep is sufficient to adversely affect performance.

There seems to be some disagreement therefore with respect to the effects of short-term PSD on performance, although the weight of evidence seems to support the contention that performance deficits are detectable when appropriate experimental procedures are utilized. Wilkinson et al. (1966) argued that negative results from PSD studies are due to the use of tests which are too short and lack of an experimental paradigm wherein the tests are scheduled throughout the work day. The recently proven sensitivity of short-duration reaction time tests to one night of TSD, however, suggests that the work load need not be so prolonged to show changes from acute sleep manipulation. Especially because of the potential usefulness of these new tests in work settings in which partial sleep loss

is a common problem, their susceptibility to the effects of PSD should be examined.

Other methodological changes incorporated in the present study are designed to minimize the effects of a number of factors which have contributed, across studies, to heterogeneity of findings and, within studies, to obscuring of main effects. Principal among these is the operation of circadian influences which can only reasonably be inferred from the pattern of diurnal changes following baseline and increasing amounts of sleep loss. Other factors relating to individual differences will be controlled by selecting for study individuals who are homogeneous with respect to sleep requirement, age, psychological status, and habitual patterns of rest-activity. As an additional control for variation in sleep time, sleep reduction will be calculated in proportion to habitual amounts rather than in arbitrary absolute amounts. Study and control of these variables should hopefully permit a less contaminated evaluation of the effects of PSD on performance.

Recovery sleep

Even less studied than partial sleep deprivation have been the effects of recovery sleep following sleep loss. If mentioned at all, this topic has traditionally received only secondary inclusion in primarily sleep deprivation experiments and has been examined from the common-sense perspective that such sleep serves a recuperative function. The exact meaning of recovery sleep, however, is not unambiguous and findings may vary substantially depending on the usage of this term. Intuitively, recovery sleep connotes that there is a sleep debt but the requirement for

such sleep may vary widely depending on the extent of sleep loss. Further, recovery sleep may be of usual duration or prolonged (oversleep), as is generally the case after acute sleep loss of 3-11 days. Conversely, oversleep may occur in the absence of sleep loss and studies of the effects of non-recuperative extended sleep are also relevant here.

The vast majority of modern-day studies have stressed the rapid return to baseline of psychophysiological indices of arousal with oversleep following acute sleep loss. Return of the alpha rhythm is initiated after 1 night of recovery sleep and is complete after 2 such nights (Naitoh, Kales, Kollar, Smith, & Jacobson, 1969; Williams, Granda, Jones, Lubin, & Armington, 1962). Peripheral measures of activation exhibit a less uniform trend; whereas heart rate reaction to cold pressor stimulus returns to baseline after 1 night, body temperature remains consistently depressed after 3 such nights (Naitoh, Pasnau, & Kollar, 1971). Tyler (1959) has suggested that the ongoing activation evident for certain peripheral indices may reflect continuing compensatory effort required to return central mechanisms to optimal functioning.

Measures of behaviour tend to exhibit a parallel course of rapid recovery. Transient symptoms resembling those of psychosis or neural damage are quickly reversed (Johnson, Slye, & Dement, 1965; Morris, Williams, & Lubin, 1960; Tyler, 1959). Subjective complaints such as dizziness, irritability, and headache (Robinson & Herrman, 1922) and feelings of fatigue and exertion (Robinson & Richardson-Robinson, 1922) are abolished by one night's sleep of 8-10 hr: and normal behaviour in general is restored by one night of oversleep (Kleitman, 1963; Patrick & Gilbert, 1896).

The beneficial effects of recovery sleep are supported by studies using sensitive indices of performance efficiency. Within 1-3 nights of recovery sleep following acute sleep loss impaired performance in vigilance (Williams et al., 1962), reaction time (Williams et al., 1959), and tracking response (Naitoh et al., 1969) is restored to normal levels. The overwhelming evidence from all sources suggests, at least when there is a profound sleep debt, that recovery sleep promotes rapid functional restitution. The efficacy of considerably lesser amounts of recovery sleep relative to amounts lost in these studies attests to the remarkable resiliency of the human nervous system after profound sleep loss.

It is perhaps not surprising when the sleep requirement is great, that subsequent extra sleep should prove beneficial. Such is not the finding, however, after less or no sleep has been lost. Nonrecuperative sleep extended from habitual amounts may even prove maladaptive. The single previous study of performance during recovery from partial sleep loss was conducted by May Smith (1916) who used herself as the subject. Although hardly valid in terms of experimental rigour, it is nonetheless interesting for its subjective point of view. Attempting to account for large and persistent declines in performance during recovery from three nights of shortened sleep, which by themselves produced no impairment, Smith drew this apt analogy: "It is as if a man who has habitually lived on his income is suddenly confronted with an unforeseen demand for money. He may, as a solution, break into his capital, i.e., he will temporarily have command of greater resources than normally are his, and his reserve force is thereby lessened so that later less is at his command." (p. 345).

More recent studies have suggested that the waking behaviour of oversleepers is characterized by a sluggishness resembling the exhaustion of energy reserves depicted by Smith. Globus (1969), on the basis of clinical observations, described it thusly: "the late sleeper on Sunday morning sometimes complains of feeling washed out and blah. Paradoxically, despite all his sleep, he feels tired or even exhausted. The late sleeper may complain of difficulty in concentrating; he feels irritable and depressed; he may note a mild headache." (p. 529). In order to examine the hypothesis that extra sleep may produce deleterious subjective effects, Globus (1969) administered questionnaires to 59 volunteer students. On this basis he described a "worn-out syndrome" following extended sleep. It is characterized by feelings of lethargy, irritability, and thick-headedness and is manifested most strongly when the duration of sleep is greater than 10 hr and no previously lost sleep is being made up. Combining these findings with those reporting the detrimental effects of sleep loss, Globus suggested: "There may be a rather narrow band for duration of sleep which is optimal in its physiological effects, with deviations on either side being disruptive." (p. 534).

The negative consequences accruing to patterns of excessive sleep are supported by clinical observations. Rechtschaffen and Roth (1968) have reported on "postdormital confusion" in hypersomniacs. They noted that these individuals were difficulty to arouse from sleep and continued to be drowsy, confused, and disoriented for as long as 1 or 2 hr following initial arousal. Other studies noting syndromes of excessive amounts of sleep in this and other clinical populations are listed in the following section.

Deficiencies in performance following extended sleep and recovery from one night of total sleep loss have also been reported. Taub and co-workers (Taub & Berger, 1969, 1973; Taub, Globus, Phoebus, & Drury, 1971) have described what they term the Rip Van Winkle Effect. It is characterized by performance degradation and mood changes most pronounced in the early morning hours following one night of non-recuperative extended sleep (9 hr).

Only one study has been designed with the main objective of assessing the aftereffects of sleep deprivation. Wilkinson (1963 a) examined performance on Leonard's five-choice serial reaction time test and a visual vigilance task after recovery sleep following 36 hr of continuous wakefulness. He found that performance declined, but in a manner dissimilar to performance decrement after sleep deprivation, i.e., the deficits now occurring primarily in the early morning and throughout the course of the testing period. Both Wilkinson and Taub and Berger interpreted the strong circadian effect as evidence of disruption of diurnal body rhythms.

The evidence that does exist suggests therefore that extended sleep following no or only moderate sleep loss precipitates disturbance in a variety of psychological functions. This is in sharp contrast to the recuperative power generally attributed to recovery from more severe curtailments of sleep. No experimental study, however, has specifically examined performance subsequent to recovery sleep following cumulative PSD, even though such a schedule is intermediate between these polar extremes with associated antithetical findings. Moreover, recovery sleep following chronic partial sleep loss is certainly a frequent social phenomenon, as well as a part of the pathology of certain medical and psychological disorders. It therefore is of interest for practical implications alone.

Cognitive changes

In recent years, a number of theories have been advanced suggesting a relationship between central information processing and sleep. One line of thought (notably Dewan, 1970; Hartmann, 1973) has maintained that the general capacity to receive and process information is fatigued during the day's activities and is restored in REM sleep. Others (e.g. Greenberg, 1970) have related aspects of the sleep process to certain specific, preliminary functions such as memory consolidation and transfer of memories into long-term storage. Definite evidence for relationships between sleep and learning are the findings exhibiting increases in REM sleep following active learning (Fishbein, Kastaniotis, & Chattman, 1974; Hennevin, Leconte, & Bloch, 1974; C. Smith, Kitahama, Valatx, & Jouvet, 1972), which do not have the complication of compounding stress factors, such as REM deprivation studies using the "flower pot" technique. Of particular relevance to the present study are those theories (Broughton, 1975; Moruzzi, 1966; Oswald, 1976) which stress the dependence of subsequent higher-order cognitive efficiency on neuronal recovery (chemical and/or structural) occurring during the prior sleep period. Moruzzi (1966) has further suggested that the critical function of sleep may be recovery of "plastic" synapses involved specifically in learning. And Jouvet (1975, 1978) has hypothesized that genetically controlled behavioural programming recurs in REM sleep.

The relationship(s) between cognitive functioning and sleep has been demonstrated in studies investigating the effects of varying sleep rations on normal populations. Acutely sleep-deprived individuals frequently experience difficulties in sustained mental operations and may have

periods of misperception and disorientation which in the extreme, may be likened to schizophrenic behaviour (Bliss, Clark, & West, 1959; Morris et al., 1960). Although the latter findings have been challenged (cf., review by Johnson, 1969), another more recent study (Friedman, Bigger, & Kornfeld, 1971) reported difficulties in thinking as the most common symptom experienced by medical interns following total sleep deprivation. The presence of certain critical errors committed by the sleepless interns suggests the importance of further study of individuals on altered sleep schedules, particularly those involved in professions where sleep deprivation is a regular part of the job and where clearheaded thinking is crucial.

The earlier reviewed works of M. Smith (1916), Wilkinson (1963a), Globus (1969), and Taub and others (Taub & Berger, 1969, 1973; Taub et al., 1971) indicate that extended sleep regimes are frequently accompanied by functional impairment (or at least perceptions of this). Especially the findings of Globus implicate deficits in the cognitive component ("foggy thinking") on a most prominent basis. Being somewhat paradoxical, these phenomena are not entirely understood; the colourful use of descriptors (worn-out syndrome, Rip Van Winkle Effect) perhaps reflecting a certain hard-to-define quality attached to their unfolding.

The translation of such observed and reported cognitive deficits following altered sleep schedules into objective measures of performance has not been easy to accomplish. Unlike the prolonged and monotonous vigilance tasks which yield evidence of impairment in primary processing functions, tasks designed to measure higher-order cognitive functions (e.g., problem-solving) are intrinsically and necessarily interesting and

motivating: and stimulating tasks are known to increase incentive thereby reducing sleep loss effects (Wilkinson, 1964). The notion that interesting tasks are not vulnerable to sleep deprivation has received support from many studies employing problem-solving and intelligence tests (Fort & Mills, 1972; Orr, 1964; Pasnau, Naitoh, Stier, & Kollar, 1968).

Despite the difficulties encountered in obtaining objective measures of cognitive impairment following reduced and extended sleep, the accumulated evidence in the broader area of information processing-sleep relationships still suggests the reality of such changes. The previously widespread emphasis on recording quantitative deficits in performance, albeit successful for detection of vigilance impairment, may not be the most suitable approach for isolating the less tangible and more resilient higher-order functions underlying performance on cognitive tasks. There is evidence, however, from studies in the cognitive psychology literature stressing the utilisation of strategies of concept formation, that subjects will modify their strategies under more difficult conditions in order to reduce increased strain on memory and inference (Bruner, Goodnow, & Austin, 1956; Restle, 1962). Bruner et al. have shown that changes in performance may be more reflective of methods of coping with stress than of actual cognitive deficits. The emphasis is thus on the quality of performance, the efficiency of the selected strategy, and how these vary under a variety of circumstances.

According to Broadbent (1971), sleep loss may be viewed as a general stressor which affects all properties of information processing systems. Like performance under other conditions of stress, performance after sleep deprivation should be characterized by changes in strategies of

information processing in order to cope with the stress. Some evidence to this effect has been provided by Hockey (1970) and by Norton (1970), who showed that sleepless subjects make attempts to narrow the range of attention in a manner similar to methods of coping with cognitive overload under other conditions of stress (Davis, 1948; Bruner et al., 1956; Bursill, 1958) and during emotional arousal (Easterbrook, 1959). However, no previous study has specifically examined changes in strategies of concept-formation precipitated by prior schedules of reduced and extended sleep, nor have the relative efficiency of these strategies under such conditions of stress been reported.

The effects on higher mental functions of sleep deprivation and oversleeping may have particular significance to certain medical disorders. Thus depression is characterized by chronic fragmented, light and non-restorative sleep (Diaz-Guerrero, Gottlieb, & Knott, 1946; Muratorio & Maggini, 1969; Snyder, 1968; Zung, Wilson, & Dodson, 1964), psychotic episodes by acute periods of (often total) sleep loss (Mendels & Hawkins, 1971; Snyder, 1969), and manic-depressive illness by acute sleep loss during the manic poles and greatly extended sleep during the depressive poles (De Barros-Ferreira & Mattos, 1969; Hartmann, 1969). Moreover narcolepsy-cataplexy is often characterized by fragmented nocturnal sleep with pressure for sleep symptoms in the daytime (Berti-Ceroni, Coccagna, & Lugaresi, 1968; Broughton & Mamelak, 1976; Montplaisir, Billiard, Takahashi, Bell, Guilleminault, & Dement, 1978; Rechtschaffen, Wolpert, Dement, Mitchell, & Fisher, 1963); and idiopathic hypersomnia is associated with non-fragmented prolonged and deep sleep at night often (50% of cases) with prolonged difficulties in morning awakening ("sleep

drunkenness", "Schlaftrunkenheit"), plus chronic daytime sleepiness and diurnal sleep periods (B. Roth, 1962; B. Roth, Nevsimalova, & Rechtschaffen, 1972). The present investigation therefore seeks to illuminate the cognitive coping styles and possible related deficits which may represent part of the symptomatology of clinical populations subject to chronic fluctuations in the sleep period.

Subjective changes

Subjective changes are frequently reported following both sleep loss and sleep extension. In their comprehensive review of sleep loss effects, Johnson and Naitoh (1974) viewed subjective attitude as the primary factor affected by sleep loss. Numerous adjectives are commonly employed to depict self-perceptions in the sleep-deprived state (see Thayer, 1967). Those varying along the dimensions of mood and sleepiness appear the most prominent and widespread. This has been shown by Bohlin and Kjellberg (1973). Using factor analysis these authors reduced the multiplicity of descriptions to 4 factors operating on 2 dimensions: sleep-wakefulness and energy factor scores related to physiological state of arousal, and stress and euphoria factor scores related to subjective interpretation of arousal level.

Changes in mood are generally the first changes to be noted after even moderate sleep loss (Johnson & Naitoh, 1974), and irritability and dysphoria are the most commonly reported symptoms. Indeed irritability and heightened activity levels represent the major findings of the effects of REM-deprivation; conversely, stage-4 deprivation seems to induce a hypoactive and depressed response state (Agnew, Webb, & Williams, 1967).

An intriguing finding is that prolonged REM-deprivation (Vogel, Thompson, & Boatwright, 1972; Vogel, Thurmond, Gibbons, Sloan, Boyd, & Walker, 1975) and total sleep deprivation (Pflug & Tolle, 1971) may be instrumental in alleviating the symptoms of endogenous depression. Such changes, however, do not generalise to normals, the principal finding for one night's loss of sleep being increased dysphoria on all scales (Cutler & Cohen, 1979).

Tom Roth and co-workers have emphasized the mood-regulating function of sleep in their studies of the effects of sleep (Roth, Kramer, & Roehrs, 1976) and lack of it (Roth, Kramer, & Lutz, 1976) on numerous mood scales. They reported that subjects become more hostile, aggressive, and sleepy after losing a full night of sleep. Nor are such changes limited to lack of sleep. As already mentioned, Globus (1969) reported that individuals feel "worn out", irritable, and jittery after extended sleep. Hartmann (1973) in his review of short, long, and variable sleepers, has associated longer sleep times with psychopathology, mainly reactive depression.

Sleep loss is perhaps best known for its potentiating effect on fatigue. Williams et al. (1959) observed that even hundreds of microsleeps could not alleviate the relentless feelings of fatigue and desire to sleep experienced by subjects deprived of 2-4 nights of sleep. Bohlin and Kjellberg (1973) reported that sleepiness and lack of energy are the most reliable subjective indicators of a full night's loss of sleep. Even after partial sleep loss "subjective feelings of fatigue are the major findings whether sleep reduction occurs in a laboratory or in an operational setting" (Johnson & Naitoh, 1974, p. 30). The intimate connection between sleep loss and desire to sleep prompted Murray (1965) to postulate a "sleep motive" which resembles all other biological motives in terms of

need, goal-directed responses, environmental contingencies, and satiation. This is similar to the sleep instinct theory of Moruzzi (1972). It does however fail to explain the lethargy associated with extended sleep.

The vulnerability of subjective phenomena to disrupted sleep patterns is in sharp contrast to the resistance of objective performance measures, which require rigorous experimental procedures to facilitate detection of deficit. This state of affairs may make it seem, as stated by Johnson and Naitoh (1974): "that the only thing we know for certain about sleep loss effects is that going without sleep makes one sleepy". (p. 1). Similarly, Rechtschaffen (1971) has argued that performance studies have failed to advance our understanding of the functions of sleep beyond this logical impasse. Thus the effects of such factors as type of task, (lack of) incentive, and knowledge of results are sufficiently explained with exclusive reference to how these influence sleepiness levels.

In partial sleep deprivation experiments, subjective measures may be the only ones to suffer. In their study of gradual sleep reduction, Friedmann et al. (1977) found that "though performance was not significantly impaired and no major psychological disturbances were observed, gradual sleep reduction did not eliminate subjective 'fatigue', which ultimately was the reason for subjects' termination of sleep reduction." (p. 249). Certainly to some extent this discrepancy between subjective and objective descriptors is a function of the insensitivity of even "sensitive" tasks and the ability of sleep-deprived individuals to functionally compensate for what is negatively experienced. Indeed a constant challenge for sleep research is the objective specification of the subjective experience attached to sleep loss.

