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Laterality, sleep and carry-over performance effects

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City University of New York, 1988

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LATERALITY, SLEEP AND CARRY-OVER PERFORMANCE EFFECTS

by

Ruth Anne Reinsel

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1988

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

9-28-88

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Abstract

LATERALITY, SLEEP AND CARRY-OVER PERFORMANCE EFFECTS

by

Ruth Anne Reinsel

Adviser: Professor John Antrobus

To test the hypothesis that RH functions are selectively facilitated during and after REM sleep, EEG measures of cerebral dominance recorded during sleep were correlated with standardized scores on a battery of cognitive and psychomotor tasks administered immediately after awakening. 33 right-handed normal volunteers spent two nights in the sleep laboratory, and were awakened twice per night (either early or late in the sleep period) from REM or Stage 2 sleep. Performance on nocturnal awakenings was compared to a waking control session. Tasks were administered in counterbalanced order across awakenings, and included measures of verbal, spatial and tactile processing, memory, and choice reaction time. EEG spectral power in six bandwidths (0.5-32 Hz) was computed from bilateral central and temporo-parietal electrodes.

No significant main effects or interactions were found for stage of sleep or time of night on any of the tasks. Performance on nocturnal awakenings did not differ significantly from waking control values. Gender effects were not present in either the behavioral measures or in EEG power. Subjects showed an overall bias towards LH dominance in Waking and in both sleep stages. Hemisphere differences were small in magnitude and did not relate to sleep stage or time of night, although frequency bands summed across both hemispheres significantly discriminated between Waking, REM and Stage 2 sleep. Correlations of total EEG power in sleep with later task performance were for the most part not significant.

It is concluded that there is no basis for assuming RH dominance in REM sleep. Previous reports of stage-specific lateralized carry-over performance effects were not replicated. Given that the current experiment has a larger sample size and consequently greater statistical power than previous studies in this area, the null findings can be accepted as a disconfirmation of the twin hypotheses of RH dominance in REM and stage-specific carry-over of cognitive asymmetry, without undue risk of Type II error. Nevertheless methodological differences between the present research and prior investigations may help to explain the divergent results.

Acknowledgements

I gratefully acknowledge the mentorship of Professor John Antrobus of the City College of New York, without whose guidance and encouragement this research could not have been undertaken. His patience and gentle good humor were unfailing during this arduous four-year project. Professor Jeffrey Rosen, also of City College, has been a major influence in my training in the areas of cerebral laterality, electrophysiology and cognitive testing. I would like to extend heartfelt thanks to Dr. George Fein, of the San Francisco Veterans' Administration Hospital, for providing the software for the power spectral analysis, and to Mr. William Isecke, for his technical assistance with the hardware. The helpful comments and kind support of Professor Cristiano Violani of the University of Rome "La Sapienza" have contributed greatly to this manuscript. Additionally, all the students who assisted me in the laboratory for all those many long nights are fondly remembered. And finally (but certainly not least) I wish to thank all the participants in this research, without whose enthusiastic cooperation and spirit of adventure this experiment would not have been possible.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES

(continued)

LIST OF FIGURES

INTRODUCTION

The Right Hemisphere and Dreaming

In recent years, the widespread interest in the specialized functions of the two cerebral hemispheres has led to the suggestion that the right hemisphere (RH) plays a special role in dreaming (Bakan, 1978; Broughton, 1975; Galin, 1974). This suggestion is based loosely on the similarity between dreaming and primary process thought, or on the evidence for RH specialization for visual imagery, spatial processing and affect (see Bradshaw and Nettleton, 1981, 1983; Davidson, 1983; De Renzi, 1978; McGee, 1979; Nebes, 1978; Young and Ratcliff, 1983). As Bakan (1978) put it in his influential formulation,

> "There are some striking similarities between REM dream thought and right hemisphere thought. The mentation of both dreaming and the right hemisphere is characterized by reliance on imagery, affect, and primary process thought ... The evidence from diverse sources converges to support the theory of a cyclic ascendance in the functioning of a right hemisphere system during sleep (and perhaps in wakefulness) which is manifested by changes at the physiological (REM state physiology) and psychological levels (dreams)." (p. 286)

However, there is reason to suspect that this proposal may be an oversimplified appraisal of the role of the RH in dreaming. Ehrlichman and Barrett (1983) reviewed the literature on the role of the RH in visual imagery, and found very little evidence to support the unique role of the RH as an image generator. Greenberg and Farah (1986) present case studies of patients with localized brain damage, and show that unilateral RH damage does not eliminate the dreaming process. Damage to temporal or parietal cortex seems to be the crucial factor, regardless of left or right sided locus; although neurological case studies reviewed by Farah, Gazzaniga, Holtzman and Kosslyn (1985) suggest that the role of the left hemisphere (LH) in generating mental imagery may be proportionately larger than that of the RH.

The literature on differential hemispheric involvement in dreaming has recently been reviewed by Antrobus (1987), who concurs with the above authors in concluding that

> "the RH may have a role in producing relatively simple images and sporadically communicating them to the LH during REM sleep. But the LH may be capable of generating all of the imagery qualities that have been associated with REM mentation and of extracting this information and producing, upon awakening, a verbal mentation report." (Antrobus, 1987, p. 366)

Do the Sleep Stages Differ in Cerebral Dominance?

In order to interpret the EEG evidence of hemispheric asymmetry, a word of explanation is in order. Cortical activation is generally accepted to be inversely related to EEG amplitude. Thus, the high amplitude delta waves of slow-wave sleep are associated with a lack of recalled mental activity, and in the waking state, the low amplitude, high frequency beta bandwidth is associated with active information processing . In hemispheric asymmetry studies, lower EEG amplitude over a particular hemisphere is taken as an indicator of heightened cerebral activation and increased involvement in cognitive processing of tasks specialized for that hemisphere (see, for example, Davidson, 1983; Doyle, Ornstein and Galin, 1974; Gale and Edwards, 1983; Galin and Ornstein, 1972; Loring and Sheer, 1984; Marsh, 1978). Thus, for example, a finding of higher EEG amplitude in the LH would imply that there is relatively more cognitive activation in the RH.

The first evidence that REM and NREM may involve differential activation of the cerebral hemispheres was advanced by Goldstein, Stoltzfus and Gardocki (1972). They compared integrated amplitude of the EEG during sleep in 7 humans, 4 cats and 5 rabbits. In the human subjects (right-handed males), EEG was recorded from left and right parietal regions. Data from the first three hours of sleep were converted to a ratio of L/R amplitude and deviations from the overall mean amplitude were plotted against time. In all seven human subjects, NREM sleep showed a lower amplitude in the left hemisphere, which shifted to a higher amplitude on the left side with the onset of REM sleep. This data was interpreted to indicate greater RH activation in REM.

identical patterns of hemispheric dominance in REM vs. NREM sleep were found in most of the animals studied.

A later study by Murri, Stefanini, Navona, Domenici, Muratorio and Goldstein (1982) found RH dominance in all stages of sleep, as compared to waking, in 13 subjects. Their findings, like those of Goldstein et al. before them, are compromised by their use of the R/L asymmetry ratio, which can be shown to be mathematically biased (Antrobus, 1987); that is, equal magnitude changes in RH or LH amplitudes do not yield equal changes in the asymmetry ratio. The correct ratio to measure degree of asymmetry is generally considered to be (R-L)/(R+L) (or, just as equivalently, the reverse order of terms). Studies using this ratio as the basis of their statistical analysis merit greater weight in the consideration of their findings than studies based on R/L or L/R ratios.

Pilot data reported by Herman and colleagues give some slight support to these claims of RH dominance in REM sleep. Herman, Roffwarg and Hirshkovitz (1981) have observed slight shifts to RH dominance in REM sleep which wax and wane over time. These shifts were seen maximally over temporo-parietal regions and were most visible in the alpha band. A later report by Herman and co-workers (1983) tended to confirm these findings, although there was considerable individual variability, and the dominance shifts were generally of small magnitude (less than 5 uv). Unfortunately, these are preliminary reports in abstract form, and quantitative data analyses are not presented.

Hirshkowitz and Karacan (1981) found that some of the variability in hemispheric asymmetry between subjects was gender related. With 11 male and 11 female right-handed subjects, they recorded integrated amplitude from bilateral temporal sites. Males showed a greater shift to RH dominance during REM sleep, whereas in females the hemispheres did not differ as greatly. This report, though also presented only in abstract form, is consistent with the larger body of findings in the laterality literature which find greater lateralized differences in males than in females (Bryden, 1982; McGlone, 1980).

Nonetheless, these few studies suggesting RH dominance in REM are outnumbered by those which found no difference between REM and NREM sleep stages. Moffitt, Hoffmann, Wells, Armitage, Pigeau and Shearer (1982) used period analysis to compare EEG from REM and NREM sleep in eight right-handed males. They found RH dominance in all sleep stages, but there was no hemispheric difference between REM and Stage 2 sleep. Pivik, Bylsma, Busby and Sawyer (1982) studied six intellectually gifted adolescent males. They found no systematic lateralization in REM sleep, and in fact there was a trend towards more hemispheric symmetry during REM sleep as compared to wakefulness, especially for beta activity recorded from central electrode sites. Gaillard, Laurian and Le (1984) used integrated amplitude to compare the temporal L/R ratio in all sleep stages. For their 14 right-handed subjects, there was no consistent hemispheric difference between sleep stages. Violani, DiGennaro and Capogna (1984) used spectral power analysis to compare temporal EEG in all sleep stages in five right-handed males; they also found no consistent asymmetry. Finally, Ehrlichman, Antrobus and Wiener (1985) report on a comparison of integrated amplitude from temporo-parietal sites in 18 right-handed subjects; again there was no significant difference in laterality between REM and Stage 2.

These latter five studies, which have found no evidence of sustained cerebral asymmetry between sleep stages, have the advantage of being reported in full, rather than as abstracts, and of having been subjected to appropriate statistical analysis. Unfortunately, however, the sample sizes in these studies are still quite small (five to eight subjects in all but the Ehrlichman et al. study, which reports on 18 subjects). Small sample sizes make it difficult to attain statistical significance and are more affected by random differences between individuals. These problems with small sample sizes increase the probability of failing to identify a small effect, even when actually present in the data (Type II Error).

Although considerable variability between subjects in patterns of interhemispheric relationships during sleep has been reported in several studies (Moffitt et al., 1982; Murri et al., 1982; Pivik et al., 1982), there are some general trends evident across studies. In general, subjects who are LH dominant during waking tend to show a shift to the RH at sleep onset (Murri et al., 1982). This RH dominance continues throughout all stages of sleep, with minor fluctuations (Murri et al., 1982; Pivik et al., 1982). Thus both REM and NREM may show RH dominance, with REM being perhaps slightly (but nonsignificantly) more right hemispheric than Stage 2 (Moffitt et al., 1982; Murri et al., 1982; Rosekind, Coates, and Zarcone, 1979). This pattern is by no means universal, however. In pilot work (Reinsel, 1985a, 1985b) the ten subjects showed, on the average, LH dominance during sleep. Pivik et al. (1982) found that patterns of interhemispheric asymmetry varied with frequency band and topographical region studied, even within the same individual on the same night. Relevant methodological aspects of the studies cited above are presented in Appendix 1.

In view of the conflicting EEG results, one might ask whether other physiological parameters show stage-related asymmetries. There have been isolated reports, based on observations of 3 or 4 subjects, of asymmetries in skin conductance response during sleep (Freixa i Baque and de Bonis, 1983), and in regional cerebral blood flow favoring the right parietal, temporal and occipital regions which are associated with reports of visual dream experiences in narcoleptics (Meyer et al., 1979; Meyer et al., 1987). Due to the small number of subjects involved, however, and the lack of replicative work, it is not clear that REM and Stage 2 actually differ on these physiological variables.

The Biological State Carry-Over Effect

The process of awakening from sleep is not instantaneous. There is reason to believe that the transition to wakefulness is a gradual phenomenon, where the influence of the prior sleep stage may persist for an appreciable amount of time after awakening. These sleep-state after-effects have been found for fantasy and dream reporting, for perception and memory, and possibly for some EEG measures. In some cases the carry-over effects appear to be stage-specific. This evidence will be summarized below.

Evidence for carry-over effects in the domain of dream-reporting and fantasy is quite robust. The superiority of dream-recall after stage REM is well-known; whether this represents a difference in mentation production during sleep itself, or whether it reflects a difference between stages in the ability to store and later retrieve sleep mentation in the waking state is not clear. Nevertheless, in the time period immediately after awakening from REM the individual appears to have greater access to prior mentation experiences. Retrieval from long-term memory also appears to be enhanced; Rosenblatt (1986) reports that subjects shown film clips prior to sleep showed better recall of these clips after REM than Stage 2 awakenings.

Differential carry-over effects on fantasy processes have been demonstrated upon awakening from sleep. Stories given in response to TAT cards were longer, more complex, and more visual and affect-laden after REM awakenings than after Stage 2 (Fiss, Klein, and Bokert, 1966); and after interrupted as opposed to completed REM periods (Fiss, Ellman, and Klein, 1969). The fantasy and affect of the TAT stories given after REM awakenings showed similarities to dreams recalled on the same awakenings. The authors suggested that the waking TAT stories reflected a continuation of the cognitive processes that are involved in dreaming. Conceptualizing dreaming as a drive state, these authors feel that "if a drive state continues to be active as a person passes from one state of consciousness to another, schemata associated with this drive will continue to be recruited." (Fiss, Klein, and Bokert, 1966, p. 550)

The process of visual perception seems to be especially influenced by carry-over effects. Here, evidence suggests that the brain state after awakening from REM sleep is somehow different from other stages. Lavie (1976) reports studies on the spiral after effect (SAE) and the beta movement or phi phenomenon, conducted after awakening subjects from either REM or NREM sleep. Susceptibility to both of these visual illusions was greater after REM sleep, as shown by the duration of the SAE and the increased range of frequencies yielding the phi phenomenon.

Several investigations of short-term and long-term memory upon sleep interruption have found stage-specific carry-over effects which may be reflected in both immediate and delayed recall of materials given for learning upon awakening from sleep. Stones (1977) gave subjects word lists to learn after REM, NREM or a Waking Control. Immediate memory was poorest after NREM awakenings, but was as good after REM as in Waking. Delayed recall was tested after a 20 minute interval filled with an interference task (Ravens Progressive Matrices) to prevent verbal rehearsal of the material. After this 20 minute interval, NREM recall declined, but REM and Waking maintained their high levels of performance. This finding suggests that the carry-over effect may dissipate at different rates for REM and NREM.

The effect of depth of sleep on memory after awakening was tested by Akerstedt and Gillberg (1979).

Looking at NREM stages only, they compared long-term memory for items presented on arousal from either a baseline night or a night of recovery sleep following 64 hours of sleep deprivation. The increased depth of sleep on the recovery night impaired morning recall for the information presented during the night. Similarly, Bonnet (1983) found that memory was worse after Stage 4 awakenings than after Stage 2, presumably due to the greater depth of sleep in Stage 4. If, however, the subjects were given 8 minutes additional time awake before beginning the memory task, scores improved. This effect was interpreted as supporting an arousal explanation; in effect, subjects needed more time to wake up after Stage 4.

This interpretation is supported by reaction-time data presented by Feltin and Broughton (1968), who found that reaction times to light flashes after slow wave sleep were significantly longer than after REM. Arousal from SWS appeared to be progressive, whereas subjects appeared more alert immediately after REM awakenings. Similarly, Goodenough, Lewis, Shapiro, Jaret and Sleser (1965) report that time to pick up a telephone and make a verbal response was nearly twice as long after NREM as after REM awakenings (13 seconds vs. 7 seconds, respectively). These response times were computed *after* EEG signs of arousal had appeared on the record.

Evidence for EEG carry-over effects is fragmentary.

It has been reported that in some normal subjects, upon awakening from slow-wave sleep, the delta waves of the prior sleep state continue to be present in the waking EEG for as long as 20 minutes in some cases (Broughton, 1968). The same effect, seen in hypersomniacs, has been termed "sleep drunkenness" (Nevsimalova et al., 1981). In their study of the visual evoked potential (VEP) in sleep, Myslobodsky, Ben-Mayor, Yedid-Levy and Minz (1976) found a sleep-specific asymmetry in the VEP alpha after-discharge which persisted for 10 to 20 minutes after awakening. A similar effect had been previously reported by Broughton (1968). On the other hand, Herman, Roffwarg and Hirshkovitz (1981) report pilot EEG data (not evoked potentials) indicating that the prevailing RH activation of REM sleep shifts back to LH dominance within 10 seconds of arousal.

Only two studies to date have attempted to relate EEG measures before and after awakening in the same subjects. With four subjects in each group, Moffitt et al. (1982) found that these correlations are high only for high dream recallers, and low for infrequent dream recallers. Pivik et al. (1982), in six subjects, found no consistent relationship in lateralization between pre- and post-awakening EEG characteristics. These studies do not provide convincing evidence that the awake-state EEG is strongly influenced by the prior sleep stage; but the hypothesis cannot be confidently rejected due to the small sample sizes in these studies.

Is the Carry-Over Effect Lateralized by Sleep Stage?

Although the difference in cerebral asymmetry between REM and NREM sleep has not been clearly established to date, the original report by Goldstein, Stoltzfus and Gardocki (1972) of RH dominance in REM aroused great interest, and was widely cited in support of Galin's (1974) and Bakan's (1978) thesis of the unique contribution of the RH to the dreaming process.

Following up on this lead, Lavie and his colleagues conducted several studies to assess the function of the RH immediately upon awakening from REM or NREM sleep. They administered a battery of lateralized cognitive tasks to 12 male subjects over two nights in the laboratory. While there was no difference in total performance between sleep stages, they found that performance of RH tasks was facilitated after REM awakenings, while LH tasks showed better performance after NREM awakenings (Gordon, Frooman and Lavie, 1982). Replication studies showed that the effect was present in right handed females as well (n=11; Lavie, Matanya and Yehuda, 1984), but not in 24 left-handed subjects (Lavie and Tzinchinsky, 1984, Expt. 2). Using two groups of nine right-handed males, these same authors also demonstrated that if the onset of cognitive testing was delayed for 35 or 75 minutes after awakening, the lateralized after-effects were no longer present (Lavie and Tzinchinsky, 1984, Expt. 1).

Independent evidence of right hemisphere facilitation during or after REM sleep, was provided by a study by a group of investigators at the University of Rome. Bertini, Violani, Zoccolotti, Antonelli and Di-Stefano (1984) used a tactile recognition task to assess performance of the contralateral hemisphere after awakenings from REM or Stage 2 sleep. Their findings indicated superior left hand (i.e. RH) performance overall, reflecting the RH advantage for spatial processing (Bryden, 1982; De Renzi, 1978). Additionally, there was a hand by stage interaction, such that the left hand (RH) advantage was significantly greater after REM awakenings, while right hand (LH) performance showed improvement after Stage 2.

Lateralized Carry-over Effects: Summary.