There is also evidence, however, that this lack of correspondence reflects true differences between self-perceptions and objective findings. Insomniacs especially tend to experience the effects of sleep loss more drastically than what is dictated by objective appraisal of the reality of their complaints. In virtually every laboratory study of insomnia patients, they have consistently exaggerated the extent of their difficulties. In one recent study of 122 such patients (Carskadon, Dement, Mitler, Guilleminault, Zarcone, & Spiegel, 1976), sleep latency was overestimated more than two-fold (62 vs. 26 min) and total sleep time was underestimated by more than an hour (273 vs 342 min). Although it is unclear why insomniacs do not experience their sleep as restful, evidence of the frequent association between insomnia and neurosis (Kales, Caldwell, Preston, Healey, & Kales, 1976) suggests that this may be related to the larger question of what constitutes mental and emotional disturbance.

For whatever reasons, it seems clear that individuals' self-perceptions regarding the effects of sleep, or lack of it, frequently tend to be more extreme than what can be ascertained objectively. Most importantly then, subjective complaints do not necessarily reflect functional impairment. Thus, although subjective rating scales may serve as a useful and uncomplicated means of gathering information concerning the phenomenological experience of disrupted sleep patterns, their interpretation must be treated with caution. Each such scale must be validated successfully against objective criteria before individual self-perceptions can be viewed as a reflection of actual behavioural efficiency. As exemplified in insomnia studies, this is particularly

crucial in the assessment of patient populations in whom exclusive reliance on subjective appraisal may lead to erroneous conclusions.

The Stanford Sleepiness Scale (SSS) (Hoddes, Dement, & Zarcone, 1972), designed to quantify subjective sleepiness levels, is currently in wide use in the study of sleep disorders and the effects of sleep deprivation. The only two validation studies of the SSS in the literature have produced encouraging results. Hoddes, Zarcone, Smythe, Phillips, and Dement (1973) showed that mean SSS-ratings were significantly increased (indicating increased subjective sleepiness) following 24-hr total sleep deprivation. Further non-significant but "high" correlations between task performance and subjective assessment were observed for the five subjects in that study, thereby indicating that the scale was at least moderately sensitive to the same effects of sleep loss that impair performance ability. Recently, Glenville and Broughton (1979) independently confirmed the findings of the Stanford group. In their study, the sensitivity of the SSS was demonstrated in terms of increased all-day sleepiness ratings and increased ratings following each of the performance tasks after 24-hr sleep loss. Moreover, the ability of the SSS to predict performance efficiency, as indexed by correlations between the two sets of measures was supported and extended to statistical levels of significance. This relationship only held true for those tasks that exhibited decrement following sleep loss, i.e., vigilance and the portable four-choice and simple reaction time tests.

Although the sensitivity of the SSS to 24-hr total sleep deprivation has been amply demonstrated, its sensitivity to the more subtle effects arising from partial sleep deprivation has not been investigated. Because

partial sleep loss represents a frequent event in various sleep disorders, as well as being experienced widely by such professionals as medical practitioners, astronauts, and airline personnel (cf., review by Johnson & Naitoh, 1974), the ability of the SSS to detect deficiencies in waking vigilance levels in these and other populations was judged to be particularly crucial.

A statement of the problem and hypotheses

The study investigates the effects of sleep reductions and extensions on performance efficiency, cognitive processing, and subjective feeling states. Based on the above discussed evidence for difficulties in vigilance and cognition, the following tests were chosen: Wilkinson's 1-hr auditory vigilance test, four-choice serial reaction time test, simple reaction time test, anagrams, and the Wisconsin Card Sorting Test. The Wisconsin Card Sorting Test was considered to be particularly amenable to qualitative and quantitative investigation of strategies of cognitive processing (see Method for rationale and description). Examination of subjective changes utilized the Stanford Sleepiness Scale as well as ratings of mood and energy.

Although the literature provides a general view of the nature of expected changes resulting from modifications to the sleep schedule, closer examination reveals that there are few clearcut expectations. Rather, these may vary widely depending on the exact operational definitions of cumulative partial sleep deprivation and recovery oversleeping and the extent of control of a number of powerful contaminating factors. Most notable among these are the effects of motivation and incentive which may

reduce or even abolish evidence of performance degradation following at least total sleep loss, and the influence of circadian rhythms.

Certainly deficits in performance do occur with cumulative PSD, but these are not readily apparent and require rigorous experimental procedures to facilitate their detection. In particular, Wilkinson and his colleagues at Cambridge have stressed the importance of prolonged testing sessions on monotonous vigilance-type tasks. More recent findings have shown, however, that certain tests of 10-min duration may be vulnerable to the effects of one night of total sleep deprivation. The sensitivity of these short tests to cumulative PSD has yet to be assessed. From this evidence, the following hypothesis has been postulated:

Hypothesis I

Five nights of cumulative PSD will result in poorer performance on the 1-hr Wilkinson auditory vigilance test, the four-choice serial reaction time test and the simple reaction time test.

The limited available information on the effects of recovery sleep provides only speculative insight into the nature of changes to be expected. In general, to the extent that there is a sleep requirement (i.e., prior sleep has been lost), recovery sleep will promote rapid functional restitution. Conversely, when no sleep has been lost, extended sleep may produce deleterious effects. Although it might seem that oversleep following cumulative PSD should have beneficial effects due to increased pressure for sleep, anecdotal and case history reports suggest that the opposite is true. From this evidence the following hypothesis has been postulated:

Hypothesis II

One and two nights of recovery oversleep will result in poorer performance on all tasks.

The literature based on observation and self-report suggests that deficits in cognitive efficiency will result following both reductions and extensions in the sleep period. Indeed a slowing of thought processes is the most frequently reported negative symptom following extended sleep. However, the translation of cognitive abilities into objective performance tests poses an enduring problem for sleep research in that such tests are necessarily and intrinsically stimulating and motivating and thereby resistant to the effects of sleep schedule changes. An alternative approach coming from studies in cognitive psychology favours the investigation of how strategies of processing information change with stress. Thus it is important to examine not only quantitative but also qualitative aspects of cognitive performance especially given the resistance of deficits in the former measure to operationalization. From this evidence, the following hypothesis has been postulated:

Hypothesis III

- a) Qualitative aspects of performance (strategy selection) on the Wisconsin Card Sorting Test will be negatively affected following five nights of cumulative PSD and 1 and 2 nights of recovery over-sleeping.
- b) There will be no difference in quantitative aspects of performance on an anagrams test and Wisconsin Card Sorting Test following five nights of cumulative PSD and 1 and 2 nights of recovery oversleeping.

Circadian effects have been shown to be a most powerful contaminating factor in PSD and oversleep studies. This is because reducing or extending sleep length necessarily involves changes in not only the duration but also

the phase of sleep. In particular, the work of Taub and Berger has shown that shifts in the phase of sleep for one night will result in performance degradation most pronounced in the early morning hours. The time of day effect is especially evident following extended sleep. This effect has generally been ascribed to a desynchronization of body rhythms which gradually readjust throughout the course of the day. From this evidence, the following hypothesis has been postulated:

Hypothesis IV

- a) Performance changes on all tasks will be most pronounced in the morning of the days following the initial alterations to the sleep schedule; i.e., after one night of sleep reduction and one night of recovery sleep. This effect may be most pronounced following one night of recovery sleep.
- b) There will be no difference in time of day performance on all tasks with continuation of each of the altered sleep regimens; i.e., after 5 nights of cumulative PSD and 2 nights of recovery sleep.

Finally, a most common finding in the literature is the effect of sleep loss on subjective feeling states. Changes in subjective estimates of sleepiness, mood, and energy are the most frequently reported and readily apparent symptoms of even moderate sleep disruption. Following oversleep the picture is more complex it having been associated with feelings of lethargy and irritability following non-recuperative oversleep but experienced beneficially with increased sleep requirement. Of related interest is an assessment of the validity of the Stanford Sleepiness Scale (SSS), which is commonly employed as a measure of subjective sleepiness levels in sleep research and sleep disorders medicine. The SSS has previously been shown to be a good predictor of the effects of one night's total sleep loss and concomitant performance efficiency, but has not


previously been assessed following cumulative PSD and subsequent recovery sleep. From this evidence, the following hypotheses have been postulated.

Hypothesis V

- a) Subjective ratings of sleepiness, mood, and energy will change in the direction of negative self-experience following 1 and 5 nights of cumulative PSD.
- b) These changes may continue following 1 and 2 nights of recovery sleep.

Hypothesis VI

SSS ratings will be highly related to concomitant measures of performance on all tasks in all conditions.



Chapter II

METHOD

Subjects

Six male and two female undergraduate volunteers were selected as subjects. Subjects were initially screened via a questionnaire (see Appendix A) and an interview for absence of major medical and psychological disorders, non-use of medication, adequate motivation, and regular and normal nocturnal sleep habits lasting 7.0 to 8.5 hr. No subjects had a history of disturbing symptoms following previous loss of sleep. The two female subjects were selected so that premenstrual and menstrual periods were outside the duration of the experiment. Subjects were paid \$50 each for their participation. They ranged from 18-23 years with a mean age of 20.6 years. One male subject withdrew from the experiment after the first testing session and no suitable replacement could be found at that late date (thus N = 7).

Procedure

Subjects were asked to abstain from napping, strenuous physical exercise, alcohol, and drug ingestion for at least a week prior to, and for the duration of, the experiment. Caffeinated beverages were discouraged but permitted up to a maximum of two cups per day and only in the early evening.

During the week prior to the commencement of the experiment, subjects completed SSS forms and awakened at 0700 hrs, this time of awakening being maintained for the duration of the experiment. Manipulation of amount of sleep was accomplished by either delaying retiring time (sleep deprivation) or advancing it (oversleeping). The sleep rations during treatment conditions were calculated relative to each individual's habitual amount, as assessed from SSS forms and questionnaire data, no major discrepancies being found between the two. Total sleep time (TST) allotment was fixed at -40% (mean TST = 4.6 hr) for all five nights of the sleep deprivation conditions, +40% (mean TST = 10.6 hr) for the first night and +20% (mean TST = 9.1 hr) for the second night of oversleep, all values calculated relative to habitual TST (mean = 7.6 hr). These values are therefore generally equivalent to partial sleep reduction of 3 hr per night and initial oversleep of 3 hr.

Throughout the course of the experiment all subjects slept at home. They were instructed to phone into the laboratory between 0700 and 0715 hrs and to report in person by 0830 hrs, at which time they could leave if it was not a testing day. During the days following sleep reduction, a "buddy" system was instituted in which pairs of subjects had to meet or phone the other at least once every hour. Those evenings, subjects came into the laboratory at 2100 hrs and were monitored by the experimenter. Their activities included schoolwork, games, walks, singsongs, television, and conversation. At the end of the evening they walked or were driven home allowing 15-30 min for bedtime preparation.

Subjects initially came in for familiarization with test procedures on the Thursday prior to commencement of the experiment. The next day

(Friday) constituted a practice day, although this was unknown to the subjects and was treated as part of the experiment. The following two days (Saturday and Sunday) involved prebaseline testing, sleep reduction being initiated on the Sunday night and continuing for the next four nights. The schedule continued as outlined in Table 1.

Each test day involved morning and afternoon testing sessions of 2 hr duration each, all subjects being tested simultaneously. Morning sessions ran from 0900 - 1115 hrs with a 15 min break half way through. Subjects were asked to eat within the next hour and to report back to the laboratory by 1415 hrs, thus hopefully avoiding the post-lunch dip in performance (Blake, 1967). Afternoon testing sessions ran from 1430 - 1645 hrs with a 15 min break half way through. The daily time periods of testing were therefore similar to those in the one night total sleep deprivation study of Glenville et al. (1978).

The five performance tests were presented in counterbalanced order across subjects. Each subject always had the four 10-min tests presented in the same order and had the same order of testing for the four short tests as one other subject, the only difference being that the vigilance task was counterbalanced across morning and afternoon sessions for the two subjects. The simple and four-choice reaction time tests never occurred in consecutive 15 min time periods. The two 1-hr blocks of vigilance and the four short tests respectively were further counterbalanced on alternate days so that each subject followed each of these two possible sequences in each experimental condition.

The Stanford Sleepiness Scale (SSS) was completed by subjects every 15 min during wakefulness except during the vigilance task. It was completed

TABLE 1
 Schedule of Sleep Time Manipulations and Testing Periods

		Day of Week											
		F	S	M	T	W	Th	F	S				
Previous night's sleep reduction or gain as % of baseline		0	0	-40	-40	-40	-40	-40	+20	0	0	0	0
Testing days		P	B1	B2	D1			D5	R1	R2		B3	B4

Note. Abbreviations: P, practice; B, baseline; D, sleep deprivation; R, recovery sleep.

after administration of each short task for the 15 min period in which the test occurred.

During the experiment (January) the room-temperature ranged from 48-54°F (9.0-12.2°C; wet bulb) and 69-76°F (20.5-24.5°C; dry bulb). This was judged to be satisfactorily comfortable and consistent.

Variables and Instruments

The performance tests consisted of a 1-hr auditory vigilance task and four 10-min tests: four choice serial reaction time test, simple reaction time test, anagrams, and the Wisconsin Card Sorting Test. Subjective assessments included self-ratings of sleepiness, mood, and energy. Pre- and post-questionnaires (see Appendices A and B) were administered to subjects. The latter served as a reliability check as well as a source of subjective impressions concerning the effects of sleep disruption and task performance.

Performance Tests

Vigilance. The standard Wilkinson auditory vigilance task was used (Wilkinson et al., 1966). Subjects wearing headphones listened to 500 msec tones regularly spaced at intervals of 2 seconds. Forty of these tones, spaced pseudorandomly in 15-min blocks (10 per block), were slightly shorter (375 msec) and represented target stimuli. In response to these, the subject had to immediately press a response key followed by pressing one of three other keys representing three levels of response confidence. All tones were submerged in a background of high intensity (85 dB) white noise. Number of hits and number of false positive responses constituted the dependent measures.

Four-choice serial reaction time (RT) test. This apparatus, developed by Wilkinson and Houghton (1975), consists of a modified cassette recording

apparatus composed of four lights arranged in a square below which are four similarly arranged keys. Subjects were required to press the key corresponding geometrically to the illuminated light. A response, either correct or not, caused the light to extinguish and another or the same light to illuminate after 120 msec in a randomly programmed sequence. Subjects were instructed to respond to this self-paced task as quickly as possible without making any errors.

Eight dependent measures were investigated for the four-choice serial reaction time test: percent errors, number of gaps (RT > 1 sec), mean reaction time, mean reaction time excluding gaps, mean reaction time for corrects, mean reaction time for errors, mean reaction time for corrects excluding gaps, and standard deviation for corrects excluding gaps.

Simple reaction time test. This visual task, used previously by Glenville et al. (1978), is based on a 10-min auditory reaction time task developed by Lisper and Kjellberg (1972). It consists of a compact digital millisecond clock connected to a portable cassette recording apparatus. The stimulus was the onset of the clock and the response was a key press stopping the clock at the reaction time. Stimulus onset of the next series of numbers occurred randomly between 2 and 10 sec after the extinction of the digital display by the previous response. Number of gaps, overall mean reaction time and standard deviation of reaction times constituted the dependent measures.

Anagrams. An anagram is a word in which one or more letters has been displaced (e.g. RSEOH): its solution requires a rearrangement of the letters into proper sequence (e.g., HORSE). Anagrams have been utilized

extensively in the study of problem-solving ability and the mental processes involved in their solution is now largely well understood (cf., Gilhooly & Johnson, 1978).

Subjects were required to solve as many as possible of 75 five-letter word anagrams within 10 min (see Appendix C). Eighteen separate lists of anagrams were counterbalanced across subjects so that each subject attempted each list at different testing sessions from the others. The pool of anagrams was selected randomly from the Thorndike-Lorge Word List (1952) of five-letter words occurring at a frequency of at least one per million. Anagrams were constructed by displacing two letters in each word and then randomly selected in blocks of 75 for inclusion in 18 mutually exclusive lists. Subjects were instructed to go in order but cautioned not to spend too much time on any one anagram. Number of correct solutions within 10 min constituted the single dependent measure.

Wisconsin Card Sorting Test (WCST). The WCST (Berg, 1948) is a neuropsychological test employed most notably in assessment of cases of frontal lobe damage (Drewe, 1974; Milner, 1963). Performance on the WCST involves a range of information processing abilities varying from the more primary levels of perception and sustained attention, through focused and alternating attention, to higher cognitive functions such as problem-solving and abstract reasoning. Within this latter context, it belongs to the general category termed "conjunctive concept-formation" tasks, performance on which can be analyzed in terms of strategies of hypothesis-testing (Bruner et al., 1956, p. 41). The WCST is thus particularly amenable to qualitative investigation of response styles in addition to allowing for objective scoring of performance criteria.

The materials consist of two decks of 64 cards, each card varying along three dimensions: type of symbol, number of symbols, and colour of symbol. Each dimension contains four different possible variations (e.g., 1, 2, 3, or 4 symbols), thus making each card unique. In the standard administration (Grant & Berg, Note 1), four reference cards are placed before the subject, each card representing one variation in each dimension (e.g., reference card of one red triangle represents the symbol triangle, the number one, and the colour red). Subjects are required to sort the 128 cards in order into the proper categories solely on the basis of feedback of correct or incorrect for each sort from the experimenter. Unknown to the subject, the sorting criterion shifts after every 10 consecutive correct sorts. Scoring procedures involve experimenter's notations of correct or incorrect, as well as the criterion (-a) forming the subject's basis for each sort (see Appendix D).

Owing largely to the number of repeated measures, the present study employed certain variations from the standard administration: a) a separate deck of cards varying additionally along a fourth dimension, shading, was used on alternate administrations so that the task would not become too easy with repetition (these 256 cards were divided randomly into two decks of 128 cards each); b) cards from both sets were not returned to the standard order but were randomly shuffled prior to each testing session; c) termination of a session was dependent on the sorting of all 128 cards and not the standard criterion of six strings of 10 consecutive responses so as to insure a constant number of session responses for statistical purposes and a session time approximating 10 min; d) the order of shifting of criteria was randomized unlike the fixed order in the standard administration.

The WCST was scored for the following measures as suggested in the Manual (Grant & Berg, Note 1):

- 1) number of categories;
- 2) total number of correct;
- 3) number of correct responses over and above each criterion 10;
i.e., the remainder of correct responses outside each successful string of 10;
- 4) total number of errors;
- 5) number of perseverative errors;
i.e., incorrect sorts according to the category which was just previously correct;
- 6) number of non-perseverative errors;
i.e., incorrect sorts also not correct for the previous category;
- 7) number of unique errors;
i.e., sorts which match none of the criteria.