The studies reviewed in the preceding sections provide a considerable weight of evidence that, while it is not clearly demonstrated that REM and NREM differ in cerebral dominance,

a) some differential effect of the previous sleep stage carries over into the waking state and can influence perception and cognitive performance;

b) awakening from REM sleep has different implications for performance on lateralized cognitive tasks than NREM awakenings;

c) this differential carry-over effect remains fairly stable for at least 15-25 mins, and thereafter declines, so that if testing is delayed for 35 or 75 mins after awakening, the effect is no longer present.

On the other hand, it must be recognized that the studies on carry-over effects that give rise to these conclusions rely on two major assumptions: i) that general brain states can be inferred from behavior, and ii) that the same brain/behavior relationships exist in waking as were present in the previous stage of sleep. Both of these assumptions require more experimental scrutiny. In the absence of direct measurements of cortical activity in the brain during and after sleep, these two assumptions cannot be taken for granted.

Time of Night Effects

In addition to investigating lateralized carry-over effects in behavior, the present study also attempts to explore time of night effects. The original report of EEG asymmetry during sleep (Goldstein et al., 1972) recorded only the first 180 minutes of sleep, while the studies of behavioral asymmetry after arousal from REM or NREM sleep have sampled only the second and third sleep cycles (Bertini et al., 1984; Gordon et al., 1982; Lavie et al., 1984). There is reason to believe that the early part of the sleep period differs markedly from later sleep. These differences are evident both in physiological measures and in aspects of dream recall. The amount of slow wave sleep (SWS) is greatest in the first half of the night and decreases thereafter; REM period intensity and duration increase in the latter half of the night. These changes are reflected in the characteristics of the mentation reported. Late REM periods yield reports judged as more complex, vivid, visual, and emotional; (Foulkes, 1962; Verdone, 1965). These changes are also found for NREM mentation (Pivik and Foulkes, 1968).

Time of night effects are also seen in the NREM sleep stages. Fein, Floyd and Feinberg (1981) established that successive periods of NREM sleep can be distinguished on the basis of normalized measures of amplitude, frequency and time/epoch in each of five frequency bandwidths. The visual impression of less delta and theta in later NREM stages was confirmed by spectral analysis. Myslobodsky et al. (1976) found both an asymmetry and a time of night effect in spindle production. Spindles were more frequent in the LH in the first third of the night, but a gradual increase in spindle production over the night in both hemispheres was sufficient to eradicate the asymmetry by the last third of the night.

One of the few direct statements of the time of night hypothesis has been formulated by Cohen (1977). Cohen hypothesized that dream content would show a greater increase in LH functioning over the course of the night. His evidence in favor of this hypothesis is rather weak, being based on a limited content analysis of the dreams of 10 individuals. His analysis is based on questionable assumptions, such that good ego functioning (measured on a three point scale) reflects LH dominance, or that the presence of affect or bizarre elements in the dream are RH products; also Cohen bases much of his argument on the direction of eye movements, which are not good correlates of hemisphericity (Ehrlichman and Weinberger, 1978). Additionally, his statistical analysis is compromised by use of the L/R asymmetry ratio, which can be shown to be mathematically biased (Antrobus, 1987).

Several studies have attempted to evaluate time of night effects in EEG measures during sleep. Rosekind, Coates and Zarcone (1979) looked for time of night effects in cerebral asymmetry, using measures of integrated EEG alpha in nine subjects. They found no evidence to suggest that late REM periods differ in interhemispheric relationships from earlier REM cycles. Cohen's hypothesis, known by the acronym GILD (Gradual Increase in Left Dominance) was tested with EEG measures by Violani, DiGennaro and Capogna (1984). Two of their five subjects did show increasing asymmetry of LH activation over the night, but only on one of the two recording nights. The authors conclude that the GILD hypothesis is not well supported by their data. In addition, Armitage, Hoffmann, Moffitt and Shearer (1985) also failed to find support for the GILD effect in measures of EEG frequency and power.

Rationale for the Present Study

The preceding review of the literature may be summarized as follows: The behavioral task-performance evidence for RH dominance upon arousal from REM sleep is fairly strong. On the other hand, the EEG evidence for RH dominance specifically during REM sleep is quite unconvincing. A major weakness of studies in this area is that no study has evaluated EEG asymmetry and behavioral task performance in the same subjects and on the same awakenings. The study proposed here would be the first to simultaneously investigate the relationship between sleep EEG and post-awakening behavioral measures. Thus, for the first time, questions pertaining to EEG asymmetry during sleep and to lateralized post-awakening carry-over effects may be directly evaluated.

The purpose of the present investigation is to assess the validity of stage-specific carry-over effects on lateralized cognitive tasks, and to evaluate, by direct EEG measurement, the nature of interhemispheric dominance during sleep. This study was undertaken, in part, to replicate the findings of lateralized performance carry-over effects reported by Gordon, Frooman and Lavie (1982), Lavie, Metanya and Yehuda

(1984), Lavie and Tzinchinsky (1984), and Bertini et al. (1984). Experimental procedures were designed to be as similar as possible to these prior studies.

To examine the hypothesis that time of night may alter or mediate hemispheric asymmetry effects, the present study incorporated a time of night manipulation into the design. Awakenings were made from REM or Stage 2 sleep either in the first or the second half of the sleep period (defined as the midpoint between the time of lights out and the time of morning wake-up). Previous reports of carry-over effects were confined to the first half of the night (awakenings in the 2nd and 3rd sleep cycles). This study proposes to investigate whether the carry-over effects would vary in accordance with the time of measurement during the sleep period.

Hypotheses

For each hypothesis, a prediction is made for the post-awakening task performance, and for the EEG recorded during sleep prior to awakening.

HYPOTHESIS 1. Hemisphere by Stage of Sleep Interaction. Tasks. The major hypothesis of the study was formulated in accordance with the findings of previous investigators (Bertini et al., 1984; Gordon et al., 1982; Lavie, Metanya and Yehuda, 1984). A significant hemisphere by stage of sleep interaction was predicted, wherein RH task performance would be facilitated after REM awakenings, while LH task performance would be improved after Stage 2 sleep. EEG. Similarly, on the assumption that asymmetric task performance reflects EEG variations during the prior sleep stage, the RH is predicted to be dominant during REM sleep and the LH to be dominant during Stage 2 sleep.

HYPOTHESIS 2. Time of Night Effect. Late awakenings are postulated to have an advantage in view of the greater amount of accumulated sleep time and the higher level of cortical arousal present towards the end of the sleep period. Tasks. It is postulated that all tasks will show improved performance on late awakenings as compared to early awakenings. EEG. Late awakenings will show greater power in the alpha and beta bands than will early awakenings.

HYPOTHESIS 3. Hemisphere by Time of Night Interaction. This hypothesis is based on Cohen's (1977) GILD formulation, and predicts that LH dominance increases across the night. Tasks. LH tasks will be performed better on late awakenings as compared to early awakenings. EEG. In both REM and Stage 2 sleep, there will be a trend towards greater LH dominance on late awakenings as compared to early ones.

HYPOTHESIS 4. Stage of Sleep by Time of Night Interaction This hypothesis is based on the assumption that the lower EEG frequencies characteristic of NREM sleep, especially early in the sleep period, will reduce task scores, while the higher EEG frequencies which are present late in the sleep period, especially in stage REM, will facilitate task performance. *Tasks.* Hypothesis 4 predicts that task performance will be lowest after Early Stage 2 awakenings, and best after late REM awakenings. *EEG.* Early Stage 2 sleep will show greater power in delta and theta bandwidths than will late REM periods. Conversely, late REM recordings will show greater power in alpha and beta bandwidths than will Early Stage 2 sleep.

HYPOTHESIS 5. Gender differences. In accordance with previous reports of task-related gender differences in EEG asymmetry (Beaumont, Mayes & Rugg, 1978; Bryden, 1982; McGlone, 1980; Trotman & Hammond, 1979) it is predicted that males will show greater differences between hemispheres in sleep EEG and in post-sleep task performance than will female subjects.

METHOD

Subjects.

33 right-handed volunteers participated in this study (22 males and 11 females); subjects' ages ranged from 17 to 36 years. Informed consent was received from all subjects prior to their participation; a sample consent form is provided in Appendix 2. Handedness was assessed by a modified version of the Edinburgh Inventory (Oldfield, 1971). Only three subjects had a left-handed relative among their immediate family. All subjects were assessed to be normal sleepers via their responses on a sleep habits questionnaire (Appendix 3). Most participants were college or graduate students, and were paid $20-$30 for their participation in the study.

Procedure.

Subjects spent one afternoon or evening control session in the lab to familiarize them with the tasks and to gather waking control data on all measures. Subjects returned to the lab for three nonconsecutive nights, of which the first served as an adaptation night. On the two experimental nights, subjects were awakened twice per night, in REM or Stage 2 in counterbalanced order, with awakenings scheduled for early or late in the night (defined as the first or second half of the sleep period, with the first REM cycle omitted from sampling).

Immediately after awakening, subjects were administered a battery of cognitive tasks chosen to assess the functions of the Left and Right hemispheres (see below). The order of task administration was completely counterbalanced within subjects using a Latin Square design, so that order and practice effects would not affect any experimental condition more than another. In order to maximize the probability of detecting carry-over effects, and/or to minimize the influence of the waking state, subjects performed the tasks while remaining in bed, with room lights at low levels, and verbal interaction with subjects was kept to a minimum. Each task required about 1-2 minutes, with the exception of the tactile task, which took about 4 or 5 minutes. The entire testing procedure was generally completed within 20-25 minutes and the subject was then allowed to return to sleep.

Tasks.

Tasks were chosen to assess cognitive functions specialized to the left or right cerebral hemisphere. Rather than employing a single measure, multiple tasks were used to assess the extent of the performance carry-over effects. By using several tasks, it was hoped to generalize the carry-over tasks to the functions of an entire hemisphere, rather than to isolated cognitive abilities. Additionally, the variety of tasks used allowed the assessment of asymmetries in the visual, auditory, tactile and motor modalities.