In addition, perseverative errors within a category and ratios of errors were considered to assist in the interpretation of data. Perseverative errors within a category refer to incorrect sorts which were previously incorrect within the same category (e.g. FC-wrong; C-wrong) and represent either perseverative or non-perseverative errors in terms of the standard scoring procedure. Ratios of errors were constructed to highlight differences in relative proportions of the various types of error between experimental conditions. Confusional errors (illogical sorts, including unique responses) were also recorded. These, however, were not considered further due to their virtual absence and their evenness of occurrence across the different conditions.

Subjective ratings

Stanford Sleepiness Scale (SSS). The SSS (Hoddes et al., 1973) consists of a 7-point scale of equal intervals varying from 1 ("feeling active and vital; alert; wide awake") to 7 ("almost in reverie; sleep onset soon, lost in struggle to remain awake") (see Appendix E).

Mood and Energy. Mood and energy ratings were completed by subjects on awakening. The mood scale ranged from 1 ("extremely unhappy") to 9 ("extremely happy") and the energy scale from 1 ("so tired unable to do anything") to 9 ("great energy and drive") (see Appendix E).

Four dependent measures were established for the subjective ratings. Global SSS ratings comprised the mean SSS value calculated from all ratings between 0800 and 1745 hr, thereby encompassing the period from one hour before until one hour after testing. Task-related SSS ratings consisted of the single SSS rating completed immediately after administration of the task, except for the vigilance task which utilized the mean of the two ratings which occurred immediately before and after administration of the test. Ratings of mood and energy levels, completed within 15 min of morning awakening, constituted the latter dependent variables.

Trends in these measures were investigated via a tripartite analysis: a) analysis of global SSS, mood, and energy ratings across experimental conditions; b) analysis of task-related SSS ratings across experimental conditions for each task taken separately; c) correlations of task-related SSS values for each subject with the central dependent measure of the vigilance, four-choice, and simple RT tests, thereby promoting direct comparison of correlations of the same measures under conditions of PSD and one night's total sleep deprivation (Glenville et al., 1978).

Design and Data Analysis

The 8 days of experimental testing, including morning and afternoon testing sessions for each, constituted 16 repeated measures. These were arranged hierarchically to form three independent variables (factors): Factor A, amount of sleep condition; Factor B, day of condition; Factor C, time of day (see Table 2). Factors B and C thus represent subfactors of Factors A and, A and B, respectively. By this method the interactive effect of sleep loss or gain with the duration of either (Factors A x B) and with circadian influences (Factors A x C and/or Factors A x B x C) can be assessed.

For all performance measures, a three-way (4x2x2) analysis of variance with repeated measures on all factors was used to evaluate the effects on performance of different sleep rations (Factor A), of varying durations (Factor B), at different times of day (Factor C). A model of the F table displaying the various crossed factors and interactions with associated error variances and degrees of freedom is presented in Appendix F. The Scheffé method was utilized for all post hoc comparisons on the performance data. Scheffé contrasts involved all means and were run only when the F for A or B was significant.

Because of the primarily ordinal nature of the self-report data, the analyses across conditions utilized the Friedman two-way analysis of variance (non-parametric) with repeated measures (Ferguson, 1976, p. 394). To accommodate the use of this statistic, morning and afternoon data were combined, each of the eight testing days therefore representing a level of the repeated factor. A Scheffé-type post hoc procedure (Marascuilo &

TABLE 2

Experimental Design: Summary of Independent Variables (Factors) and their Levels

Factor	Factor level							
	Prebaseline (B)		Sleep deprivation (D)		Recovery sleep (R)		Postbaseline (B)	
A Sleep condition	1 (B1)	2 (B2)	1 (D1)	2 (D5)	1 (R1)	2 (R2)	1 (B3)	2 (B4)
B Day of condition	AM	PM	AM	PM	AM	PM	AM	PM
C Time of day	AM	PM	AM	PM	AM	PM	AM	PM

McSweeney, 1977, p. 326) utilizing a correction (C) for a small, fixed number of contrasts ($J = 5$) and an alpha level constant at .05 (Penfield, Note 2), investigated simple contrasts between means. Correlations between SSS and performance data utilized the Pearson product-moment correlation coefficient. This is based on equal intervals between ratings (Hoddes et al., 1973) and precedence involving fruitful results (Carskadon & Dement, 1979; Glenville & Broughton, 1979).

Given the present experimental design, a number of statistically significant results emerge (in particular those due to practice effects), which do not relate to the experimental hypotheses. Such effects are only included where appropriate. Similarly, post hoc comparisons have been selected to investigate only deviations from the practice curve attributable to the effects of sleep reduction or gain. Unless otherwise specified, all post hoc tests will compare effects of interest to the mean of all other conditions combined.

An alpha level of .05 was adopted as the minimal requirement for all tests of significance.

Chapter III

RESULTS

The central measures studied and the results are summarized in Table 3. For the performance tests, the main relevant findings after five nights PSD were the decrements in number of hits on the vigilance task and the increases in mean and standard deviation of reaction time on the simple RT test. During the oversleep period, the number of non-perseverative errors on the WCST increased. Time of day effects were evident for number of hits in the vigilance task after one night PSD and after one night of recovery sleep, for mean RT excluding gaps on the four-choice test after both nights of PSD combined, and for number of anagram solutions throughout both sleep manipulation conditions.

For the subjective ratings mean all-day sleepiness levels (global SSS) increased with sleep loss, and energy on awakening was reduced after cumulative PSD and elevated after both nights of recovery oversleeping. Sleepiness estimates following all the tasks also increased with sleep loss although this effect was significant only for the anagrams test and the Wisconsin Card Sorting Test.

Although it cannot be firmly stated without electrophysiological sleep recordings, certain observations indicate that subjects adhered to the prescribed schedule of under- and over-sleeping with only minor deviations. Evidence for subject compliance includes: a) the previously mentioned controls of wake-up calls and early morning appearances at the laboratory,

TABLE 3

Summary of Results for Performance Measures and Subjective Ratings

Dependent Measures	Experimental conditions							
	Prebaseline B1	B2	DI, D1	Sleep depr'n D5	R1	Recovery sleep R2	Postbaseline B3	B4
Vigilance								
Hits	26.3	26.4	27.1 ^{a*}	21.9 [*]	25.3 ^{b*}	28.3	25.3	26.1
False Positives	6.4	6.9	8.5	7.4	5.3	4.9	4.3	2.4
Four-choice RT								
MRT	537.9	506.1	483.3	477.8	445.2	441.6	445.0	431.3
% errors	4.5	6.0	6.8	10.1	12.6	12.2	10.2	11.6
Gaps	23.4	11.0	9.2	b**	6.5	4.7	3.7	4.4
MRT without gaps	521.3	495.1	476.4	470.0	441.1	438.6	442.3	431.3
Simple RT								
MRT	228.1	217.5	230.6	268.6 ^{**}	230.9	231.9	236.4	237.7
SD of RT	74.6	54.7	61.9	122.0	72.2	57.6	64.0	70.2
Anagrams								
Solutions	39.1	44.3	47.1	50.8	52.8	51.0	51.1	54.5
Winsconsin Card Sort								
Nonperseverative errors	9.3	10.8	9.0	7.9	10.4	12.0	9.9	9.7
Subjective ratings								
SSS	3.2	3.4	3.6	3.7	3.2	3.3	3.7	3.5
Mood	6.4	5.4	5.7	5.7 [*]	6.0	5.3	5.3	6.1
Energy	4.3	3.7	4.3	3.3	5.9	5.1	5.0	4.9

Note. Abbreviations: MRT, mean reaction time; SD of RT, standard deviation of reaction time.

Note. All values are in absolute numbers except for reaction times and standard deviations which are in milliseconds.

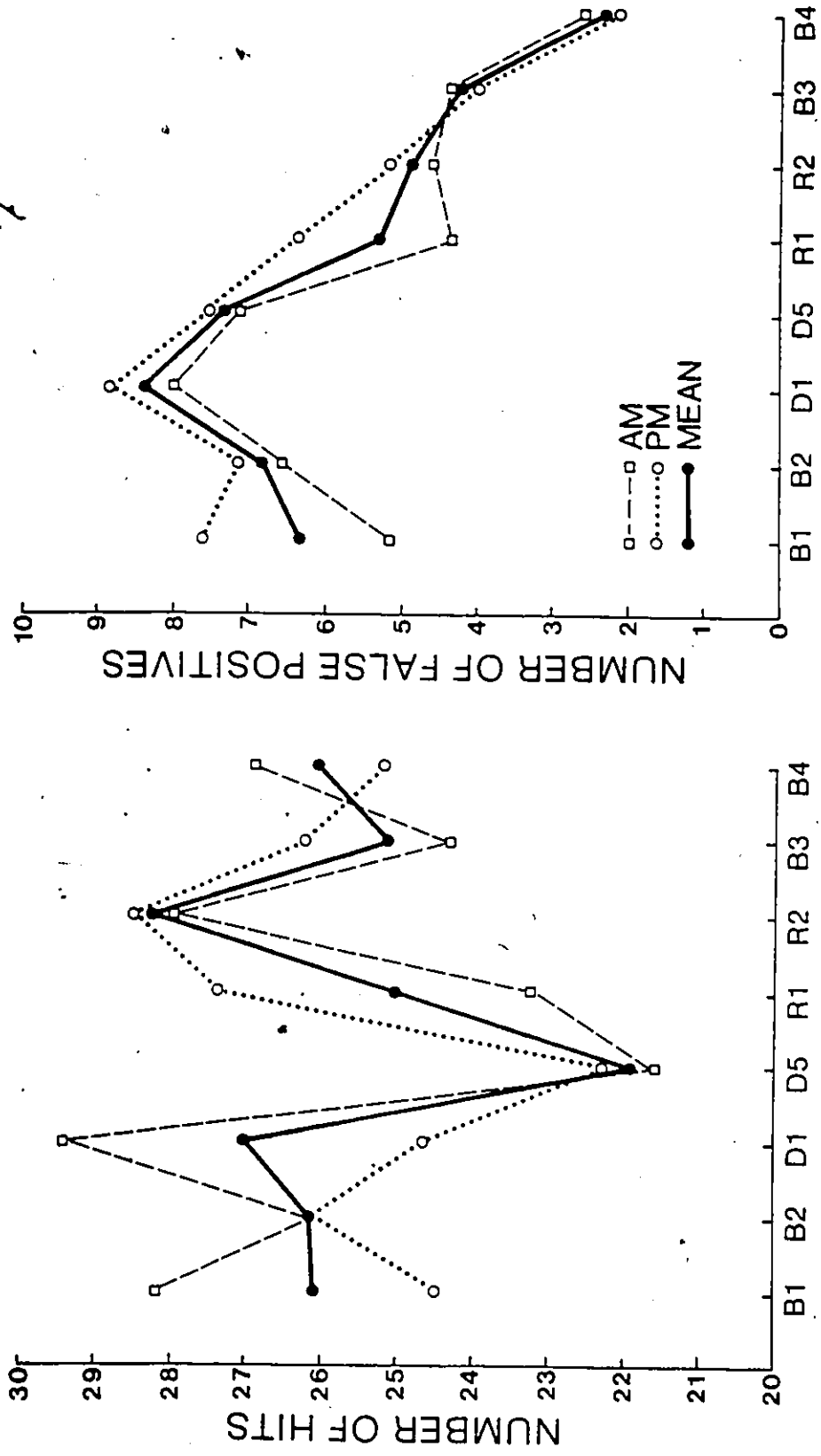
Note. All levels of significance are derived from post hoc comparisons of the highlighted value to the mean of all other conditions.

a a.m. performance superior to p.m. performance.

b p.m. performance superior to a.m. performance.

* $p < .05$

** $p < .02$



SLEEP CONDITION

Figure 1. Mean number of hits and false positives on the vigilance task (B, baseline; D, sleep deprivation; R, recovery sleep).

as well as evening monitoring and the buddy system throughout the sleep deprivation period; b) consistent recording of sleep time on SSS forms with no reported deviations larger than 1 hr; c) confirmation of compliancy by subjects on post-questionnaire (after experiment terminated and subjects paid). Further, it was our observation that all subjects were highly motivated and curious regarding their abilities under "challenging" conditions and thus not inclined to "cheat" on themselves.

Performance Measures

Vigilance test: Figure 1 illustrates the trends in mean number of hits and false positives in the vigilance task for a.m., p.m., and mean a.m. and p.m. values over the various experimental conditions. Number of hits exhibited no significant effect due to practice, whereas number of false positives decreased significantly over the repeated measures but was not altered by changes in amount of sleep.

The reduction in mean values for number of hits was reflected in a significant interaction of amount of sleep condition (Factor A) and day of condition (Factor B), $F(3,18) = 4.35$, $p < .02$. A Scheffé analysis of simple main effects revealed that the number of hits after five nights PSD was significantly reduced compared to one night PSD, to one night of recovery sleep, and to the average of all other conditions ($p < .05$ for each). Thus vigilance detection performance is impaired by cumulative partial sleep loss and restored by one night of recuperative oversleeping.

Time of day effects (Factor C) emerged as significant in combined interaction with sleep time condition (Factor A) and day of condition.

(Factor B), $F(3,18) = 4.97$, $p < .02$ for number of hits. Differences (d) between a.m. and p.m. performance after one night PSD ($d = 5.0$) and after one night of recovery sleep ($d = 4.0$) were greater than the average difference of all other conditions (Scheffé test; $p < .05$ for each). Of particular interest was the shift in time of day changes in performance from a.m. superiority after one night PSD to a.m. inferiority after one night of oversleeping.

We observed that subjects sometimes fell asleep during the vigilance task, particularly during the sleep loss condition. It was therefore decided to estimate and extrapolate for these apparent sleep periods to see if statistically significant results could be attributed to time apparently spent asleep rather than to a decline in waking vigilance levels. A non-responding period of greater than 7.5 min (1/8 of record) was arbitrarily chosen as indicating the likelihood of a sleep period. As depicted in Figure 2, the total time of non-responding periods rose sharply after five nights PSD and remained elevated after one night of recovery sleep. With these non-responding periods eliminated, the number of hits and false positives were then recalculated by extrapolation from the remainder of the record and reanalyzed according to the same statistical procedures. Correction for non-responding periods yielded no new significant effects, the same statistically significant results being observed as in the original analysis. The F ratios are therefore not presented.

Signal detection theory (Tanner & Swets, 1954) parameters (d' & β) were not calculated from the vigilance data due to the very low false

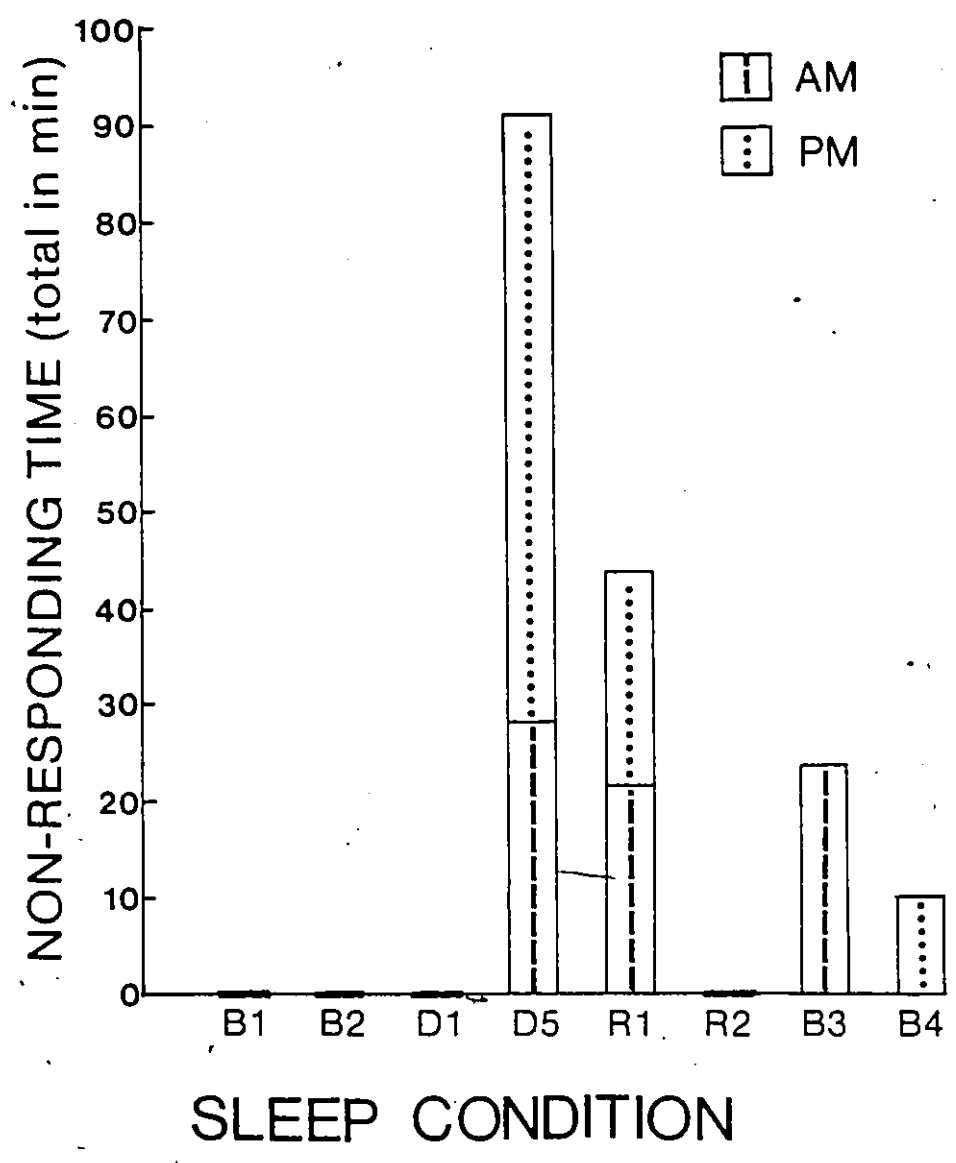
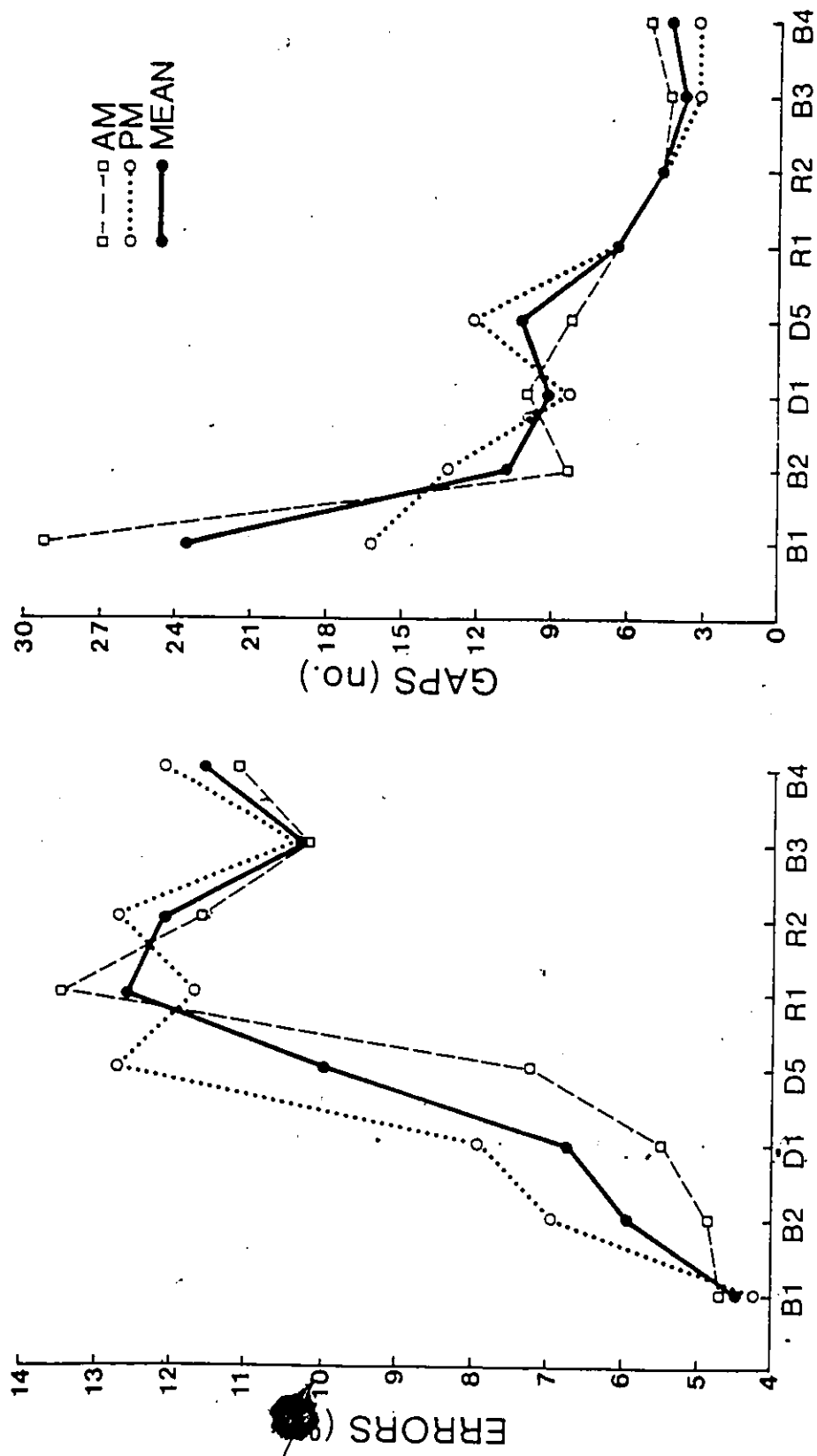