In order to control for order effects (such as fatigue, increasing or decreasing arousal as a function of time after task initiation, and practice over the five awakenings) the six tasks used were administered in counterbalanced order following the Latin Square method described by Kirk (1968). A 6x6 "seed" square was randomly selected from the tables published in Fisher and Yates (1963). Rows and columns of the 6x6 matrix were individually randomized. The result of this procedure is that each task appears only once at every possible position in the sequence. Each of the six possible orders was utilized: one in the practice and task familiarization session, one for the Waking Control session, and the remaining four on the nocturnal awakenings.

In order to replicate the Gordon, Frooman, and Lavie (1982) study as closely as possible, several tasks from the Cognitive Laterality Battery (CLB) used in their study were retained for use. The CLB has been validated as reliably measuring lateralized cerebral function in brain-damaged and normal adults (Bentin and Gordon, 1979; Gordon, 1986) and in learning-disabled children (Gordon, 1983). Gordon (1986) reports satisfactory split-half and test-retest reliabilities for the individual subtests, as well as the results of a factor analysis which confirmed the grouping of the eight subtests along two dimensions reflecting verbal-sequential and visuo-spatial skills. The CLB tasks are marked with an asterisk in the descriptions below. These tasks included *Serial Numbers (a modified digit span) and Anagrams as measures of LH function; and *Form Completion (a Gestalt picture recognition task) and *Point Localization, a spatial orientation task, as measures of RH functioning.

The Tactile Recognition task was included to replicate the results of Bertini et al. (1984). On a movable plastic belt are affixed plexiglass shapes which the S is asked to explore with the first two fingers of each hand, without looking at the stimuli. A matching to sample response is required, by choosing the correct stimulus from three response alternatives. The task is performed with alternate hands for 7 trials with each hand, in counterbalanced order. This task is considered lateralized since when tactile stimulation is received from the index and middle fingers of each hand, the sensory input is processed entirely by the contralateral hemisphere (Brinkman and Kuipers, 1972; Ghez, 1981, p. 283). Previous work presenting tactile stimuli and requiring selection of the identical stimulus from a visually- presented array found this task to involve RH abilities in brain-damaged patients (De Renzi, 1978) and in split-brain patients (Nebes, 1978).

While the Tactile Recognition task may be understood to represent processing of sensory input, a Choice Reaction Time (RT) task was also included to assess motor output. These latter two tasks, when performed with the left hand, assess RH function; with the right hand, LH performance. The Choice RT task employed a device which presented the subject with stimulus lights on either side of a central "warning" indicator. After a two second foreperiod, the left-side or right-side was illuminated in random sequence. The subject was instructed to press the response button on the same side as the illuminated stimulus light. The subject's response stopped a clock which indicated reaction time to the nearest hundredth of a second. Six trials were conducted with each hand, of which the last five were averaged to provide a mean score for each hand. The order of starting hand was counterbalanced across trials. RT scores were log-transformed and averaged to remove skew before being entered in the data analysis.

Thus, four measures are designated Left Hemisphere Tasks: Anagrams, *Serial Numbers, right-handed Tactile Recognition (TAC-rh), and right-handed Reaction Time (RT-rh). The Right Hemisphere Tasks consist of *Form Completion, *Point Localization, left-handed Tactile Recognition (TAC-lh), and left-handed Reaction Time (RT-lh). Further details on the administration and scoring of the individual tasks, and justification of their lateralized representation in the human brain, are given in Appendix 4.

Stanford Sleepiness Scale (SSS). The SSS is widely utilized in sleep research when a subjective rating of sleepiness is desired (Herscovitch and Broughton, 1981; Hoddes, Zarcone, Smythe, Phillips, and Dement, 1973). In order to determine if there is any systematic variation in subjective sleepiness as a function of time of night or stage of sleep, the SSS was administered to each subject immediately upon awakening and prior to the administration of any other task. The scale consists of 7 statements identified with a number from 1 to 7, where 1 is the most alert end of the scale, and 7 is the sleepiest. Appendix 3 presents the SSS in its entirety. In pilot work (Reinsel, 1985b) the SSS significantly discriminated between Waking, REM and Stage 2 awakenings and showed significant time of night effects over repeated awakenings within the night.

Statistical Analysis of Task Peformance Scores. Analysis of Variance (ANOVA) with repeated measures were computed for each of the individual tasks to examine the main effects of State of Consciousness (Waking, REM, and Stage 2), Time of Night, and Gender. Interactions between these variables were also evaluated. Differences between the three states of consciousness were further examined using planned orthogonal contrasts between Waking and Sleep (REM and Stage 2 combined) and between REM and Stage 2 sleep individually. Additionally, to replicate the data analysis used by Lavie and his collaborators as exactly as possible, individual task scores were normalized within subject. The resulting z-scores were combined into summary variables for all LH tasks combined (the variable ZLEFT), all RH tasks combined (ZRIGHT), the sum of these two (ZSUM, corresponding to the Cognitive Performance Quotient or CPQ), which is a measure of total performance, and their difference (ZDIFF, corresponding to the Cognitive Laterality Quotient or CLQ), a measure of lateralized performance asymmetry. Further repeated measures ANOVAs were conducted on these standardized summary variables.

EEG Recording.

Polysomnography. Using a Grass Model 78 polygraph, bipolar EEG was recorded from homologous central and temporo-parietal regions referenced to Cz. The temporo-parietal electrode sites were found by Ehrlichman and Weiner (1980) to show the greatest degree of hemispheric asymmetry. For purposes of scoring sleep stages, vertex EEG referenced to linked mastoids was recorded, along with EOG and EMG. Sleep was scored in accordance with the guidelines of Rechtschaffen and Kales (1968).

Analog to Digital Conversion (A/D). 4 channels of EEG data (C3/Cz, C4/Cz, TP3/Cz and TP4/Cz) were recorded by one of two methods. In the first method, analog signals were recorded on cassette tape on a

Vetter Model D four-channel FM instrumentation recorder, and later digitized off-line by an IBM PC-XT equipped with a Quadram PC-Mate LabMaster A/D board. In the second method, (as the ASYST software was implemented about halfway through the experiment) EEG signals were sampled on-line by the above-mentioned IBM PC-XT. In both cases, sampling was at a frequency of 128 Hz with the high filters set at 30 Hz (except for a few of the first subjects, where the high filter cutoff was 60 Hz). Digitizing was conducted with on-line artifact rejection based on eye movement amplitude of 200 uv peak to peak. Very few epochs were actually rejected since care was taken in the original recording to include only epochs free from movement artifact or state changes. Analog amplitude values (in uv) were converted to arbitrary A/D units with reference to a 10 Hz calibration signal of 100 uv peak to peak.

Spectral Power Analysis. Spectral power analysis was conducted, using the Fast Fourier Transform (FFT) technique, by the IBM PC-XT with 640K memory and the ASYST version 1.53 scientific programmming package. Programs for the spectral power analysis were developed by Dr. George Fein of the San Francisco Veteran's Administration Hospital. EEG power was computed in seven bandwidths: Delta (0.5 - 3.5 Hz), Theta (4.0 - 7.5 Hz), Alpha (8.0 - 11.5 Hz), Spindles (12.0 - 15.0 Hz), Beta1 (15.5 - 20.0 Hz), Beta2 (20.5 - 32.0 Hz), and Total

Power (0.5 - 32 Hz). For the purposes of further data analysis, the low power Beta1 and Beta2 bands were combined and will be referred to hereafter simply as Beta (15.5-32.0 Hz).

Statistical Analysis of FFT data.

EEG power values were log-transformed before being submitted to statistical analysis.

Hemisphere Differences. To evaluate the degree of asymmetry between the cerebral hemispheres, the algebraic difference of the log power values was derived for homologous electrode pairs. Thus, the Hemisphere Difference (HD) for the temporo-parietal electrodes in any given bandwidth is equal to Log TP3 - Log TP4. (The commonly used ratio (L-R)/(L+R) seen in studies using, for example, visual reaction times to tachistoscopic stimulus presentation, is not appropriate for use with logarithms.)

As discussed above, higher power values are associated with higher amplitude and lower frequency EEG activity. When the HD is positive, it indicates greater power in the LH and consequently is interpreted as showing greater activation in the RH. When the HD is negative, it indicates greater power in the RH, and by extension, greater LH activation.

Hemisphere Sums. In addition, to evaluate the nature of global cortical power effects, log power values were summed across both hemispheres for homologous electrode positions. These sums (combined cortical power, or CCP) shift the focus from differences between the cerebral hemispheres to the total picture over both sides of the brain. The questions of state and time of night differences in global cortical power are logically distinct from the issue of imbalances or asymmetries in power between the two hemispheres.

Analysis of Variance. For separate HD and CCP dependent variables, repeated measures ANOVAs were computed on each band width as well as total power to assess the main effects of sleep stage, time of night and gender, as well as their interactions. In these analyses, data from the different electrode sites was examined to see whether differences in the HDs appear between central and temporo-parietal sites, and whether these differences vary with stage of sleep, or differ between sleep stages and waking.

RESULTS

Results of this experiment will be considered in three major sections. First, the EEG data recorded during sleep will be reviewed a) by electrode placement and bandwidth, b) for evidence of asymmetry between the cerebral hemispheres, and c) for total power summed across the hemispheres. Results of the repeated measures ANOVAS for the main effects of gender, stage, time of night and electrode placement will be discussed. Second, the results of the behavioral tasks performed after awakening will be presented for each task individually, as well as for the normalized hemisphere summary variables. Lastly, the EEG measures recorded during sleep will be correlated with the scores on the behavioral tasks performed after awakening.