Figure 2. Total time duration of non-responding periods on the vigilance task (B, baseline; D, sleep deprivation; R, recovery sleep).



SLEEP CONDITION

Figure 3. Mean percent errors and number of gaps on the four-choice serial reaction time test (B, baseline; D, sleep deprivation; R, recovery sleep).

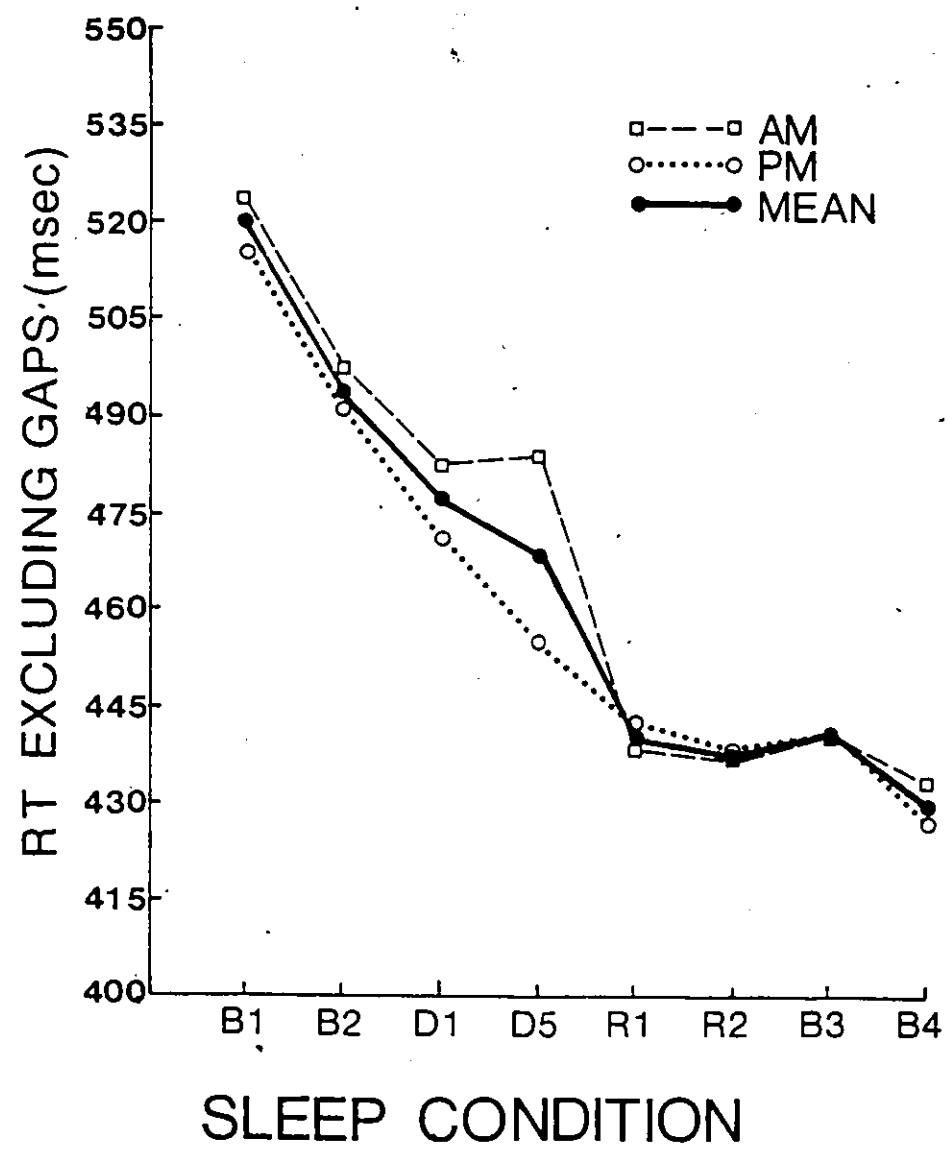


Figure 4. Mean reaction time excluding gaps on the four-choice serial reaction time test (B, baseline; D, sleep deprivation; R, recovery sleep).

positive rate. The range of proportion of false positive responses varied from a minimum of .0014 at B4 to a maximum of .0048 at D1. As these proportions approach a value of 0, measures of d' and β were judged to be too unreliable to justify meaningful interpretation.

Four-choice serial reaction time test: The overall findings for all measures was a learning curve of improved performance that was not significantly affected by experimental conditions. Figure 3 presents these curves for percent errors and number of gaps. Error rate rose steadily and then levelled off, whereas gaps showed an initial abrupt decline followed by a gradual reduction.

All other measures closely resembled the pattern depicted in Figure 4 for mean reaction time excluding gaps. The interruption in the a.m. curve for mean reaction time excluding gaps after both sleep loss nights was the only significant effect found. The Scheffé test revealed the interaction of Factors A x C, $F(3,18) = 3.31$, $p < .05$, to be significant for the mean a.m. - p.m. difference for one and five nights PSD combined ($d = 39.0$, $p < .02$). Time of day differences over all experimental conditions (Factor C) were also significant for mean reaction time excluding gaps, $F(1,6) = 16.66$, $p < .001$, thus indicating that time of day divergences in reaction time after sleep loss represent an amplification of a circadian trend. The same effects of time of day differences over all conditions and after sleep deprivation were present for mean RT for corrects excluding gaps but not for mean RT overall. Given that the shape of all three curves was virtually identical, it is interesting to note that time of day differences emerged only when the variability due to gaps had been removed.

TABLE 4

Four-Choice Test: Intercorrelations of Percent Errors,
Gaps, and Mean RT for Individual Subjects

Subject	Pearson correlation coefficients (r)		
	% Errors & MRT (msec)	Gaps (no.) & MRT (msec)	% Errors & gaps (no.)
1	-.63***	.87****	-.26
2	-.95****	-.38	.46*
3	-.44*	.61**	.23
4	-.93****	.84****	-.66***
5	-.69***	.86****	-.49*
6	-.16	.91****	.08
7	-.74****	.61**	-.34

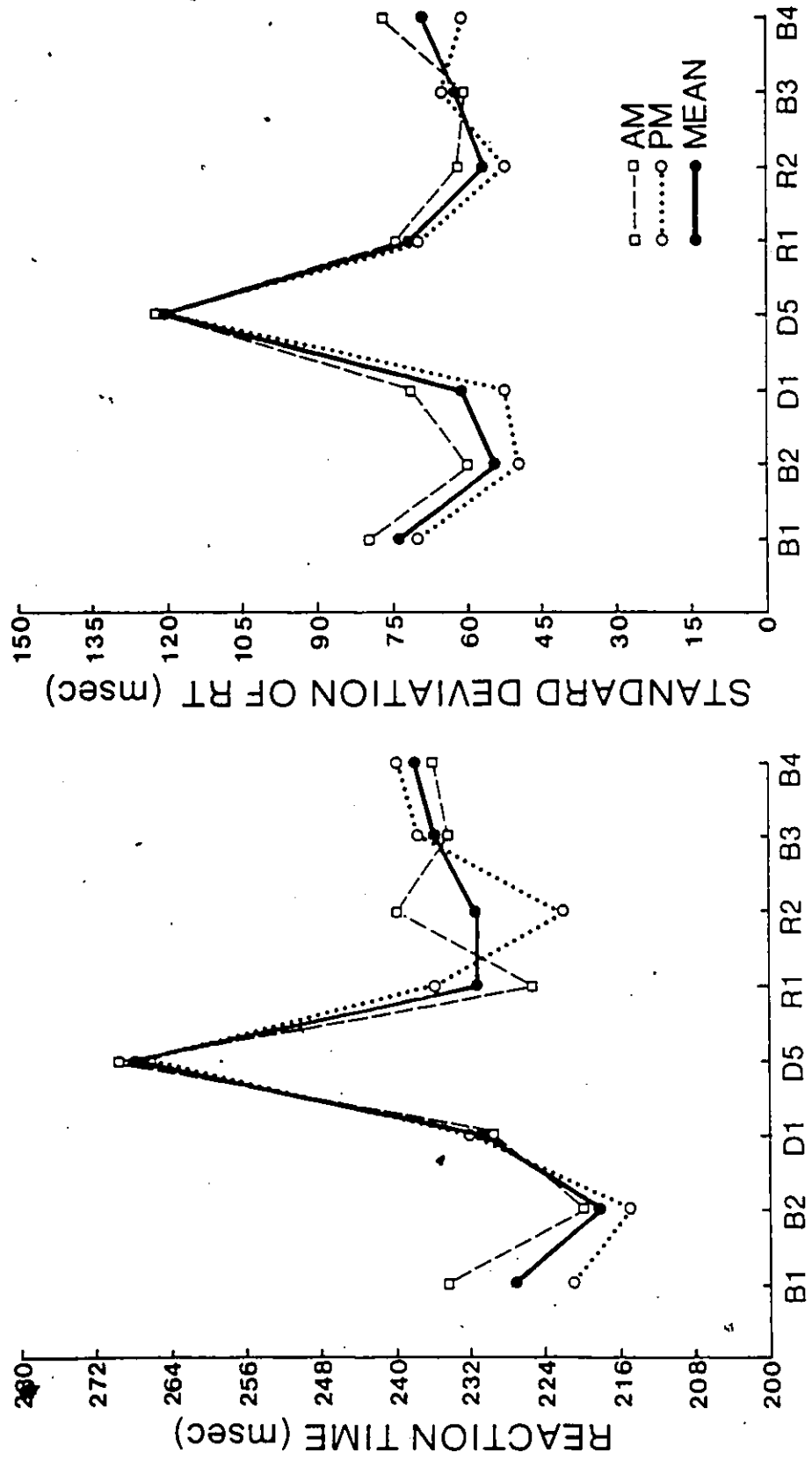
Note. Abbreviations: MRT, mean reaction time.

*p < .05
 **p < .01
 ***p < .005
 ****p < .001

Because of great intersubject variability in many of the four-choice measures and because performance on this test necessarily involved a tradeoff between speed and accuracy, a further analysis was conducted to investigate individual differences in response style. This analysis studied the relationships between mean RT, number of gaps, and percent errors for individual subjects.

Pearson product-moment correlation coefficients were calculated for each subject over all 16 experimental conditions. Table 4 summarizes the results of the intercorrelations of mean RT, number of gaps, and percent errors. The most general trend, significant for six of seven subjects, was for accuracy (percent errors) to be inversely related to reaction time speed (mean $r = -.65$; $SD = .26$). The tendency for mean RT to be associated with overly long reaction times (gaps) was also clearly significant but much more variable (mean $r = .62$; $SD = .42$), owing largely to one subject approaching significance in the opposite direction ($S2, p = .071$). Correlations between percent errors and number of gaps yielded a more modest and variable relationship (mean $r = -.14$; $SD = .38$). Thus, despite strong overall trends in response style, there were still marked deviations from the overall group pattern.

Simple reaction time test: For the simple reaction time test, both the mean and standard deviation of reaction times were significantly elevated after five nights of PSD. Unlike for the four-choice test, there was no significant learning effect over the 16 repeated measures (see Figure 5). Number of gaps was not analyzed due to their rare occurrence,



SLEEP CONDITION

Figure 5. Mean and standard deviation of reaction time on the simple reaction time test (B, baseline; D, sleep deprivation; R, recovery sleep).

there being a total of only 14 gaps out of approximately 7,000 reaction times.

Separate analyses of variance of both mean RT and of standard deviation of RT yielded significant effects for the interaction of Factors A x B ($F(3,18) = 3.90, p < .05$; $F(3,18) = 5.72, p < .01$, respectively). Scheffé post hoc tests for simple main effects for both variables revealed that reaction time was both slower and more variable after five nights of PSD compared to the average of all other conditions ($p < .01$ for each). No significant time of day effects were found.

Anagrams: On the anagrams test, mean number of correct solutions for a.m. and p.m. sessions combined increased significantly over all experimental conditions, $F(3,18) = 11.36, p < .001$. Subjects as a group therefore were able to continue to improve performance despite imposed reductions and extensions in prior amounts of sleep.

Such modifications to the sleep schedule produced effects, however, which interacted with time of day. Figure 6 illustrates the general superiority of p.m. relative to a.m. performance over all conditions, $F(1,6) = 21.69, p < .005$, and particularly during sleep loss and oversleeping periods. The increase in time of day differences (d) during the treatment conditions was significant for the mean a.m.-p.m. difference for five nights PSD and one night oversleeping combined ($d = 11$), compared to the mean difference for all other conditions ($d = 4.8$). Thus diurnal fluctuations in problem-solving efficiency were amplified following reductions and extensions of the sleep period, achieving maximum divergence

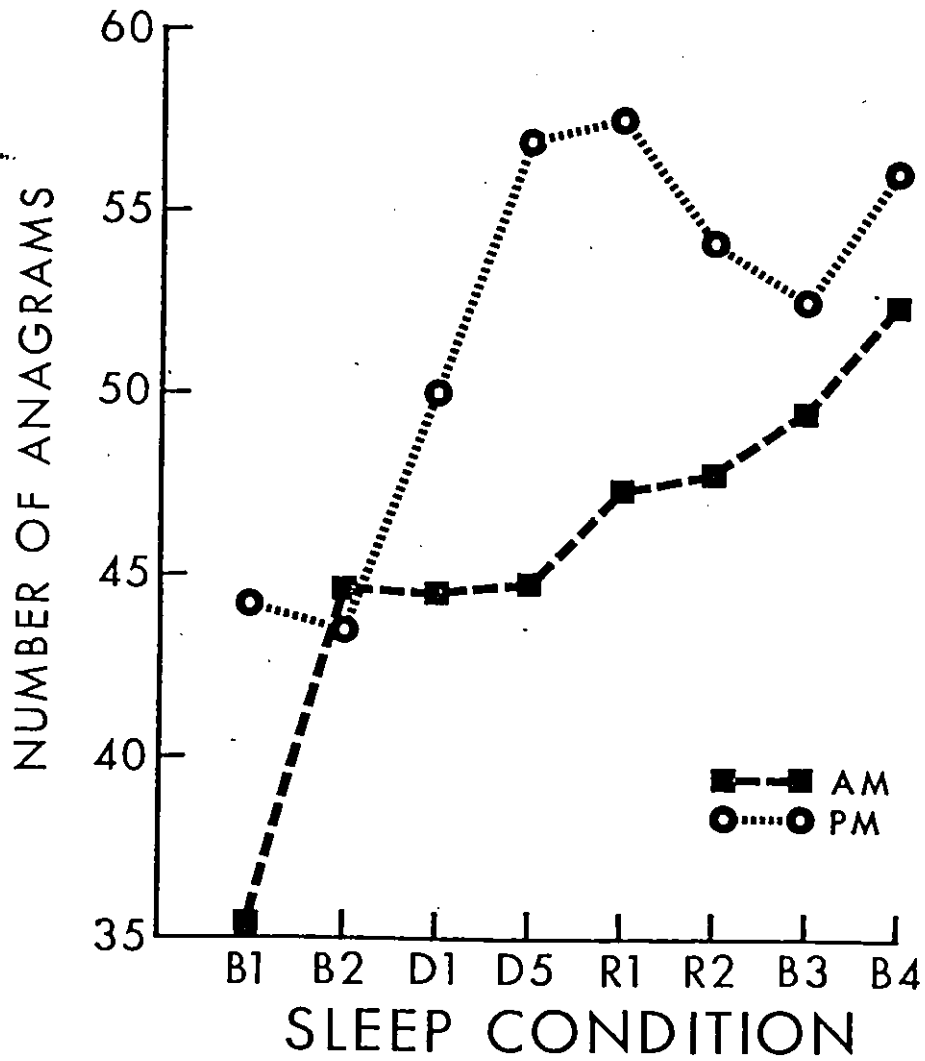


Figure 6. Mean number of a.m. and p.m. anagram solutions (B, baseline; D, sleep deprivation; R, recovery sleep).