I. EEG Measures

EEG Power by Bandwidth and Electrode Placement

EEG measures are presented as power (the square of amplitude, measured in microvolts squared). The natural log of each EEG measure was taken to reduce the extreme skew typical of such data. A negative log power value indicates the actual raw power was a decimal value between zero and one. A positive log power value indicates raw power greater than one. Technical difficulties in the recording of the EEG necessitated dropping the data from two subjects, leaving 31 subjects in the data base.

Table 1 gives the log power values across the three minute sampling period for left and right central (CN) and temporo-parietal (TP) electrodes in Waking, REM and Stage 2 sleep. The values across the three minute sampling period are for the most part quite consistent. The slightly more posterior TP placements show much higher EEG power values in all bandwidths and in all states of consciousness.

Delta (0.5-4 Hz). At the CN placements, EEG amplitudes (power) are somewhat higher in the LH in waking, whereas in sleep they are very slightly higher in the RH. The TP placements show fairly similar power values in both hemispheres, with a tendency for power to be very slightly higher in the LH in all states. At all sites, delta power in Stage 2 is greater than in REM, as expected, while the lowest values of delta power are seen in Waking.

Theta (4.5-7.5 Hz). For the CN electrodes, EEG amplitudes are higher in the RH in Waking, REM and Stage 2, thus giving an overall left activation in all stages. At the TP sites, power in the LH is quite similar to the RH. For all sites, the states can be ranked Stage 2 > REM > Waking in terms of theta power. There is some overlap betweeh the mean power values in Waking and in REM at the central electrodes.

Table 1. Mean EEG Power by Electrode Position, Bandwidth and State of Consciousness.

A. CENTRAL ELECTRODE PLACEMENTS

	WAKING		REM		STAGE 2	
BAND	C3	C4	C3	C4	C3	C4
DELTA						
Min. 1	3.301	3.061	3.338	3.292	3.603	3.740
Min. 2	3.164	2.997	3.397	3.479	3.671	3.832
Min. 3	3.244	2.916	3.445	3.531	3.740	3.850
THETA						
Min. 1	1.563	1.743	1.735	1.845	2.211	2.424
Min. 2	1.542	1.699	1.786	1.946	2.228	2.458
Min. 3	1.507	1.689	1.846	1.998	2.254	2.463
ALPHA						
Min. 1	1.448	1.800	0.775	0.882	1.214	1.434
Min. 2	1.339	1.663	0.793	0.922	1.240	1.456
Min. 3	1.284	1.662	0.886	1.034	1.249	1.437
SPINDLE						
Min. 1	0.829	1.172	-0.095	0.059	0.753	0.977
Min. 2	0.717	1.024	-0.119	0.058	0.757	0.966
Min. 3	0.579	1.013	0.003	0.160	0.722	0.926
BETA						
Min. 1	0.423	0.921	-0.598	-0.421	-0.228	0.129
Min. 2	0.332	0.720	-0.637	-0.381	-0.196	0.148
Min. 3	-0.043	0.626	-0.398	-0.180	-0.242	0.089
TOTAL						
Min. 1	7.564	8.697	5.155	5.657	7.552	8.703
Min. 2	7.093	8.102	5.221	6.024	7.700	8.859
Min. 3	6.571	7.906	5.782	6.543	7.723	8.764

Table 1 (continued).

B. TEMPORO-PARIETAL ELECTRODE PLACEMENTS

	WAKING		REM		STAGE 2	
BAND	TP3	TP4	TP3	TP4	TP3	TP4
DELTA						
Min. 1	3.746	3.707	4.151	4.026	4.721	4.736
Min. 2	3.754	3.616	4.197	4.122	4.838	4.819
Min. 3	3.834	3.602	4.319	4.255	5.010	4.888
THETA						
Min. 1	2.707	2.792	2.975	3.054	3.412	3.494
Min. 2	2.675	2.731	3.013	3.109	3.434	3.503
Min. 3	2.750	2.782	3.047	3.010	3.500	3.544
ALPHA						
Min. 1	2.960	3.166	1.952	2.089	2.337	2.418
Min. 2	2.848	3.041	1.986	2.112	2.388	2.438
Min. 3	2.803	2.986	2.072	2.183	2.407	2.470
SPINDLE						
Min. 1	2.133	2.393	0.991	1.090	1.877	1.941
Min. 2	2.029	2.228	0.966	1.083	1.890	1.938
Min. 3	1.942	2.189	1.080	1.159	1.858	1.918
BETA						
Min. 1	2.322	2.550	1.201	1.303	1.726	1.755
Min. 2	2.232	2.365	1.204	1.276	1.720	1.744
Min. 3	2.092	2.284	1.380	1.398	1.700	1.751
TOTAL						
Min. 1	13.868	14.609	11.270	11.562	14.073	14.343
Min. 2	13.538	13.981	11.365	11.702	14.270	14.442
Min. 3	13.421	13.842	11.898	12.095	14.475	14.570

Alpha (8-11.5 Hz). For both the CN and TP electrodes, amplitudes are highest in the RH in all stages, showing LH activation overall. The difference between the hemispheres is greatest in Waking at the central placements, though there is some overlap between the mean values for Waking and Stage 2 sleep at these same sites.

Spindles (12-15 Hz). Spindles are generally considered to be a characteristic of sleep, and are particularly typical of Stage 2 (Rechtschaffen & Kales, 1968). However, Johnson, Lubin, Naitoh, Nute and Austin (1969) found spindle activity in all stages of sleep. In the present data, Waking and Stage 2 have the greatest degree of spindle activity, while in REM there is much less activity in this bandwidth. Spindle amplitudes tend to be greater in the RH, where the values in waking are even higher than in sleep, especially at the TP sites. The unexpected predominance of spindle activity in waking may be explained if activity in this band is assumed to be spillover from the neighboring alpha and beta bands.

Beta (15.5-32 Hz). The two original bandwidths in the beta range (beta1: 15.5-20 Hz, and beta2: 21-32 Hz) were combined into one composite measure of beta activity. It is this combined beta measure that is used in all subsequent analyses. As expected, beta power is highest in Waking. This finding is congruent with the concept of waking as the state of highest cortical activation. Unexpectedly, REM sleep shows less beta power than Stage 2, even though the cerebral cortex in REM is considered to be more activated than in Stage 2. At both placements, beta amplitudes are higher in the RH in all states, but differences between the hemispheres are most noticeable at the CN electrodes.

Total Power (0.5-32 Hz). This composite measure is obtained by summing log power in all other bands within a given hemisphere. Total EEG power across states may be ranked as Stage 2 > Waking > REM. The EEG amplitudes are higher in the RH in all states, giving the impression of a consistent LH activation in both Waking and Sleep. There is some overlap between the power values in Waking and Stage 2 sleep. Total Power values at the TP placements are nearly double the amplitudes seen at the CN sites.

Differences Between the Hemispheres

Differences in EEG power between the hemispheres (HDiffs) were assessed by entering log power values from homologous electrode placements into the formula Log L - Log R. These differences were computed separately for CN and TP placements in each bandwidth. Using this formula, a positive ratio indicates more power in the LH, and thus greater RH activation; a negative ratio indicates more power in the RH, and thus greater LH activation.

Table 2. Means and Standard Deviations of Hemisphere Differences* (HDiffs): by Electrode Placement, Bandwidth and State of Consciousness.

* (Log L - Log R)

	WAKING		REM		STAGE 2	
BAND	CN	TP	CN	TP	CN	TP
DELTA						
Mean	+0.257	+0.150	-0.046	+0.094	-0.230	+0.046
s.d.	0.782	0.516	0.845	0.406	0.777	0.343
THETA						
Mean	-0.164	-0.045	-0.099	-0.105	-0.253	-0.078
s.d.	0.457	0.250	0.817	0.242	0.383	0.302
ALPHA						
Mean	-0.336	-0.181	-0.064	-0.168	-0.221	-0.063
s.d.	0.705	0.354	1.057	0.400	0.323	0.438
SPINDLE						
Mean	-0.345	-0.220	-0.125	-0.117	-0.224	-0.061
s.d.	0.723	0.325	0.731	0.173	0.315	0.234
BETA						
Mean	-0.526	-0.164	-0.098	-0.092	-0.401	-0.047
s.d.	1.212	0.436	1.397	0.345	0.859	0.432
TOTAL						
Mean	-1.113	-0.459	-0.433	-0.387	-1.329	-0.203
s.d.	2.905	1.500	4.344	1.221	2.506	1.454

Table 2 presents the mean hemisphere differences (HDiffs) for each state and bandwidth. The most striking thing to note from this table is that the HDiffs tend to be fairly small. The magnitude of both the HDiffs and the standard deviations, however, tend to be greater at CN than at TP sites. Total EEG power shows most asymmetry at the central positions in Waking and Stage 2. At the TP placements, Stage 2 shows very little asymmetry relative to the other states. Asymmetry in REM sleep tends to be less than in Waking. Another very striking observation from Table 2 is the quite consistent direction of the sign of the HDiffs. Except for the delta band, the HDiffs are consistently negative in all states, indicating greater power in the RH and consequently a relative LH activation. The standard deviations of the HDiffs are also presented in Table 2. At the CN electrodes, REM sleep shows greater variability than the other states; whereas at the TP electrodes, variability tends to be similar across the three states.

<u>Between State Analysis.</u> The three minutes of EEG data were combined into one database for the repeated measures analysis of variance (RM ANOVA). For each of six bandwidths (delta, theta, alpha, spindle, beta (15.5-32 Hz) and Total Power (0.5 - 32 Hz), an RM ANOVA was computed to evaluate the effects of Gender (G), Electrode Placement (P), State (S) and Minute recorded

(M). Results of these RM ANOVAs are presented in Table 3. The sample size for these analyses (N=29) was slightly reduced since, when there is missing data for any condition, all data for that subject is excluded from the repeated measures analysis. The probability values reported in this table are for the univariate F tests, except in the case where the sphericity test (Mauchly's criteria) applied to the orthogonal components of the transformed variables was significant, giving reason to doubt the compound symmetry assumption underlying the analysis of variance. In this case the p value reported is for the Huynh-Feldt epsilon, a more conservative estimate of the F ratio giving more accurate significance levels. (Note: in the case where a variable has only two levels, as for Electrode Placement, or in the Time of Night analyses below, sphericity tests are not required, and all p values given are from the univariate F tests.)

Table 3. Results of RM ANOVA on Hemisphere Differences on three minutes of recorded EEG in Waking, REM and Stage 2 Sleep. p values for main effects and interactions are given; trends up to p<.10 are indicated.

(Note: abbreviations: ns = not significant;
G = Gender, M = Minute, P = Placement, S = State (W,R,2)

BANDWIDTH

EFFECT	Delta	Theta	Alpha	Spindle	Beta	Total
G	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	ns	ns
S	=.04*	ns	ns	ns	ns	ns
MxG	ns	ns	ns	ns	ns	ns
PxG	ns	ns	ns	ns	ns	ns
SxG	ns	ns	ns	ns	ns	ns
MxP	ns	ns	ns	ns	ns	ns
MxPxG	ns	ns	ns	ns	ns	ns
MxS	<.09*	ns	ns	ns	ns	ns
MxSxG	ns	ns	ns	ns	ns	ns
PxS	ns	ns	ns	ns	ns	ns
PxSxG	ns	ns	ns	ns	ns	ns
MxPxS	ns	ns	ns	ns	ns	ns
MxPxSxG	<.10*	<.03*	<.10*	ns	<.09*	<.02*

*Sphericity test significant (compound symmetry assumption rejected); p value reported is for Huynh-Feldt epsilon test.

The ANOVA results given in Table 3 indicate that the main effect of gender was not significant for any bandwidth. Minute by minute fluctuations in EEG asymmetry did not approach significance for any bandwidth. The main effect of electrode placement (central vs. temporo-parietal) was not significant for any bandwidth. Differences between states of consciousness were significant in the delta band, but did not even approach significance in any other bandwidth. Helmert orthogonal contrasts were computed between Waking and both sleep stages combined, and between REM and Stage 2 sleep specifically. HDiffs proved to differ significantly between Waking and Sleep only for the delta bandwidth ($\underline{p}<.05$); REM and Stage 2 did not differ on any measure. Interactions between stage and gender or placement and gender were not significant, although a complex four-way interaction appeared to be present in most bandwidths. This interaction was not predicted and is not clearly interpretable, though it may reflect gender differences between stages in minute-to-minute fluctuations in EEG power at the different electrode sites.

Time of Night Analysis. Since this first RM ANOVA showed no meaningful variations between the three minutes of EEG recorded, they were averaged together for the next stage in the data analysis. The focus in the next analysis was on the differences between early and late awakenings in REM and Stage 2 sleep; waking control data was not considered. Subjects with missing data for any of the four conditions were dropped from the analysis, reducing the sample size to 24.

Table 4 shows the average interval elapsed between lights out and the two successive awakenings per night. The first awakening in the "early" condition took place about three hours after lights out (the result of skipping the first REM cycle). If the second awakening was also in the early condition, the interval between awakenings was about 90 minutes; if it was to be a late awakening, the interval was 215 minutes on the average. If, on the other hand, both awakenings were in the late condition, the interval between them was about two hours. Thus, early awakenings occurred in the first 3-5 hours of continuous sleep, while late awakenings occurred more than 5-7 hours after lights out.

Table 4. Mean Elapsed Sleep Time between Lights Out (LO) and the First and Second Awakenings of a Night. (Times shown do not include the approximately 25-30 minutes required for administration of the task battery.)

ELAPSED SLEEP TIME TO AWAKENING

(in minutes)

	TYPE OF AWAKENING		
INTERVAL	BOTH EARLY	MIXED	BOTH LATE
LO - Awak. 1	178	191	307
Awak. 1-Awak. 2	91	215	126
LO - Awak. 2	239	376	403

Table 5. Results of RM ANOVA on Hemisphere Differences: Time of Night analysis in REM and Stage 2 sleep (averaged over 3 minutes of recorded EEG). *p* values for main effects and interactions are given; trends up to *p*<.10 are indicated.

(Note: abbreviations: ns = not significant;
G = Gender, P = Placement, S = Stage of Sleep, T = Time of Night)

	BANDWIDTH					
	Delta	Theta	Alpha	Spindle	Beta	Total
EFFECT						
G	ns	ns	ns	ns	ns	ns
P	ns	ns	<.07	ns	ns	ns
S	<.05	ns	ns	ns	ns	ns
T	ns	ns	ns	ns	ns	ns
PxG	ns	ns	ns	ns	ns	ns
SxG	ns	ns	ns	ns	ns	ns
TxG	ns	ns	ns	ns	ns	ns
PxS	ns	ns	ns	ns	ns	ns
PxSxG	<.01	ns	ns	ns	ns	ns
PxT	ns	ns	ns	ns	ns	ns
PxTxG	<.01	<.09	ns	<.05	<.10	<.05
SxT	<.02	ns	ns	<.06	<.04	<.06
SxTxG	ns	ns	ns	ns	ns	ns
PxSxT	ns	ns	ns	ns	ns	ns
PxSxTxG	ns	ns	ns	ns	ns	ns

Results of the Time of Night analysis using HDs as the dependent variable are given in Table 5. Contrary to the hypothesis, the main effect of time of night was not significant for any bandwidth. Differences between electrode placements were significant only for the alpha band, but did not vary with time of night or sleep stage in any bandwidth. The difference between REM and NREM sleep was significant only for the delta band. The stage of sleep by time of night interaction (SxT) was significant for the delta and beta bands, and approached significance for spindles and total power. Figure 1 shows this interaction for the delta bandwidth. Gender was uniformly nonsignificant as a main effect, but the three-way interaction between gender, electrode placement and time of night was significant for delta, spindles and total power, and showed similar trends in the theta and beta bands. Figure 2 presents this interaction for the total power band. The three-way interaction of gender, electrode placement and stage of sleep was significant only for the delta bandwidth.

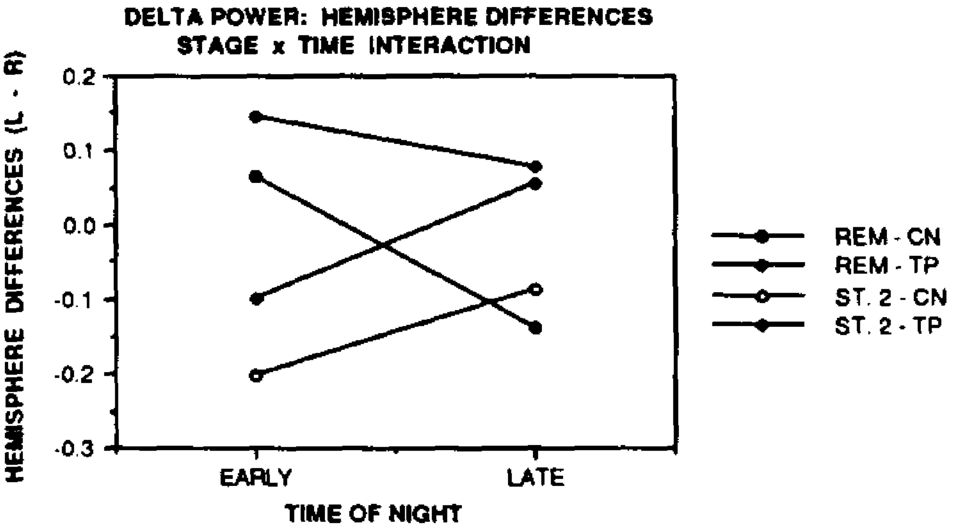

Figure 1. Sleep Stage by Time of Night Interaction in Cerebral Asymmetry in the Delta Bandwidth.

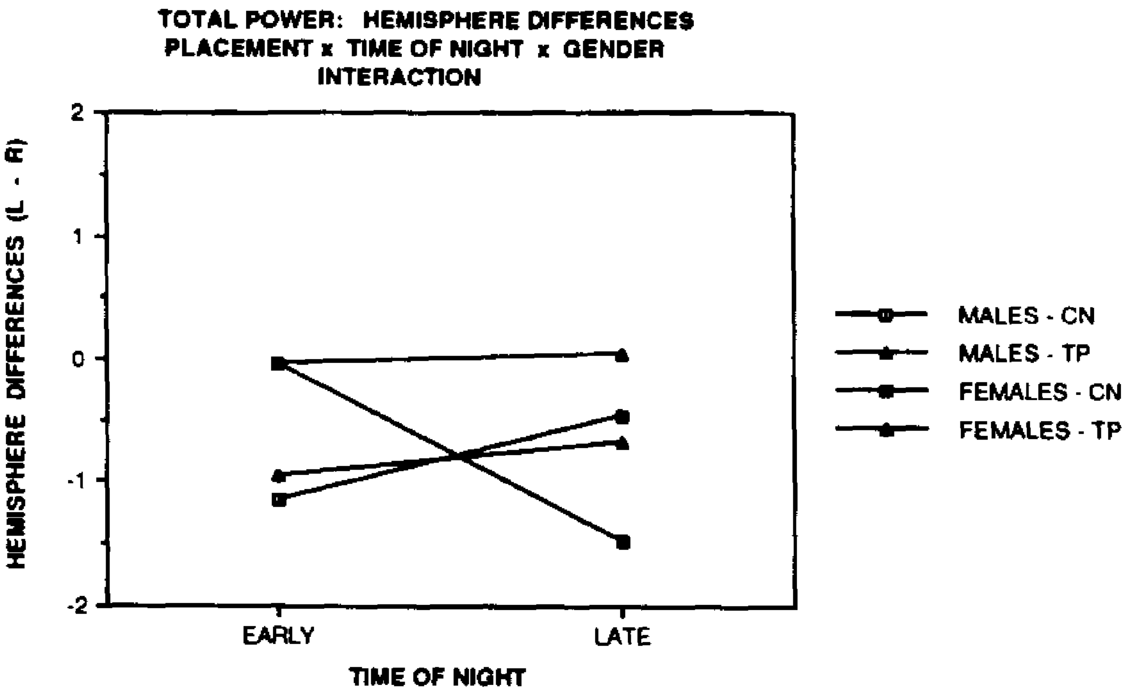

Figure 2. Electrode Placement by Time of Night by Gender Interaction in Cerebral Asymmetry in the Total Power Bandwidth (0.5 - 32 Hz).