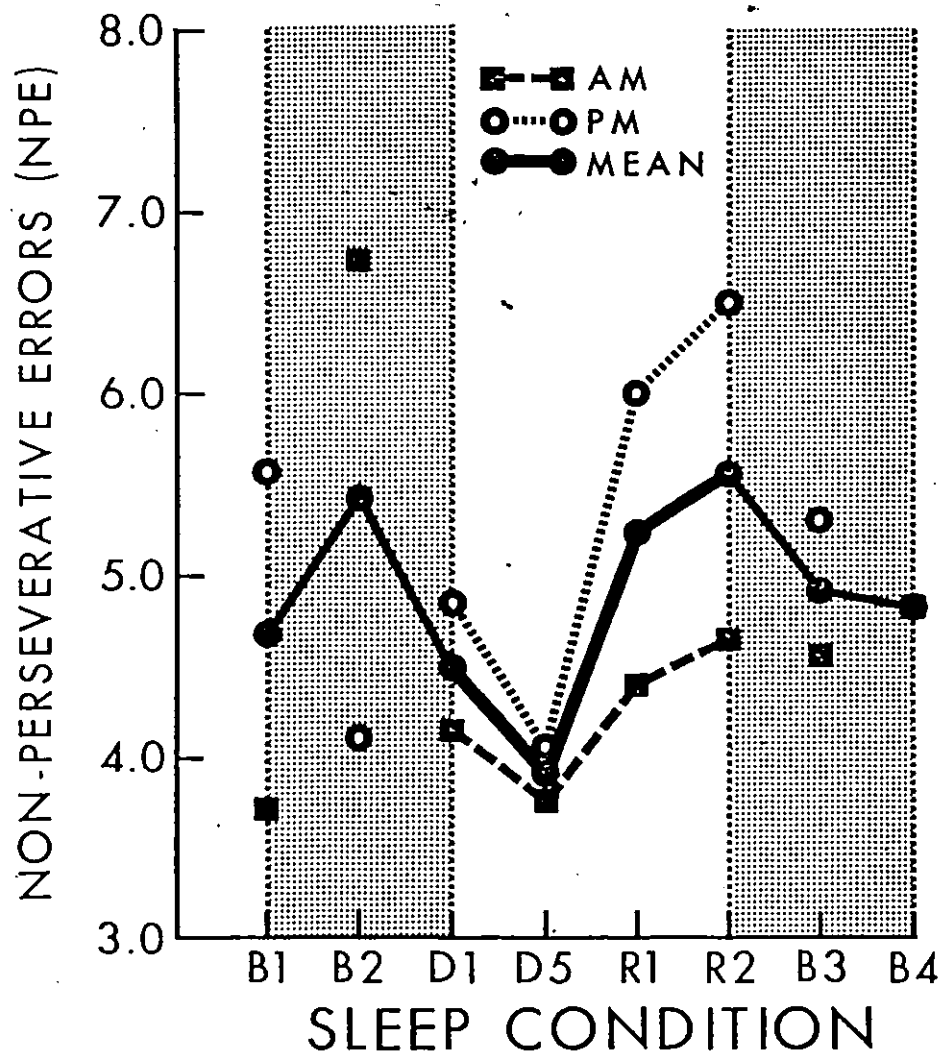


Figure 7. Mean number of non-perseverative errors on the WCST (B, baseline; D, sleep deprivation; R, recovery sleep. Shaded areas indicate unreliable baselines not included in statistical analysis).

in the days immediately following the most extreme sleep time manipulations (i.e., days D5 and R1).

Wisconsin Card Sorting Test: Because of the exploratory nature of the WCST investigation, i.e., application of a clinical test to an experimental paradigm, there was little a priori expectation regarding outcome. Wisconsin Card Sorting Test data differed markedly from all other test data and this necessitated some modifications in analysis. The most general finding was the very large inter- and intra-subject variability most pronounced during the initial days of testing and as a function of time of day. This substantial heterogeneity in performance on the WCST suggested the greater complexity of this task relative to all others and the desirability of collapsing data to observe the most general trends, if any. Prebaseline measures in particular were judged to be unreliable due to marked individual differences in the rate at which subjects acquired this more complex task. Both baseline conditions were thus eliminated from the analysis, thereby allowing for a direct comparison of under- and over-sleeping regimens under well-practiced conditions. Baseline data has been included, however, in the Figures (shaded areas) to give some indication of the effects of learning over repeated exposures.

Time of day differences were also highly variable and nonsignificant according to preliminary analyses. Thus, in order to obtain a more reliable estimate of performance, the results from a.m. and p.m. sessions were combined. Performance measures on the WCST were subsequently analyzed according to a one-way (4x1) analysis of variance with repeated measures,

each treatment testing day (D1, D5, R1, R2) representing a level of the repeated factor.

Figure 7 illustrates the variation in number of non-perseverative errors (incorrect sorts also not correct for previous category) over experimental conditions, $F(3,18) = 7.08$, $p < .005$. These were significantly elevated ($p < .01$) during the period of recovery sleep (overall mean = 11.2) relative to values following sleep reduction (overall mean = 8.4). Moreover, number of non-perseverative errors tended to vary as a function of the duration of each condition, inversely with cumulative sleep loss and directly with cumulative oversleep.

An increase in number of non-perseverative errors is generally attributed to increased attempts to isolate the new criterion and not to performance deficits per se. Such an interpretation may seem warranted for the present findings in that subjects performed at par after oversleeping, as assessed by measures of "general task performance" (number of categories, mean = 9.9 for each; number of correct responses over and above criterion 10, mean = 8.5 for each). Examination of the number of correct responses left over at the end of each record reveals, however, that subjects exhibited a reduced efficiency in search strategies during the oversleeping period. Relative to values when sleep-deprived, the number of correct sorts remaining at the end of each record (after last consecutive string of 10) averaged one fewer per subject during the oversleep condition (25 fewer in 28 records). Thus subjects at this time required an average of one more sort to achieve the same number of categories, and this additional sort represented a non-perseverative error (25 of 38 more).

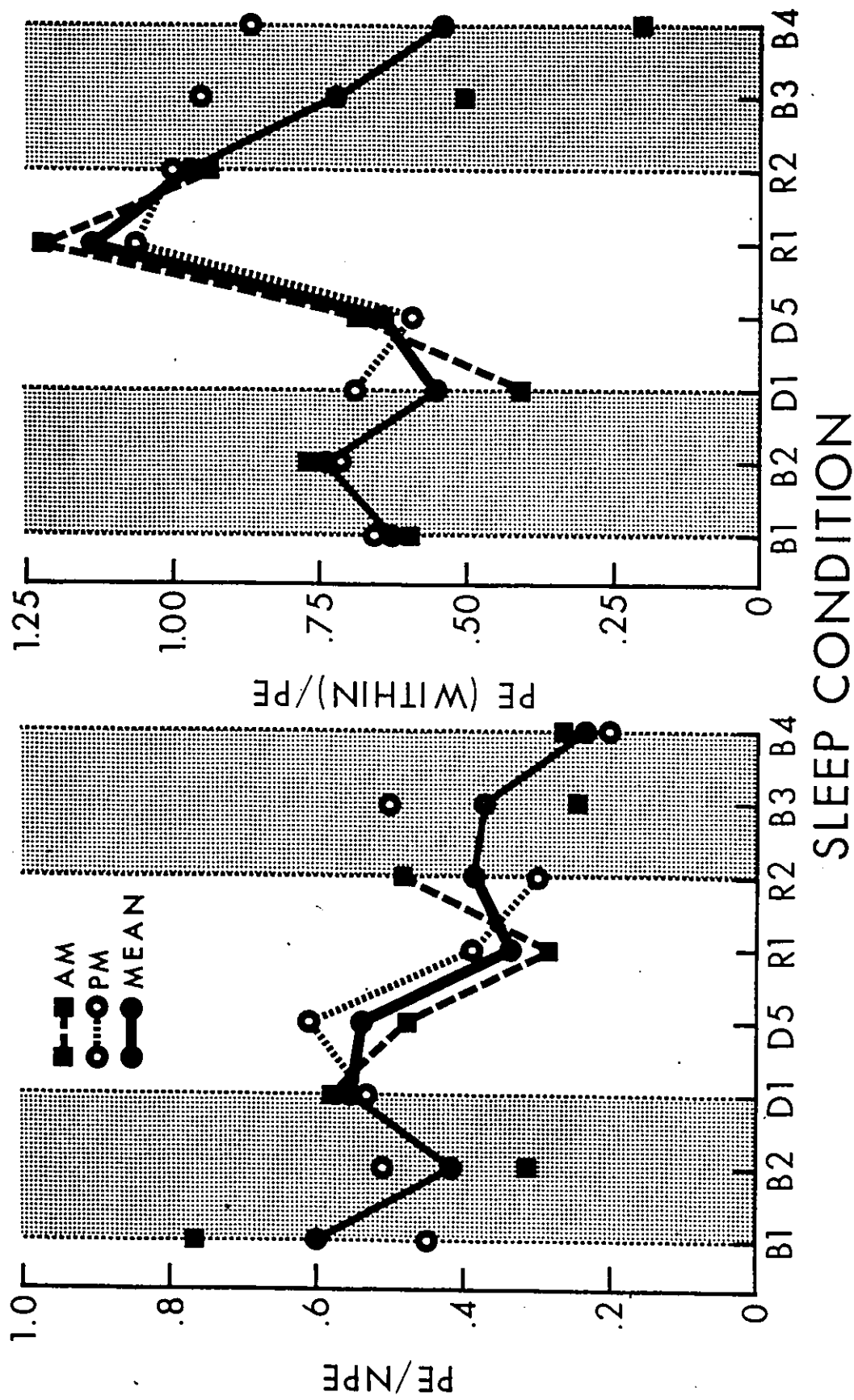
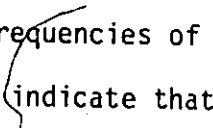


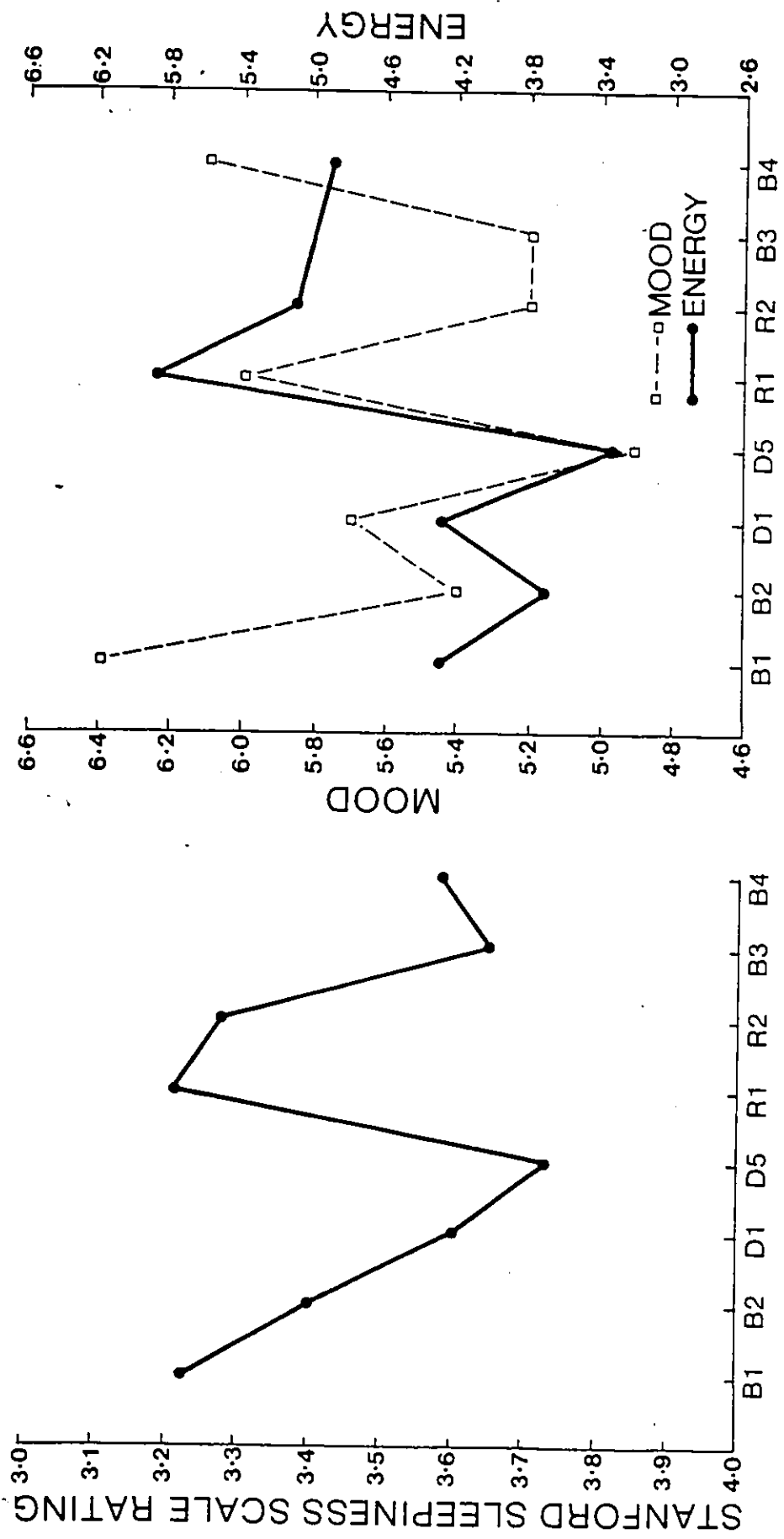
Figure 8. Mean proportions of perseverative errors (PE) to non-perseverative errors (NPE) and perseverative errors within a category {PE (within)} to perseverative errors (PE) on the WCST (B, baseline; D, sleep deprivation; R, recovery sleep). Shaded areas indicated unreliable baselines not included in statistical analysis).

This reflects a reduction in economy of search strategy following oversleep for the same overall level of performance. Card-sorting performance after recovery sleep was therefore characterized by increased attempts to isolate the new concept yet less efficient deployment of search strategies towards that end.

Further analysis of relative frequencies of errors served to highlight qualitative differences in performance between conditions of reduced and extended sleep. Although for all subjects non-perseverative errors increased significantly following oversleeping, number of perseverative errors declined at the same time. The relative frequency of occurrence of perseverative to non-perseverative errors after PSD was 1.5 times greater than that after recovery sleep (see Figure 3a). It therefore appears that the capacity to shift to a new criterion was relatively impaired following cumulative partial sleep loss.

Calculation of perseverative errors within a category further revealed the nature of performance changes in the two sleep conditions. More than half (18) of the non-perseverative errors following recovery sleep were perseverative of previous errors within the same category. Comparing the proportions of these errors to perseverative errors over all testing days yielded an emphatic trend (see Figure 3b). The frequency of perseverative errors within a category relative to perseverative errors of the preceding criterion was twice as great after one night of oversleeping as after one night of PSD and was three times as great in the morning of these days. The differing relative frequencies of these two types of error following under- and over-sleeping indicate that the method and/or the efficiency of





SLEEP CONDITION

Figure 9. Mean all-day sleepiness (SSS) ratings and levels of mood and energy upon awakening (B, baseline; D, sleep deprivation; R, recovery sleep).

TABLE 5

Mean Subjective Ratings Over Experimental Conditions

Dependent Measures	Experimental Conditions							
	Prebaseline B1	B2	Sleep depr'n D1	D5	Recovery sleep R1	R2	Postbaseline B3	B4
Global SSS	3.2	3.4	3.6	3.7	3.2	3.3	3.7	3.5
Mood	6.4	5.4	5.7	5.7	6.0	5.3	5.3	6.1
Energy	4.3	3.7	4.3	3.3*	5.9	5.1	5.0	4.9
Vigilance SSS	2.8	2.6	2.9	3.5	2.6	2.7	2.8	2.8
Four-choice RT SSS	2.4	2.4	2.7	3.4	2.8	2.6	2.9	2.5
Simple RT SSS	2.1	2.4	3.7	3.1	2.5	2.9	2.9	2.4
Anagrams SSS	2.2	2.1	2.8	3.4	2.1	2.4	2.8	2.1
Wisconsin Card Sort SSS	2.3	2.1	2.7	3.3	2.7	2.5	2.8	2.6

Note. All levels of significance are derived from post hoc comparisons of the highlighted value(s) to the mean of all other conditions.

* $p < .05$

concept formation was differentially affected by the different sleep regimens. Whereas after sleep loss subjects exhibited a tendency towards rigidity in concept-shifting, after oversleeping they were less able to maintain optimal performance in acquiring the new concept, although the shift was accomplished with relative ease.

Subjective ratings

Analysis of subjective ratings comprised three parts: a) global SSS (mean all-day sleepiness ratings), and mood and energy scores upon awakening; b) task related SSS ratings (mean rating associated with each task); c) correlations between task-related SSS ratings and concomitant task performance for the most sensitive tasks.