Total Power across the Cortex: the hemispheres combined

The presence or absence of cerebral asymmetry and its relationship to behavior is logically distinct from the issue of whether EEG power in a given band, measured globally across both hemispheres, may predict performance on cognitive tasks. Since hemisphere differences are not a notable effect in the present data, the data was reanalysed, not for the differences between the hemispheres, but for their sum (HSum). These new indices of combined cortical power (CCP) reflect EEG activity in both the LH and the RH simultaneously within a given bandwidth. Means and standard deviations for the HSums in each bandwidth and electrode site are given in Table 6. The HSum data were analysed in the same manner as the HDiffs.

Table 6. Means and Standard Deviations of Hemisphere Sums* (HSums): by Electrode Placement, Bandwidth and State of Consciousness.

* (Log L + Log R)

	WAKING		REM		STAGE 2	
BAND	CN	TP	CN	TP	CN	TP
DELTA						
Mean	6.322	7.609	6.900	8.421	7.516	9.556
s.d.	2.076	1.809	1.494	1.357	1.298	0.877
THETA						
Mean	3.336	5.583	3.685	6.087	4.675	6.892
s.d.	1.721	1.791	1.465	1.064	1.329	1.009
ALPHA						
Mean	3.074	5.939	1.682	4.074	2.660	4.757
s.d.	2.123	2.233	1.454	1.146	1.550	1.254
SPINDLE						
Mean	1.766	4.301	-0.064	2.055	1.696	3.763
s.d.	1.959	1.649	1.510	1.283	1.434	1.266
BETA						
Mean	1.067	4.696	-1.137	2.473	-0.086	3.331
s.d.	3.764	3.083	2.785	2.372	2.802	2.350
TOTAL						
Mean	15.566	28.129	11.066	23.110	16.461	28.298
s.d.	10.411	8.595	7.773	6.483	7.466	6.022

When looking at EEG power across the cortex, the mean values in Table 6 show that total power is least in REM and approximately equal in Waking and Stage 2 sleep. Power is consistently higher at the more posterior sites. The delta band shows quite similar values across the three states. Theta power is highest in Stage 2 and somewhat less in Waking and REM. As expected, alpha power is highest in the Waking state, and somewhat less in REM than in Stage 2. Spindle power, unexpectedly, is not greatly different in Waking than in Stage 2. In REM spindles are of much greater amplitude at TP sites than at CN, where the negative sign of the mean indicates fractional power (raw power < 1.0 gives a negative log). Not surprisingly, beta power is lower in REM and Stage 2 than in Waking, but the negative means at CN sites in Stage 2 and especially in REM indicate very low beta power over the central cortex.

<u>Between State Analysis.</u> The first set of RM ANOVAs using HSum as the dependent variable utilised the three minutes of recorded EEG and compared Waking, REM and Stage 2 for each of the six bandwidths. Again, the sample size was *N*=29 for these analyses. Sphericity tests were again computed and where significant, Huynh-Feldt epsilon *p* values are reported. Results of the RM ANOVAS for HSum in each bandwidth are presented in Table 7.

Table 7. Results of RM ANOVA on Hemisphere Sums (HSums) for three minutes of recorded EEG in Waking, REM and Stage 2 Sleep. *p* values for main effects and interactions are given; trends up to *p*<.10 are indicated.

(Note: abbreviations: ns = not significant;
G = Gender, M = Minute, P = Placement, S = State (W,R,2)

	BANDWIDTH					
EFFECT	Delta	Theta	Alpha	Spindle	Beta	Total
G	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns	ns
P	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S	<.001*	<.002*	<.0001*	<.0001*	<.0001*	<.0006*
MxG	ns	ns	ns	ns	ns	ns
PxG	ns	ns	ns	ns	ns	ns
SxG	<.03*	<.04*	ns	ns	<.02*	<.03*
MxP	<.05	ns	ns	ns	ns	ns
MxPxG	ns	ns	ns	=.05	<.04	ns
MxS	ns	ns	ns	ns	ns	ns
MxSxG	ns	ns	ns	ns	ns	ns
PxS	<.0001*	ns	ns	ns	ns	ns
PxSxG	<.02*	<.02*	<.03*	<.06*	<.10*	<.02*
MxPxS	ns	ns	ns	ns	ns	ns
MxPxSxG	<.02*	ns	ns	ns	ns	ns

*Sphericity test significant (compound symmetry assumption rejected); *p* value reported is for Huynh-Feldt epsilon test.

In contrast to the hemisphere asymmetry analysis, differences between states of consciousness are very striking when both hemispheres are considered as a unit. Once again, gender was not significant as a main effect, but the interaction between State of Consciousness and Gender was significant for delta, theta, beta and total power. In contrast to the HDiffs presented above, in the HSum data differences in electrode placement are highly significant for every bandwidth. The interaction between Placement and State is significant for the delta band, while the three-way interaction between Placement, State and Gender is present in every bandwidth (see Figure 3 for the total power band). It would appear that state of consciousness contributes more to this interaction than does placement, for the PxG interaction is not present in any bandwidth, whereas the SxG interaction is a fairly strong effect.

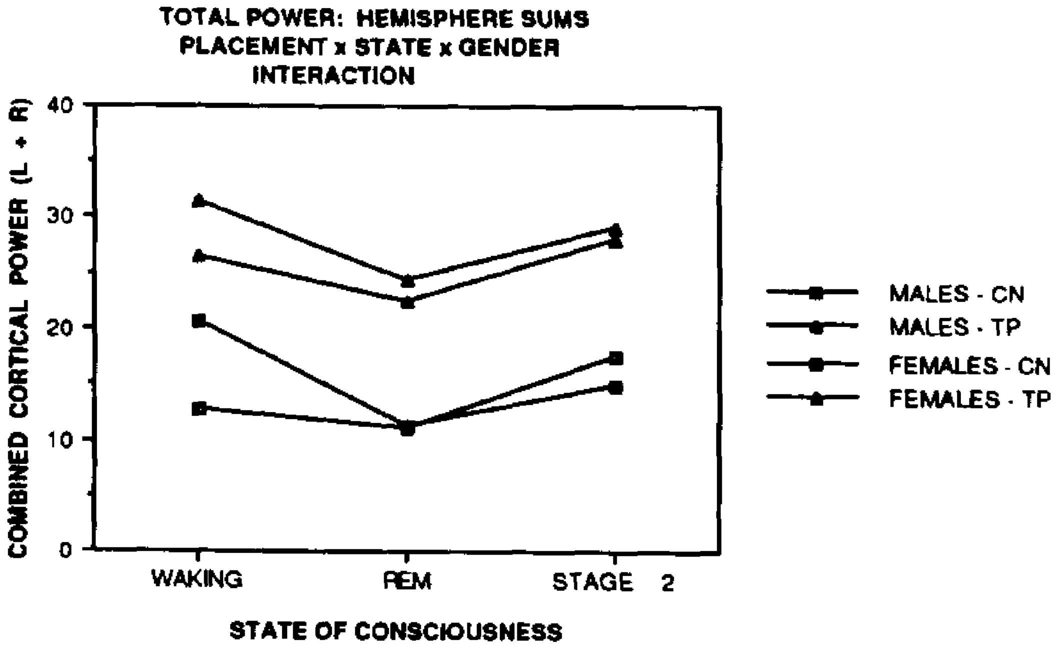

Figure 3. Electrode Placement by State of Consciousness by Gender Interaction for Combined Cortical Power (Hemisphere Sums) in the Total Power Bandwidth (0.5 - 32 Hz).

Table 8. Results of RM ANOVA on Hemisphere Sums (HSums): Time of Night analysis in REM and Stage 2 sleep (averaged over 3 minutes of recorded EEG). *p* values for main effects and interactions are given; trends up to *p*<.10 are indicated.

(Note: abbreviations: ns = not significant;
G = Gender, P = Placement, S = Stage of Sleep, T = Time of Night)

	BANDWIDTH					
	Delta	Theta	Alpha	Spindle	Beta	Total
EFFECT						
G	ns	ns	ns	ns	ns	ns
P	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S	<.0003	<.0001	<.0002	<.0001	<.0003	<.0001
T	<.09	ns	ns	ns	ns	ns
PxG	ns	ns	ns	ns	ns	ns
SxG	ns	ns	ns	ns	ns	ns
TxG	ns	<.06	<.09	<.09	ns	<.09
PxS	ns	ns	ns	ns	ns	ns
PxSxG	ns	ns	ns	ns	ns	ns
PxT	ns	ns	ns	<.07	ns	ns
PxTxG	ns	ns	ns	ns	ns	ns
SxT	ns	ns	ns	ns	<.10	ns
SxTxG	ns	ns	ns	ns	ns	ns
PxSxT	ns	ns	ns	ns	ns	ns
PxSxTxG	<.10	ns	ns	ns	<.06	=.09

To further clarify the differences between states of consciousness, Helmert orthogonal contrasts were performed comparing Waking to both sleep states, and specifically comparing REM to Stage 2. CCP in Waking was significantly different from sleep in every bandwidth (delta: $p<.02$, theta: $p<.04$, alpha: $p<.0007$, spindles: $p<.0001$, beta: $p<.0004$, total power: $p<.06$). REM sleep also differed significantly from Stage 2 sleep at the $p<.0001$ level in every bandwidth.