Global SSS, Mood and Energy Ratings: The overall tendency for sleepiness ratings to increase and mood and energy ratings to decrease after five nights PSD, and to return to near or beyond baseline levels after one night of recovery sleep, is illustrated in Figure 1. These fluctuations were significant for SSS and energy ratings only ($\chi_r^2(7) = 16.51, p < .05$; $\chi_r^2(7) = 15.75, p < .05$, respectively)

Selected post hoc contrasts ($C = 2.69, J = 5; \alpha = .05; df = 48$) revealed that both SSS and energy ratings were significantly changed after five nights of PSD relative to one night oversleeping and to the average of all other conditions. Sleepiness estimates were significantly elevated after one and five nights PSD combined. Energy levels increased after one and two nights of oversleeping combined. For the SSS, ratings after five

TABLE 6

Inter-Task Comparisons of Mean SSS Task-Related Ratings Within
Major Experimental Conditions

Experimental Condition	Task					$\chi^2_r(4)$
	Vigilance	Four-choice RT	Simple RT	Anagrams	Wisconsin Card Sort	
Prebaseline (B1-B2)	2.7	2.4	2.3	2.2	2.2	11.29*
Sleep depr'n (D1-D5)	3.2	3.0	2.9	3.1	3.0	-2.91
Recovery Sleep (R1-R2)	2.7	2.7	2.7	2.3	2.6	5.44
Postbaseline (B3-B4)	2.8	2.7	2.6	2.5	2.7	4.33

* $p < .05$

nights PSD were statistically different from pre- but not post-baseline values, whereas for energy ratings the converse was true.

Task-related SSS Ratings: Change in mean SSS values following each of the five performance tests over experimental conditions yielded a pattern similar to that of mean all-day (global) SSS ratings (see Table 5). The general tendency for subjective sleepiness estimates to vary with increasing sleep loss and to return to baseline levels following one night of recovery sleep was significant only for the anagrams test ($\chi_r^2 (7) = 19.73, p < .01$) and the Wisconsin Card Sorting Test ($\chi_r^2 (7) = 18.70, p < .01$).

Selected post hoc contrasts of each significant effect ($C = 2.69; J = 5; \alpha = .05; df = 48$) revealed that, for both tests, the mean SSS value over both sleep loss days was elevated compared to the mean of all other conditions. While sleepiness levels following cumulative PSD were significantly higher than those of the mean of each baseline, one night of oversleeping, and the mean of all other conditions for the anagrams test, they differed from only prebaseline values for the Wisconsin Card Sorting Test.

Inspection of Table 5 reveals that SSS scores following the anagrams test and the Wisconsin Card Sorting Test exhibited the greatest variability across conditions but not the most extreme values as a result of sleep reduction. The four-choice RT test and particularly the vigilance test were associated with higher mean SSS ratings when sleep time was not manipulated. In order to test the hypothesis that task-related SSS ratings varied as a function of the type of task, a further analysis was done.

Table 6 summarizes the mean SSS task-related ratings and results of the Friedman analyses of variance comparing the five tasks within each major (collapsed) condition. Mean ratings associated with the vigilance test were always numerically at least as great as those following the other tests and this difference was significant for the prebaseline condition. Post hoc contrasts ($\underline{J} = 5$; $\underline{C} = 2.75$; $\underline{\alpha} = .05$; $\underline{df} = 30$) revealed that vigilance-related ratings were significantly elevated compared to those following the anagrams test and the Wisconsin Card Sorting Test but did not differ statistically from ratings following the two reaction time tests.

Correlations of Task-related SSS Ratings and Performance Measures:

Pearson correlations between performance measures and subsequent task-related SSS ratings were computed for each subject individually over the 16 testing sessions. The three selected tasks with associated dependent measures and null and alternate hypotheses were: a) vigilance - number of hits; $\underline{H} : \underline{r} = 0$; $\underline{H} : \underline{r} > 0$; b) four-choice serial RT - mean RT; $\underline{H} : \underline{r} = 0$; $\underline{H} : \underline{r} < 0$; simple RT - mean RT; $\underline{H} : \underline{r} = 0$; $\underline{H} : \underline{r} < 0$.

Inspection of Table 7 reveals substantial individual differences between subjects for all tests and a general lack of correspondence between the two sets of measures. Mean SSS ratings correlated significantly with vigilance performance for two subjects; three subjects had correlations in the non-anticipated direction, the overall effect being modest and inconsistent (mean $\underline{r} = -0.15$; $\underline{SD} = 0.32$). Correlations for the four-choice serial RT test yielded significance for only one subject and a near random overall relationship (mean $\underline{r} = -0.01$; $\underline{SD} = 0.24$). Simple reaction time test data displayed the greatest correspondence between performance and

subjective sleepiness measures, significant for three subjects but again highly variable (mean $r = 0.25$; $SD = 0.29$). Looking across tasks, for only one subject (S6) did the two sets of measures vary together for all tasks; one other subject (S7) maintained this close correspondence for two of the tasks.

TABLE 7

Pearson Correlations of Task-Related SSS Ratings
and Performance Measures for Individual Subjects

Subject	Pearson correlations		
	Vigilance (No. of hits)	Four-choice RT (\bar{x} RT)	Simple RT (\bar{x} RT)
1	0.28	-0.28	0.16
2	0.08	0.01	-0.02
3	-0.18	-0.26	0.54**
4	0.18	0.01	0.00
5	-0.32	0.00	-0.17
6	-0.61***	0.51*	0.64***
7	-0.54**	-0.04	0.58***
Mean	-0.15	-0.01	0.25
<u>SD</u>	0.32	0.24	0.29

* $p < .05$

** $p < .02$

*** $p < .01$

Chapter IV

DISCUSSION

The present findings demonstrate that a schedule that approximates a typical work week for many individuals, undersleeping on week days and oversleeping on weekends, may produce a certain pattern of performance, cognitive, and subjective changes. The effects of partial sleep deprivation are initially reflected in self-reports of negative experience and exaggerated circadian trends in performance. With cumulative sleep reduction, deficits in vigilance become readily apparent on certain sensitive performance tests. Recovery oversleeping generally permits rapid functional restitution, although time of day effects and some evidence of impairment in cognitive processing is apparent at this time. The validity of these findings, although limited by incomplete monitoring of sleep times, is strengthened by support of previous observations and/or inferences from the literature.

The present chapter discusses the results relating to performance deficits, circadian effects, cognitive processing, and subjective changes respectively. The following chapter will provide a more general, integrative, and speculative discussion of the effects of sleep reductions and extensions in humans.

Performance deficits

Previous studies of short-term partial sleep deprivation have reported performance decrements after sleep reduction of 3 hr for two nights (Wilkinson et al., 1966), 3.5 hr for two to four nights (Hamilton et al., 1972), and 3.5 hr for seven nights (Webb & Agnew, 1965). The present study found that an intermediate schedule consisting of a mean reduction of

3 hr sleep for five nights, produced significant deficits in performance on the vigilance and simple reaction time tests. Nights of extended sleep following the period of sleep deprivation served to return impaired levels towards baseline, although limited evidence of impairment was observed in the morning after the first such night.

The decline in performance on the vigilance test is a confirmation of these earlier findings. Wilkinson (1961, 1964, 1969) has related such deficits to motivational factors. For Wilkinson, tests sensitive to sleep deprivation effects need be prolonged, monotonous, and lacking in incentive, and the schedule of testing should be prolonged and replicated to minimize the stimulating effects of a perceived challenge situation. The present findings indicate that sleep loss effects can become apparent with the utilization of a short-duration task on a less prolonged testing schedule without replication. It may be worthwhile, therefore, to consider what aspects of the present tests rendered them sensitive or insensitive to sleep loss deficits.

The classical division between subject-paced and experimenter-paced tasks (Williams et al., 1959) provides a useful distinction in terms of discussing the effects of learning and motivation on the tasks. In experimenter-paced tasks, such as the vigilance and simple reaction time tests, the experimenter controls the display of stimuli and the response rate. Conversely, in the subject-paced four-choice RT test, the subject controls these parameters and, under such conditions, performance after sleep loss suffers less (Lubin, 1967). It may be argued that the subject who is in control of rate of presentation of stimuli is expending greater effort towards bettering his performance. The steady

improvement on all four-choice measures with repeated administrations may reflect an underlying incentive to do better; and such incentive has been shown by Wilkinson (1961) to tend to abolish sleep loss effects.

Further, one might expect greater intersubject variability in performance when the mode of response is more complex and controlled by the subject. Of the three vigilance-type tests utilized in the present experiment, the four-choice test exhibited the most extensive pattern of individual differences on all measures. The overall pattern of performance was for subjects to increasingly sacrifice accuracy for speed over repeated test administrations. However; correlations between mean reaction time and percent errors revealed that this trend was not always followed. For one subject in particular, who judged speed of reaction time to be more important than accuracy throughout the experiment, error rate was elevated and gaps absent. Moreover, significant time of day effects for four-choice mean reaction time were attained only once the variability due to gaps had been removed. This suggests that detection of group trends may be obscured by individual differences in response style.

On the vigilance and simple reaction time tests, the presentation of stimuli was randomly controlled by the experimenter and the mode of response clearly unambiguous. On these tests, subjects exhibited a more uniform trend of inability to improve performance with repeated exposures, and greater susceptibility to sleep loss effects. On the vigilance task, the steady decrease in false positives suggests that subjects' willingness to perform generally declined (Webb & Agnew, 1965, 1974). However, the elevation in false positive rate after both 1 and 5 nights of sleep loss may indicate that subjects were exerting greater effort at this time. This

is in accordance with Wilkinson's (1970) observation that subjects react to the challenge of performance after sleep deprivation. The significant reduction in number of detections after five nights PSD therefore most likely reflects a diminution in sensory capacity (d') to discriminate signals. Although no measure of d' is available in the present study, this finding resembles that of Hamilton et al. (1972) who found that the main effect of cumulative PSD was on the ability to maintain a normal rate of improvement in detection efficiency (d').

The overall decline in motivation over the course of the experiment became particularly evident on the last two days of testing (postbaseline). The return of subjective sleepiness estimates to near levels following sleep loss and the presence of apparent sleep periods at this time, as well as subjects' comments on the follow-up questionnaire, indicate that motivation materially declined towards the end of the experiment. Moreover, performance on both the simple reaction time and vigilance tests was inferior relative to earlier levels. This suggests that the greater resistance of experimenter-paced tasks to learning may induce in the subject an unwillingness to exert greater effort on the task. Certainly, the extent to which a subject perceives action as profitable is considered a significant determinant of willingness to perform in signal detection theory (Tanner & Swets, 1954).

Another variable which has been shown to raise incentive levels, thereby reducing or abolishing sleep loss effects, is knowledge of results (Wilkinson, 1961). The superior sensitivity to sleep loss effects of the simple RT test, which supplies knowledge of results, is a contrary finding. It could be that differing types of feedback, whether supplied by the

apparatus or the experimenter, evoke qualitatively different responses (Glenville et al., 1978), or that knowledge of results is not as crucial a variable as previously thought (Buck & Gibbs, 1972). Again, the effect of knowledge of results may depend on interaction with the type of task; if task performance did not improve with practice, then the effect of such feedback could be benign or even frustrating.

The relative immunity of the simple reaction time test to learning follows from Mackworth's (1969) theory that vigilance decrement proceeds by habituation of neural circuits. According to the constructors of the original auditory version of the simple reaction time test (Lisper & Kjellberg, 1972), the test was designed with the specific intention of optimizing the conditions for habituation. The critical features of the test which were shown to foster more rapid habituation included shorter interstimulus intervals (Lisper & Kjellberg, 1972), temporal uncertainty of the stimulus (Lisper, Melin, & Sjöden, 1973; Lisper & Tornrös, 1974), and low performance demand of one stimulus-one response (Bohlin, 1976).

Because gaps were virtually absent on the simple reaction time test and their elimination contributed to the only significant effects on the four-choice test, performance decrement after sleep loss, at least for these tasks, cannot be explained in terms of the lapse hypothesis (Williams et al., 1959). Rather, a general attentional deficit due to lowered arousal (Kjellberg, 1977b; Tharp, 1978) may have caused a general slowing of all reaction times, irrespective of major and more sporadic lapses in attention. Although it cannot be firmly stated without EEG monitoring, the greater incidence of probable sleep periods after sleep loss on the more complex and more monotonous vigilance test, suggests that periods of

microsleep were at least moderately responsible for deficits on this task. Although not measured, a more general reaction time slowing may also be occurring on the vigilance test, as has been reported by Buck (1966), who found deteriorations in reaction time before any significant detection decrement. The greater sensitivity of the simple reaction time test is at least partly due to the greater information inherent in continuous (reaction time) relative to dichotomous (yes-no) data.

The most general finding for recovery oversleep was that it tended to return impaired sleep loss levels to baseline. Only morning detection efficiency on the vigilance task was negatively affected following one night of recuperative sleep. This is generally the pattern observed after recovery sleep following 24 hr total sleep deprivation (Wilkinson, 1963a) and sleep extended from habitual amounts (Taub & Berger, 1973), although deficits in those studies were more pervasive across tasks and evident also at other times of day. It is difficult to compare findings resulting from the present schedule to Wilkinson's more modest extension of sleep after more acute sleep loss, and Taub and Berger's non-recuperative extensions. However, the return of all subjective measures to near or beyond baseline levels with oversleep in the present study suggests a self-perceived positive valence attached to such sleep; and this is the opposite of what is found when that extra sleep is not required (Globus, 1969; Taub & Berger, 1973, 1976b). Relative to Wilkinson's schedule, it could be that recovery from a more modest curtailment of sleep (PSD), represents a less acute and less abrupt variation in accustomed sleep-waking patterns; correspondingly modest effects would be predicted from Taub and Berger's findings.

The present findings show that five consecutive nights of 40% sleep loss precipitate decrement in performance. Moreover, the effects due to partial sleep loss have been demonstrated using portable short-duration tasks, previously shown sensitive to 24 hr total sleep deprivation (Glenville et al., 1978). Their sensitivity, portability, and short duration suggest their suitability for research in field situations. The simple reaction time test is of particular benefit where repeated measurements are wanted, due to its sensitivity and relative immunity to practice effects.

The four-choice and simple reaction time tests may prove useful for the assessment and treatment of such patient populations as insomniacs, for whom attentional deficits, if undetected, may accumulate to acute proportions (Lubin, 1967) and narcoleptics, who express impaired alertness levels as a major problem in daily living (Broughton & Ghanem, 1976).

Research in the work environment has previously been hindered by the impracticality of traditional tests and testing paradigms (Preston, 1978) and the insensitivity of tasks used (Naitoh, 1976). Certainly, these portable tests could fulfill a valuable role in terms of evaluation of worker efficiency and accident control. Fieldwork utilizing these tasks is currently being undertaken for the study of airline personnel (as reported by Preston, 1978) and shiftwork studies (Glenville & Wilkinson, in press). The results of these workers and others will be important for validation of the efficacy of portable tests in settings outside the laboratory.

Circadian effects

One of the most prevalent and general findings in the present study was the interaction of circadian influences with changes in the usual sleep

schedule. Time of day effects were evident on simpler tasks such as the vigilance test and four-choice serial reaction time test, as well as on the more complex anagrams test and, to a limited extent, on the WCST. Only the simple reaction time test yielded no such effect. Further, differences in time of day performance were evident not only after sleep reduction but following recovery sleep as well, thereby constituting one of the principal findings for the effects of extended sleep on performance.

With one exception, performance tended to improve over the course of the day. This is the pattern observed for most psychological functions especially for more preliminary abilities such as vigilance and psychomotor responding (e.g., Blake, 1967; Hockey & Colquhoun, 1972). Only memory usually exhibits the "inverse rhythm" of superiority in the morning and of steady decline following midday (Hockey & Colquhoun, 1972; Monk, Knauth, Folkard, & Rutenfranz, 1978).

According to Lubin (1967), the early morning hours are the most likely time to observe sleep loss effects as sleep loss tends to amplify the circadian rhythm. This was our finding for four-choice mean reaction time, which was longer in the morning relative to the afternoon, over all conditions and particularly so after sleep deprivation. Such a finding is also in accordance with Kjellberg's (1977c) proposal that the effect of sleep loss depends upon the current state of the organism. In this latter view, potential performance deficits would be manifested primarily in the morning as the background state of lowered arousal due to sleep loss interacts with the natural tendency for poorer performance earlier in the day. Colquhoun (1971) has postulated a similar mechanism for morning performance deficits.

However, the greater number of signal detections in the vigilance task in the morning after one night PSD represents a more puzzling finding. It is certainly the opposite pattern from that observed by Taub and Berger (1973, 1976a, 1976b) for similar curtailments of sleep time. Support for the legitimacy of this finding is derived from one subject's comment that he learned to detect signals by matching them to a subjective template. If performance on the vigilance task did involve a memory component, particularly during initial administrations, then the discrimination of the exact specification of the signal based on memory traces, could well have been superior on that morning, as is the case for memory under normal conditions and possibly after limited PSD (Hamilton et al., 1972). Of particular interest is the reversal of this trend after one night of oversleeping. The superiority of vigilance performance in the afternoon at this time provides evidence of a "circadian shift" between conditions of reduced and extended sleep. The existence of such a phenomenon requires substantiation by other laboratories.

On the anagrams test, performance was superior in the afternoon particularly during the periods of reduced and extended sleep. Other related higher-order abilities such as logical reasoning normally follow this pattern (Folkard, 1975). Hockey and Colquhoun (1972) have shown that, to the extent that a task involves immediate processing and a low memory load, performance will tend to improve throughout the day. Both of these component abilities have traditionally been incorporated in models of the mental processes involved in anagram solution (Solso, Topper, & Macey, 1973; Warren & Thompson, 1969). More recent findings (Gilhooly & Johnson,

1978), however, have isolated the initial probe construction process (immediate processing) as the critical step towards anagram solution. The present finding of relatively superior afternoon performance is therefore in accordance with this finding.

For all tasks then, the pattern of time of day performance suggests that both sleep loss and (at least recuperative) sleep extension induce circadian changes, or reveal otherwise more occult circadian fluctuations, in performance variations across the day. Other evidence exists for time of day effects in performance following both recovery sleep (Wilkinson, 1963a) and extended sleep (Taub & Berger, 1973), and these authors have ascribed this phenomenon to a desynchronization of body rhythms which gradually readjusts throughout the course of the day. This proposal is further strengthened by Taub and Berger's (1973) more general finding that abrupt shifts in the phase of sleep are just as instrumental in inducing performance deficits as are changes in the duration of sleep. The accumulated evidence therefore seems to suggest that short-term fluctuations in the sleep schedule contribute to a disturbance of body rhythms which is manifested in performance earlier in the day or until such time that body rhythms can adjust to the change.

Cognitive processing

One of the purposes of the present study was to examine both quantitative and qualitative changes in cognitive performance precipitated by prior schedules of reduced and extended sleep. The finding that problem-solving ability on the anagrams test and general task performance on the Wisconsin Card Sorting Test were generally undisturbed by the

altered sleep-waking schedule supports Wilkinson's (1964, 1969) contention regarding the general insensitivity of stimulating tasks to this event. More detailed and qualitative analysis, however, revealed the operation of more subtle effects such as the interaction of fluctuations in sleep time with diurnal changes in problem-solving ability, as well as differences in the utilisation and efficiency of strategies of concept-formation (WCST) between conditions of reduced and extended sleep. It is particularly noteworthy that performance on both tasks, especially on the WCST, exhibited some evidence of impairment following oversleeping, given that deficits in sustained attention and disturbances in self-perceived feeling states resulting from sleep reduction tended to be reversed by recovery sleep. The consideration that under- and over-sleeping may exert their effects at different levels of information processing appears as an interesting possibility worthy of further scrutiny.

On the WCST, overall task performance (number of categories; number of corrects) was virtually unaffected by experimental manipulations of sleep time. Breakdown of errors into specific types, however, revealed that the number of non-perseverative errors increased significantly following extended sleep with a concomitant increase in errors perseverative within a category. Non-perseverative errors reflect attempts to shift the category of response and should decrease as the subjects become more selective in the manner in which they isolate the new criterion (Grant & Berg, 1948). The finding that the majority of additional non-perseverative errors committed during the oversleeping period involved redundant confirmation of incorrect concepts (perseverative errors within a category) further

suggests the inability at this time of subjects to maximally exploit all the information available to them. This is perhaps a quantitative measure of the "foggy thinking" described by Globus (1969) and may form part of the phenomenon of sleep drunkenness in hypersomnia and part of the features of the depressive phase of manic-depressive illness.

Bruner et al. (1956) have aptly commented that, within limits, number of errors on a conjunctive concept-formation task is more reflective of the subject's method of coping with task conditions than it is of actual cognitive deficits. When confronted with "in the head" transformations their subjects tended to resort to modified forms of the strategies of successive scanning and conservative focusing. Successive scanning is characterized by choosing one hypothesis at a time and its success is limited by the likelihood of selecting redundant hypotheses, which increases with increasing memory load. When the memory store is strained the overloaded subject may fail to keep track of discarded alternatives, thus allowing them to creep back into the pool of potential hypotheses (Cohen, 1977). This is what Bruner et al. have termed "lazy" successive scanning. The increase after oversleeping of number of errors perseverative within a category may reflect such redundant confirmation of forgotten hypothesis testings. The significant elevation in this measure in the afternoon across all testing days ("inverse curve") suggests further the diurnal limitations imposed by the restraints of memory in the selecting of the new category.

Subjects may also have adopted other strategies during the period of recovery sleep. In conservative focusing and focus gambling, modifications are made to attributes of a focus card. Either or both of these

possibilities can well account for the concomitant increase in perseverative errors within a category, the perseveration reflecting the repeated modified usage of the focus card. Although differences in the proportion of this and other types of error between treatment conditions are strongly suggestive of shifts in strategy selection, the exact strategies cannot be specified without subjective "in process" comments. This may be a fruitful area for further investigation. At present, the most parsimonious hypothesis is that, after oversleeping, subjects experienced greater difficulty in extracting the maximum possible amount of information from hypothesis testing, probably because memory processes were not as efficient at this time.

It must be emphasized that subjects after oversleeping accomplished the shift of categories with ease, particularly when compared to their performance following sleep loss. With PSD, subjects exhibited a much greater tendency to respond with perseverative errors relative to non-perseverative errors and especially relative to errors perseverative within a category. Such differing patterns of errors between the two conditions suggest the operation of qualitatively different methods of information processing. An increase in perseverative errors has been equated to inability to shift concepts thereby preventing fresh modes of analysis (Grant & Berg, 1948). It can be likened to "set thinking" and to the "functional fixedness" of the Gestalt psychologists in which the tendency is to remain with the most common or recent function of an event.

The concept of shifting is generally the first strategy to be learned by normal individuals (Grant & Berg, 1948). In cases of frontal lobe damage, however, perseverative errors on the WCST may increase to a

pathological level (Drewe, 1974; Milner, 1963). Milner has described this deficit as a failure to suppress an ongoing reaction tendency, due to loss of the function of inhibition of interference normally performed by the frontal lobes. Because the mechanisms of arousal and attention share common final pathways through the ascending reticular activating system to frontal lobe destinations (Moruzzi & Magoun, 1949) with reciprocal descending projections from the frontal lobes selectively controlling the afferent information flow (Luria, 1973), the intriguing possibility exists that attentional and perhaps higher cognitive deficits following sleep loss result from functional impairment in fronto-limbic structures. Some electrophysiological evidence to this effect has been provided by Skinner and Lindsley (1973).

Broughton (1975) has postulated that during the activities and stresses of wakefulness progressive cortical depolarization (negative transcortical DC shift) occurs and that one of the functions (effects) of sleep is to repolarize the cortical DC resting level for optimum neural function the following day. There is experimental evidence for such sleep-related repolarization from recordings in experimental animals (Kawamura & Pompeiano, 1969; Kawamura & Sawyer, 1964) and Broughton (1975) has suggested that it is probable that this phenomenon is maximum in the frontal and prefrontal regions. Moreover, it has been shown that sleep loss abolishes the contingent negative variation (CNV) (Naitoh, Johnson, & Lubin, 1971), the frontal-generated wave which reflects activation of the cortex for anticipated attentional duties. In accordance with Tecce's (1972) model concerning the relationship of arousal to the CNV, inability to produce a CNV after sleep loss may be due to ceiling effects resulting

from excessive cortical depolarization. It therefore appears that such nocturnal cortical repolarization may be important in the mental efficiency of individuals the following day. Further, it is hypothesized that the present findings indicating a tendency towards perseveration with sleep loss may represent a specific instance of functional disturbance in frontal-mediated behaviour. Although highly speculative at the present time, there is evidence that such a phenomenon may be manifested in the behaviour of those chronically sleep-deprived (see Chapter V).

The present study represents a preliminary investigation into possible quantitative and qualitative changes in cognitive functioning resulting from partial sleep loss and from recuperative oversleeping. The hypothesis that changes in the strategies and/or the efficiency of information processing are precipitated by too much or too little sleep remains unproven, although some evidence of such a phenomenon has been reported here. Certain modifications to the present study may allow these potential effects to become more evident. Because it is well-known that significant effects are difficult to demonstrate following PSD, particularly if the tasks used are brief and stimulating, cognitive changes may become more apparent on more prolonged tests following more acute curtailment of sleep time or longer durations of sleep loss. Similarly, oversleeping effects could be investigated following previous schedules yielding positive results, such as recovery sleep following total sleep deprivation (Wilkinson, 1963a) and sleep extended from habitual amounts (Taub & Berger, 1969, 1973).

Measures of response latency in card-sorting could be incorporated in future studies, particularly given previous observations that this is the critical variable reflecting breakdown following acute sleep deprivation in

selective attention (Norton, 1970; Wilkinson, 1964) and perhaps concept-formation (Williams et al., 1959). This may have occurred in the present study as it was our observation, as well as the subjects' own assessment, that at certain trials they would hesitate momentarily before selecting a category. Inclusion of response latency would further permit analysis of the tradeoff between speed and accuracy, a most potent source of information on subject-paced tasks (Buck & Gibbs, 1972). Finally, it is recommended in order to more fully ascertain the nature of the strategies utilized, that regular subjective reports as to method of solution be recorded.

In sum, two separate findings have been reported for cognitive processing following changes in the sleep schedule. In a problem-solving task (anagrams) involving concentrated immediate processing of information, the natural circadian rhythm of poorer a.m. performance was amplified during periods following both reduced and extended amounts of prior sleep. In a concept-formation task (WCST) allowing a quantitative and qualitative investigation of work on related trials, performance following oversleeping was characterized by a lesser efficiency in extracting all possible information whereas performance following sleep loss indicated a relative lack of flexibility in the shifting of concepts. This latter finding is considered of special interest as it suggests the operation of different strategies and/or levels of ability in higher-order processing between conditions of reduced and extended sleep, and is of heuristic and theoretical importance in terms of hypothesized neural substrates for such phenomena.

Subjective changes

The purpose of analysis of subjective effects was twofold: first, to examine changes in sleepiness, mood, and energy precipitated by alterations in the sleep schedule; second, to establish the sensitivity of the Stanford Sleepiness Scale (SSS) to these events.

Sleepiness, mood, and energy ratings all tended to change in the direction of negative self-experience following 1 and 5 nights of PSD. The ease with which changes in self-perceived feeling states occur with sleep loss is supported by numerous studies in the literature. This contrasts sharply with the resistance of objective indicators to decrement and suggests that the perceived effects of sleep loss are more extreme than are its effects on performance.

All three sets of measures returned to near or beyond baseline levels with only one night of recovery oversleeping, as has previously been observed by Carskadon and Dement (1979) for recuperative sleep following one night of TSD. However, this represents quite a different finding from that reported by Taub and Berger (1973) and Globus (1969) for their subjective measures of arousal following extensions of sleep from the usual amount. It seems likely that extended rations of sleep, whether following sleep loss or habitual amounts, represent qualitatively different phenomena, at least in terms of the individual's own perceptions of well-being. The positive valence attached to recuperative sleep was particularly evident in the present study for energy ratings which increased significantly after one such night relative to not only sleep loss levels but also initial baseline levels. This suggests further that the effects of recovery sleep are experienced subjectively as more beneficial than a regular night's sleep.

Previous studies (Carskadon & Dement, 1979; Glenville & Broughton, 1979; Hoddes et al., 1973) have found that a single night of total sleep deprivation results in a significant increase in mean SSS scores. The present study confirms and extends these findings to the more common experience of a less acute curtailment of sleep time. The sensitivity of the SSS to internal changes following PSD supports the work of Friedmann et al. (1977) who observed significantly elevated SSS ratings during long-term gradual restrictions in sleep time.

However, unlike the all-night sleep deprivation studies of Hoddes et al. and Glenville and Broughton, the present findings indicate a general lack of correspondence between SSS ratings and level of performance. Correlations between the two sets of measures were low and subject to large individual differences. Elevated sleepiness ratings after short-term partial sleep loss are therefore not predictive of performance deficits for individual subjects and cannot reliably serve as an estimate of performance efficiency.

Sleepiness ratings associated with each of the tasks also tended to vary with increasing sleep loss and to return to baseline levels with one night of recovery sleep. However, the significance of this trend was contingent upon the arousal propensity of the task prior to any experimental manipulation of sleep time. Those tasks which resulted in the least initial fatigue, i.e., anagrams and the Wisconsin Card Sorting Test, were associated with significantly elevated post-test sleepiness ratings following sleep loss owing to departure from earlier feelings of relative alertness. Moreover, the tasks that were rated as initially more sleepiness-inducing, vigilance and four-choice and simple RT tests, were

also the tasks in which subjects exhibited the greatest performance deficits. This is in accordance with Wilkinson's (1969) proposal as to the sensitivity of unstimulating tasks to sleep loss effects.

The present and earlier (Glenville & Broughton, 1979) observation that SSS scores tend to vary as a function of the type of task may be viewed in more general terms as reflective of the sensitivity of the SSS to situational variables. In this context, the nature of the task exercises an effect on some underlying variable such as motivation. The finding that the prolonged and monotonous vigilance test was associated with higher sleepiness ratings in all conditions whereas the simple RT test, which provides supposedly incentive-producing knowledge of results (Wilkinson, 1961), was followed by the lowest SSS values after sleep loss, tends to support this hypothesis. The influence of motivation on SSS scores was particularly evident on the last two days of testing (postbaseline), when sleepiness ratings were elevated and willingness to perform reduced, as suggested by the low false positive rate on the vigilance test as well as subjects' comments on the follow-up questionnaire.

The evidence suggests that the SSS is not a unidimensional measuring instrument but rather is subject to influence by a number of other internal factors. As such, the scale may reflect variations in the self-perceived state of the individual which are not reflected in performance measures, as has occurred previously (Friedmann et al., 1977; Glenville & Broughton, 1979). This was certainly the case in the present study for those tests not sensitive to sleep loss deficits, whose pattern of associated SSS scores resembled that of the sensitive task-related ratings.

Transient situational variables may have exerted an even stronger effect when acting upon a background of relatively modest de-arousal such as that following PSD. Comparing the range of task-related SSS ratings in the present study to that of the all-night sleep deprivation study of Glenville and Broughton for the same tasks, vigilance and simple and choice RT, values during initial control conditions were roughly equivalent (mean = 2.5; mean = 2.9 respectively), whereas they were substantially reduced after five nights PSD (mean = 3.3) relative to TSD (mean = 5.0). This comparative difference supports the original observations (Hoddes et al., 1973) that SSS values vary as a function of the magnitude of sleep loss. Given the reduced ceiling of SSS values after PSD, even minor fluctuations in subjective assessment of arousal resulting from such situational variables as motivation could have become more readily apparent. The general lack of correspondence between SSS ratings and performance was probably therefore a result of the greater sensitivity of the SSS to transient phenomena which introduced substantial noise within a small range of values.

Previously, Glenville and Broughton (1979) reported that the SSS was predictive of performance efficiency only for those measures which showed sleep loss deficits. Although no such robust correspondence was observed for the same tasks in the present study, the number of significant correlations between task performance and sleepiness ratings did increase with greater sensitivity of the tasks to PSD. }

Irrespective of this finding, the overall pattern of relationship between the two sets of measures was one of large inter-subject variability. It is interesting to note that the only two subjects for whom

sleepiness ratings were predictive of performance efficiency were the two female subjects. Although this could well be a chance occurrence, it was our clinical observation that the male subjects tended to react to the condition of sleep reduction with a certain kind of bravado. Any reluctance to admit to the effects of sleep loss could then have been reflected in a narrower range of SSS scores. It is certainly well-known (e.g., Wilkinson, 1969) that subjects will react to sleep deprivation as a challenge situation, but to our knowledge there is no data on sex differences in this phenomenon.

In sum, the Stanford Sleepiness Scale is a reliable indicator of the effects of PSD, particularly when analyzed globally for mean all-day ratings. However, due to its sensitivity to transient fluctuations imposed by the situational context, its predictive efficiency of performance ability is at best minimal. The observation that SSS ratings do not generally reflect capacity to function after partial sleep loss contains negative implications concerning its usage in assessment of such clinical populations as narcoleptics and insomniacs, for whom attentional deficits may be manifested as a result of chronic sleep reduction. In such situations, the subjective SSS can serve as a useful adjunct tool but not as a substitute for objective performance measures of impaired alertness (Glenville & Broughton, 1979; Glenville et al., 1978; Wilkinson et al., 1966) or for measures of pressure to fall asleep from wakefulness measured by the multiple sleep latency test (Richardson, Carskadon, Flagg, Van den Hoed, Dement, & Mitler, 1978).

Chapter V

GENERAL DISCUSSION

A long-standing question in sleep research is how much sleep is required for a given individual. Recently, several authors (notably, Baekeland & Hartmann, 1970; Dement, 1965; Hartmann, 1973; Webb, 1973) have speculated that the latter portion of a usual night's sleep may not be essential but rather may vary with individual needs for psychological restoration. Evidence that REM deprivation in humans does not yield major deleterious effects and may even be beneficial for certain clinical populations (cf. review by Vogel, 1975), along with experimental findings that individuals can tolerate, adapt to, and maintain voluntarily, long-term reductions in amount of sleep (Friedman et al., 1977), tend to support such a view.

Although it appears that many individuals can function adequately with less sleep, particularly if the new sleep-waking schedule is implemented gradually (Naitoh, 1975), the present findings indicate that at least relatively short-term reduction of sleep yields negative consequences for performance ability and subjective feeling states. Moreover, these subjects were partially sleep-deprived by going to bed later to keep the duration between awakening and daytime testing constant. Thus these findings would tend to support the view espoused by Taub and Berger (1973, 1976b) that a sudden shifting in the phase of sleep, rather than sleep loss per se, is the major factor producing disruptive effects on the organism.

As with their data, the pattern of results in the present study reveals that the effects of the initial shifting of the phase and duration of sleep, results in performance deficits evident primarily in the morning.

Time of day differences were also present throughout the periods of sleep loss and recovery sleep, but only for those tasks (anagrams and four-choice RT) which did not yield mean all-day effects. For the more sensitive tasks, however, circadian differences were either absent throughout (simple RT) or abolished (vigilance) with continuation of the schedules of sleep reduction and extension, converging to impaired levels after cumulative PSD and normal levels following cumulative extended sleep.

Such differing patterns after initial and continuing variations in the sleep schedule suggest a two-step mechanism. Sudden disruption of the habitual diurnal pattern of sleeping between more or less consistent clock hours may exert a desynchronizing effect on normal body rhythms, thereby enhancing circadian fluctuations. Such a model has been proposed by Wilkinson (1963a) to explain time of day effects after recovery sleep. With accumulation of sleep loss or gain a more general deficit due to dearousal may assert itself, as has been suggested by Kjellberg (1977a, b). The limited evidence available from long-term PSD studies suggests that there is probably a third phase wherein the imposed schedule is gradually tolerated and adapted to.

The present study incorporated certain methodological procedures designed to allow the emergence of a clearer picture of PSD effects without resorting to massive testing procedures. First, the relative sensitivity of the 10-min simple reaction time test has shown that tests sensitive to sleep loss effects need not be prolonged, for even short-term PSD and

supports its sensitivity documented for one night of total sleep deprivation (Glenville et al., 1978). Second, manipulation of sleep rations have been calculated relative to habitual sleep amounts. This was judged to be particularly important because the degree of impairment after shifts in the phase and duration of sleep varying with habitual sleep amounts (Taub & Berger, 1976a) may contribute to large inter-subject variability in performance following PSD (Kleitman, 1963; Webb & Agnew, 1965). Finally, time of day has been considered as a separate factor to study the effects of reduced and extended amounts of sleep in interaction with circadian trends, whereas previous studies (notably Hamilton et al., 1972; Wilkinson et al., 1966) have tended to pool data over different times of day or experimental conditions.

Although the institution of such controls has certainly facilitated the specification of impairment in certain abilities, notably the capacity for sustained attention, there still remains a certain elusive quality attached to the documentation of these and other sleep loss effects. This is seen most clearly in the discrepancy between subjective and objective appraisal of the effects of sleep loss. Whereas profound changes in self-experience are a frequent counterpart of even moderate amounts of sleep deprivation, performance studies have generally shown that it is necessary to administer acute doses of sleep loss followed by prolonged testing sessions on monotonous tasks to achieve an equivalent level of objectively specified change (Wilkinson et al., 1966).

The dichotomous nature of sleep loss effects is perhaps most commonly explained with reference to the resiliency of the sleep-deprived individual to compensate functionally for what is experienced negatively.

Wilkinson especially, reminds us of the powerful role played by incentive and motivational factors. Appropriately, this has been posed as a methodological concern; to the extent that we can minimize sources of stimulation, the true effects of sleep loss will emerge. Most of us, however, do not live in a world devoid of stimulation. Yet when we lose sleep, experience teaches us that we are not performing at optimal capacity. Certain very highly-motivated individuals have subjected themselves to total loss of sleep for periods as prolonged as 11 days (Johnson et al., 1965). Inability to maintain normal functioning inevitably results no matter how much stimulation the individual has assured for him- or her-self during the period of continuous wakefulness. Some (Bliss et al., 1959; Johnson et al., 1965; Morris et al., 1960) have even described symptoms resembling those of acute paranoid psychosis during these prolonged vigils. These findings dramatically emphasize that there are limits of tolerance which cannot be exceeded without functional deterioration despite more than adequate motivation and stimulating conditions.

At a less extreme level, a variety of evidence suggests that chronic or prolonged schedules of altered sleep length harbour definite consequences for the individual, though these may be initially subclinical. Lubin (1967) has discussed the buildup of attentional deficits which may accumulate to serious levels in the chronically sleep-deprived. Although there is no hard evidence that short-term PSD increases the risk of mental and physical illness, recent epidemiological studies (Belloc, 1973; Kripke, Simons, Garfinkel, & Hammon, 1979) show that self-reported short and long sleep may be related in the long run to increased mortality rates.

Although only a correlative relationship, this finding can be related to the abundant literature suggesting the presence of active tissue restoration during sleep (e.g., see review by Adam & Oswald, 1977).

Exclusive reference to performance efficiency may lead to erroneous conclusions regarding the effects of long-term PSD. In the Friedmann et al. (1977) study, subjects experienced relentless feelings of fatigue whereas their performance did not decline throughout the 8-month period. Is this finding to be interpreted that the latter part of a night's sleep is superfluous? In the present view, it rather suggests that the deterioration in certain abilities is not being measured.

Kjellberg (1977 a, b, c) has presented a model which perhaps best incorporates the various features of sleep loss effects. According to Kjellberg, the consequences of sleep loss depend on interaction with the current state of the organism. The sleep-deprived individual confronted with a monotonous situation would then feel the effects of sleep loss more acutely than would he or she when involved in more stimulating activities. Perhaps the most original concept in his thesis is that there is an underlying effect of sleep loss which becomes manifest only in certain situations. For the last 20 years, the lapse hypothesis has dominated the orientation of researchers in the area of sleep deprivation and performance. It states that other than the brief periods of no-response (lapses), the sleep-deprived person experiences little difficulty in maintaining usual levels of functioning. For Kjellberg, such lapses are but the tip of the iceberg. With careful exposition of a number of findings which cannot be explained solely on the basis of lapses in performance, Kjellberg has stressed the logical necessity of postulating

the existence of a more general attentional deficit. The present findings support his hypothesis. A general slowing of response speed rather than intermittent overly long responses (gaps; lapses) seems to have been the principal deficit in performance following short-term cumulative PSD. On the most sensitive task, gaps were virtually absent.

The above arguments do not deny the potentiating influence of motivation and incentive, nor the existence of lapses in performance. Motivational factors are surely the most common source of variance in sleep deprivation studies. At least following total sleep loss, pressure for sleep may build to critical levels causing the intrusion of sleep stages into wakefulness. It would appear, however, that enough evidence has been gathered concerning changes (or lack of changes) following sleep loss which cannot be explained solely on the basis of motivational factors, when negative, or lapses in performance, when positive.

Examination of the nature of changes accruing to fluctuations in the sleep period may involve a deemphasis of conventional frameworks and greater attention directed towards the objectification of subjective complaints. A preliminary effort in such a direction has been made in the present study with the examination of changes in cognitive processing following under- and over-sleeping. Prompted by the frequency of reports related to mental changes following such modifications to the sleep schedule, this investigation borrowed from models in cognitive psychology which provide a framework wherein stress-related cognitive changes can be understood. Of particular interest was the finding that recovery sleep precipitated the largest modifications in cognitive processing, as this was in direct contrast to the pattern of performance on simpler tasks.

Previously, the existence of slowed thinking under such conditions was based exclusively on self-reports and clinical observations. It may be a fruitful endeavour for future studies to examine the degree of correspondence between efficiency of cognitive strategies and subjective reports, when both sets of measures are administered concomitantly following extended sleep.

Although even more speculative, the possible occurrence of a tendency towards perseveration with sleep loss is of interest in relation to possible analogues in the literature. Narcoleptics commonly experience prolonged behavioural automatisms with retrograde amnesia (Guilleminault, Billiard, Montplaisir, & Dement, 1975), which may be likened to the phenomenon of perseveration with memory impairment. These episodes are characterized by the efficient and semiautomatic execution of simple actions yet failure to respond appropriately to more complex task requirements. Case studies reveal that in its most extreme manifestations unyielding perseveration may ensue in a manner reminiscent of frontal lobe 'patients' behaviour. This phenomenon is of particular present interest in light of the view that many of the symptoms of narcolepsy may represent the extreme pathological result of chronic sleep deprivation.

Luby, Frohman, Grisell, Lenzo, and Gottlieb (1960) have described a similar syndrome in one normal subject during 220 hr of continuous wakefulness. This individual was subject to "blackout" periods in which he would automatically continue certain behaviours, such as playing records, then suddenly "awaken" with no memory of the event. Sleepwalking episodes are other amnesic automatic behaviours which occur in a matrix of confusional arousals from deep stage 3-4 sleep (Gastaut & Broughton, 1965;

Jacobson, Kales, Lehmann, & Zweizig, 1965), and may represent even greater degrees of similar mechanisms.

Behaviourally, perseveration on the WCST and automaticity of behaviour are markedly similar. They both involve a reliance on familiar and simple patterns of activity which are often unsuited to environmental demands. They may also have in common a similar predisposing upset in psychophysiological functioning. It is well-known that cases of frontal lobe damage commonly exhibit perseverative behaviour. A similar functional deficit in sleep-deprived individuals, may be related to a lack of opportunity for the restoration of basal firing rates in cortical (mainly prefrontal) neurons during REM sleep. This may represent the electrophysiological underpinnings of deficits in consciousness in chronically sleep-deprived individuals as has been suggested by Broughton (1975). The striking similarity of attentional, cognitive, and mood changes resulting from sleep loss and frontal lobe damage attests further to a common underlying mechanism. That certain behaviours following sleep loss represent a minor functional version of the frontal lobe syndrome thus appears as an intriguing possibility.

Conversely, the "fogginess" of thought processes following extended sleep may be related to a shift in the balance of repolarization-depolarization during NREM and REM sleep respectively. A relative predominance of NREM could then induce a state wherein the potential for cortical reactivity is reduced due to insufficient priming during REM. Such concepts are not new. The basic electrophysiological model has been proposed by Broughton (1975). Ephron and Carrington (1966) have described and elaborated such concepts as "cortical tonus", "cortical

homeostasis", "functional deafferentation" during NREM, and "endogenous afferentation" during REM, by which they refer to the sleep-related homeostatic control of "appropriate limits" of cortical excitability. In their view, "REMS may have the functional effect of counteracting deafferentation in NREM ... reinvigorating the cortex following depletion of cortical functions in NREMS." (p. 511). Thus disorganization in thought processes on awakening relates to "residual effects from the night's deafferentation, which persist into the postsleep morning hours ..." (p. 515). Similarly, Hartmann (1965) has postulated that a need for REM builds up during NREM sleep periods. That the effects of oversleeping tend to be most pronounced when no prior sleep has been lost supports a homeostatic model of electrophysiological restoration during sleep.

On the behavioural level, there appears to be a qualitative difference between the pattern of changes precipitated by under- and over-sleeping. The changes attributed to sleep loss are better known and may be related most predominantly to preliminary stages of information processing. These include inability to sustain attention, slower psychomotor responding, disorientation and misperception, and, as has been suggested here, a tendency towards automaticity of behaviour. With oversleep, the types of changes shift more to impairment of higher-order cognitive processing, and these changes have variously (perhaps vaguely) been described as slowed thinking, "foggy thinking", "thickheadedness", and lesser efficiency of cognitive strategies.

The differing patterns of events accruing to sleep loss and oversleeping may further be related to a variety of clinical disturbances, most notably narcolepsy and the hypersomnias, depression, and the

depressive and manic poles of manic-depressive illness. These illnesses are so inextricably linked to patterns of aberrant sleep as to render the unravelling of what constitutes a symptom of the disease from a symptom of sleep upset untenable. Again, syndromes involving insufficient sleep may be related to poorer vigilance and automatic behaviour, as has already been discussed with reference to narcolepsy. The fitful sleep of endogenously depressed patients may contain consequences in such symptoms as slower psychomotor responding and inability to shift from set patterns of morbid thought. The great frequency with which depressive symptoms are reported by narcoleptics (Broughton & Ghanem, 1976; Passouant & Billiard, 1976) attests further to the association between such symptoms and chronic sleep disturbance.

Syndromes involving excessive sleep contain their own unique set of behavioural correlates. The sleep drunkenness of idiopathic hypersomnia (B. Roth, 1956; B. Roth et al., 1972) is markedly similar, albeit more extreme, than the thickheadedness of individuals arising from overly prolonged sleep. The slowed thinking characteristic of reactive depression and the depressive pole of manic-depressive illness may have similar origins.

It is hoped that the reader has seen fit to grant the author license for the degree of speculation in the preceding pages. Some of these ideas will certainly be discarded while others may come to bear some fruitful findings. It is the author's contention, however, that new perspectives are necessary at the present time in sleep deprivation research. This has been exemplified most dramatically perhaps in the unfortunate dropoff of

research efforts in this area during recent years. It appears to be a topic needy of revitalization and new direction. Let us hope that our own thought processes do not come to resemble those of the sleep-deprived individual, locked into the execution of familiar patterns of thinking and doing.

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APPENDIX A

Prequestionnaire

SLEEP DEPRIVATION STUDY QUESTIONNAIRE (CONFIDENTIAL)

Name: _____ Age: _____ Sex: _____
 Address: _____ Tel.no. _____ Date: _____

List any Psychology courses that you currently take with the professors' names. _____

How long do you usually sleep each night during the week?

_____ on weekend nights (Fri. & Sat.)? _____

At what times do you usually go to sleep and wake up on week nights? _____

on weekend nights? _____

How long do you generally take to fall asleep after turning out the light? _____

Describe any difficulties you might have in falling or staying asleep. _____

Are you a regular sleeper?; ie. does your sleep pattern vary substantially from night to night? _____

Do you do _____ or have you done _____ shift work? If yes, when and for how long? _____ Did you adapt easily _____, or only with great difficulty? _____

Do you waken at times with a "thick head" lasting at least 30 minutes? If so, does it occur: more than once a month? _____ more than once a week? _____

Have you ever had a scary dream? _____

Do you feel you get enough sleep? _____

Do you nap? _____ If so, how often and for how long? _____

Are you willing to give up napping for the week during which you will be losing some nighttime sleep? _____

Do you frequently sleep more than 8 hours? ____ If so, how do you feel the day after? _____

How do you think you will function on 4½ hours of sleep per night for five consecutive nights without napping? _____

Are you curious about the effects of under- and over-sleeping on your performance? _____

Do you take any medication? ____ If yes, what kind and in what amount? _____

Do you drink alcohol? ____ If yes, how often, how much, and when? _____

Do you take nonmedical drugs (eg. marijuana)? ____ If yes, how often, how much, and when? _____

Approximately how many cups of coffee or tea do you drink per day? _____

Would you agree to abstain from alcohol, nonmedical drugs, coffee, and tea on those days that we request during the course of the experiment? _____

Have you recently sought treatment for any physical health problems? ____ If yes, which one(s)? _____

Have you been treated for any psychological problems? ____ If yes, which one(s)? _____

Do you work part-time or hold any other commitments aside from school? ____ If so, when? _____ If necessary, can they be rescheduled? _____

Will you be in town and available for the experiment for the entire month of November including all weekends? _____

Is there anything else that may be important for us to know about you? _____

THIS SECTION FOR WOMEN

When do you anticipate that you will have your menstrual period during the month of November? _____

To what extent are you regular? _____

To what extent (if any) do you feel your functioning is impaired before or during menstruation? _____

If I will be a subject in the experiment, I agree to complete it once started and comply with all insructions as have been outlined for me.

(signature)

Handwritten scribbles and a signature at the bottom of the page. The signature is a large, stylized loop. To its right is a jagged horizontal line. There are also some smaller, less distinct scribbles above and around the main signature.

APPENDIX B

Postquestionnaire

SLEEP DEPRIVATION STUDY FOLLOWUP QUESTIONNAIRE

Name: _____

1. List in order your reasons for initially volunteering for this experiment." (1-6)

Money _____ Marks _____ Interest _____ Meeting others _____
 Challenge _____ Other _____

2. Give your subjective appraisal as to what each of the tasks was measuring; i.e., what abilities did you have to use to perform well on the tasks? In the second column rank the tests in order of difficulty. (1-5)

Vigilance	_____	_____
4-choice RT	_____	_____
simple RT	_____	_____
Card Sort	_____	_____
Anagrams	_____	_____

3. List any other functions or states that might have improved or deteriorated as a result of sleep loss or oversleeping which this experiment did not seem to measure.

4. Was your motivation constant throughout the experiment? _____ If it varied, on what testing days were you most and least likely to try your hardest on the tasks? Include any A.M. - P.M. differences.

5. Do you think your performance would have been any different had you been run through this experiment alone? _____ If so, how? _____

6. Do you feel that a knowledge of your own or others' performance on the tasks affected your subsequent performance? _____
- _____
- _____

7. What strategies did you use in improving your performance on the various tasks. Try also to give an indication as to approximately when (what day of testing) your performance started to show significant improvement on each task as a result of these strategies.

Vigilance _____

4-choice RT _____

simple RT _____

Card Sort _____

Anagrams _____

8. Vigilance

List any factors that might have improved or interfered with your performance on the vigilance task (e.g., tape quality, hearing another's response, people walking through the room, etc). _____

9. Four-choice and simple RT

List any factors that might have improved or interfered with your performance on these tasks. _____

10. Card Sort

Were there times you were more likely to become confused, lose track, or take longer in sorting the cards even if your sorting was correct? _____ If so, when (on what testing days)? Include any A.M. - P.M. differences.

11. Anagrams
How many times do you think you have to take the anagrams before you reach the limits of your ability on this task? _____

12. Describe any other factors that might have contributed to your better or poorer performance on any of the tasks. _____

13. We realize that many of the controls for this experiment were quite rigorous and difficult to maintain; occasional straying from the rules is understandable. It would help us greatly in terms of data analysis if you could report now any such events which you have not otherwise reported (e.g., napping, sleeping more or less than allotted time, taking medication, alcohol, or other drugs, etc.). State when. _____

- Did you ever fall asleep during any of the tasks? _____ If so, on what tasks and when? _____
- Were you entirely consistent about filling out the SSS forms? _____
If not, when did this slip the most? _____
14. Are you interested in receiving the results of this experiment? _____
15. Please include any additional comments or suggestions on the back of this sheet. Thank you.

APPENDIX C

Example of Anagrams Test

ptlse _____
 nustt _____
 lacor _____
 fltau _____
 lafat _____
 alfse _____
 jeect _____
 cmaig _____
 armla _____
 ualqe _____
 eoynv _____
 ugeag _____
 uilbd _____
 asyet _____
 arsty _____
 ibtre _____
 nryea _____
 racte _____
 neash _____

itcwh _____
 saptr _____
 urcve _____
 ncfay _____
 fryai _____
 infat _____
 theig _____
 velas _____
 ectle _____
 neact _____
 dobro _____
 hgcou _____
 lufsh _____
 rtisk _____
 wastr _____
 ustdy _____
 kcflo _____
 ytpar _____
 inswe _____

plepa _____
roapn _____
ekevo _____
tusoh _____
edspa _____
kcspe _____
nnfuy _____
ecody _____
tnshu _____
ilgud _____
enmit _____
domel _____
nceim _____
irmth _____
iltug _____
uiedg _____
ouths _____
ldasc _____
ngiuf _____

nodem _____
ltfai _____
apsce _____
srepa _____
arteh _____
styug _____
lifrl _____
gupro _____
urshg _____
esgui _____
unmis _____
klmiy _____
eyhna _____
mstoi _____
ssbli _____
simty _____
nrfot _____
ramol _____

2

APPENDIX D

Wisconsin Card Sorting Test
Scoring Sheet

APPENDIX E

Stanford Sleepiness Scale and
Scales of Mood and Energy

PREVIOUSLY COPYRIGHTED MATERIAL
IN APPENDICES "D" AND "E", LEAVES
135 AND 137, NOT MICROFILMED

135 - Wisconsin Card Sorting Task

137 - Stanford Sleepiness Scale

APPENDIX F

Model of F Table for 4x2x2 ANOVA

Source	Sum of Squares	Degrees of Freedom (df) ^a	Mean Square	F	Tail Prob.
1. Mean Error	-	1 6	-	-	-
2. A - Amount of sleep Error (AxS)	-	3 18	-	-	-
3. B - Day of condition Error (BxS)	-	1 6	-	-	-
4. A x B Error (AxBxS)	-	3 18	-	-	-
5. C - Time of day Error (CxS)	-	1 6	-	-	-
6. A x C Error (AxCxS)	-	3 18	-	-	-
7. B x C Error (BxCxS)	-	1 6	-	-	-
8. A x B x C Error (AxBxCxS)	-	3 18	-	-	-

Note: Abbreviation: S, subjects variance.

^a df for numerator = $k - 1$; df for denominator = associated factor levels from formula, $df = (k_a - 1) (k_b - 1) (k_c - 1) (k_s - 1)$.