Time of Night Analysis. Given that the minute by minute fluctuations were not significant, the three minutes sampled were averaged together and entered into the time of night analysis. (Again, waking control data was not included in this analysis, and the sample size was reduced to 24 due to missed awakenings.) The RM ANOVAs evaluating the time of night manipulation are presented in Table 8.

Whereas the HDiffs showed few significant effects of Placement or Stage, power summed across both hemispheres shows highly significant effects for both these variables. The Time of Night manipulation, however, appears to have no effect on CCP (except possibly for a weak trend towards lower amplitudes in the delta band on later awakenings). However, though gender as a main effect is not significant, there are suggestions of a Time x Gender interaction which is weakly present for theta, alpha, spindles and total power (and also for delta, $p<.13$). The predicted Stage x Time interaction is present as a weak trend only in the beta band. There is however a Placement x Time interaction which is marginally significant for spindles, recalling Myslobodsky et al.'s (1976) observation, using unipolar occipital electrodes, of a time of night effect in spindle production. The more anterior placement of electrodes in this study may have reduced the magnitude of this time of night effect.

Summary of EEG Data.

Looking at the sum of both hemispheres (CCP), very significant differences in EEG power were found between waking and the two sleep states, and between REM and Stage 2 sleep specifically. Significant differences between central and temporo-parietal electrodes were found for every bandwidth, despite the fact that these sites are only about an inch and a half apart on the scalp. EEG power in each bandwidth was fairly stable across the three minutes sampled. Gender effects were notably absent, although there were some two and three-way interactions with either stage or placement. Time of night effects in EEG power were generally not present, and the predicted Stage x Time of night interaction was not found.

For the hemisphere differences (HDiffs), the most notable finding is the general lack of significance of any of the predictor variables in any bandwidth. Gender differences were not present. Electrode placement was generally not an important factor. State of consciousness affected the magnitude of the HDs only for the delta band, when comparing Waking to Sleep generally. HDiffs in REM and Stage 2 did not differ significantly in any bandwidth. The Time of Night analysis is also disappointing for its lack of relationship to hemispheric asymmetry, although the several bands showing the predicted Stage x Time interaction do not allow us to discard this variable entirely. There are also some indications of a possible interaction between electrode site, gender and time of night which should be replicated before too much importance is ascribed to them.

The overall conclusions to be drawn are that a) EEG power is fairly stable when averaged over 60-second intervals; b) EEG activity summed over both hemispheres shows marked variations between states of consciousness and sites of measurement, though not with time of night; and c) the differences in EEG power between the hemispheres tend to be very small, and are not meaningfully related to differences in state of consciousness, time of night, or electrode placement; and d) there are no gender differences in EEG power during sleep, or during relaxed wakefulness without any specified cognitive task.

II. Behavioral Measures

Tasks. The raw-score means for each of the six tasks are presented in Table 9. The between-subject variability in performance, as indexed by the standard deviations in Table 10, was generally quite comparable between the waking control and the nocturnal awakenings, regardless of stage or time of night.

Repeated measures analysis of variance tests were computed for each task individually to examine the main effects of stage of sleep, time of night, and gender. The results of these ANOVAs were quite disappointing. No significant differences between REM and Stage 2 awakenings were found for any task. There was no indication that performance differed consistently between early and late awakenings. Males and females did not differ significantly on any task.

The only measure to show significant variation between experimental conditions was the Stanford Sleepiness Scale (SSS). Here, stage of sleep had by far the most powerful effect, with REM awakenings resulting in reports of more sleepiness ($F(1,25)=15.47$, $p=.0006$). The main effect of time of night was not significant in itself, but the interaction of Stage of Sleep with Time of Night suggested greater changes between early and late REM awakenings, while Stage 2 did not vary (Stage x Time: $F(1,25)=3.88$, $p=.06$).

In the attempt to replicate previous claims of differences between REM and NREM for lateralized tasks, the results of the Tactile Recognition task were of particular interest. Unfortunately our data show no sign of any difference between left and right hands in tactile sensitivity as a function of prior stage of sleep. Possible explanations for the discrepant results between this study and the Bertini et al. (1984) experiment will be considered in the Discussion section.

Dream Recall. Since Violani et al. (1983) found that individual differences in dream recall were an important factor in modulating the effect of this lateralized tactile task, we also examined this variable. In the Violani et al. study, low recallers showed more RH activation following REM sleep (i.e. better left hand performance on the tactile task). In the present data, however, no such effect was found. Subjects' self-report of their dream recall frequency was obtained on the initial screening questionnaire. Subjects were divided into groups of High Recallers (*n*=16) and Low Recallers (*n*=15). High Recallers reported remembering a dream at least once a week, or more often. However this individual difference variable did not account for significant variance for either hand, as a main effect or in combination with other variables.

Table 9. Means for all tasks by Condition (Waking, REM, Stage 2) collapsed across early and late awakenings.

VARIABLE	WAKING	REM	STAGE 2
SERIAL NUMBERS	277.2	266.3	274.1
ANAGRAMS	9.4	8.3	8.4
POINT LOC.	3.4	3.7	3.7
FORM COMPLETION	3.3	3.1	2.8
TACTILE (rh)	5.7	5.3	5.3
TACTILE (lh)	5.3	5.4	5.5
LOG RT (rh)	0.167	0.176	0.177
LOG RT (lh)	0.171	0.180	0.176
SSS	2.7	5.3	4.6

Table 10. Standard deviations for all tasks by Condition (Waking, REM, Stage 2) collapsed across early and late awakenings.

VARIABLE	WAKING	REM	STAGE 2
SERIAL NUMBERS	53.7	64.4	67.8
ANAGRAMS	4.8	3.6	3.4
POINT LOC.	1.0	1.1	1.2
FORM COMPLETION	1.7	1.9	1.6
TACTILE (rh)	1.2	1.3	1.6
TACTILE (lh)	1.4	1.2	1.3
LOG RT (rh)	0.02	0.03	0.03
LOG RT (lh)	0.03	0.03	0.03
SSS	0.9	1.2	1.2

Standardized Scores. To further replicate the data analysis used by Lavie and his colleagues, data for each task was converted to z-scores. Standardization of the data in this manner has the advantage of reducing the influence of skew in the distribution of scores, and increasing the validity of parametric statistical tests. Additionally, once the scores have been transformed to a common metric (i.e. standard deviation units) data from one task can be more easily compared with other tasks using different numbers of trials and scoring systems. Z-score transformation was accomplished for each task using the pool of all scores on that task, for all subjects and all awakenings.

The standardized scores thus derived for each task were then summed and averaged to provide a total mean score for all LH tasks (ZLEFT), and similarly for all RH tasks (ZRIGHT). Thus, the summary score ZLEFT includes standardized scores for Anagrams, Serial Numbers, RT-rh and TAC-rh. The summary score for the RH tasks includes Form Completion, Point Localization, RT-lh and TAC-lh.

These summary variables were then combined in various ways to duplicate the variables used in the Cognitive Laterality Battery described by Gordon, Frooman and Lavie (1982). The variables ZLEFT and ZRIGHT were summed to give ZSUM, which corresponds to the CLB's Cognitive Performance Quotient (CPQ), a measure of total performance for both hemispheres. ZDIFF, the difference between ZLEFT and ZRIGHT, corresponds to the Cognitive Laterality Quotient (CLQ), a measure of asymmetry in performance between these groups of lateralized tasks.

The data for these summary z-score variables are given in Table 11. Since the time of night manipulation was not significant in any of the analyses, scores were averaged over Early and Late awakenings for each stage. For these z-score variables, a positive sign indicates performance above the mean of the distribution, while a negative sign indicates below average scoring. Inspection of the LH task means (ZLEFT) show that both REM and Stage 2 performance on these tasks falls very close to the theoretical mean of the distribution (zero). The RH tasks (ZRIGHT) are performed slightly better in REM than in Waking, but REM and NREM scores are identical. For both sets of tasks, deviations from the mean are on the order of less than one tenth of one standard deviation, and as such are more likely to represent sampling error than any meaningful variation in the data.

Next, ZDIFF (ZRIGHT - ZLEFT) was computed as a measure of difference in lateralized performance similar to the CLQ. In this case, positive values indicate higher scores on the RH tasks; negative values are associated with better performance on LH tasks. Lavie's laboratory has found significant differences between REM and NREM using the CLQ variable. As expected, the LH tasks are performed best in the Waking Control. REM gives a very slight advantage to the RH tasks, but in NREM there is no difference between the two sets of tasks. However, differences between the three conditions are not significant. Thus, the present data do not confirm the Technion group's findings of stage-specific performance differences on these lateralized tasks.

If we combine the ZLEFT and ZRIGHT scores into one global measure of performance (ZSUM), we have the index which the CLB calls the Cognitive Performance Quotient, or CPQ. Lavie and his co-workers found that this total performance score did not vary with stage of sleep. We confirm this finding. There is no evidence of any difference in total performance between sleep stages, or between early and late awakenings. More surprisingly, there is no difference even between the waking control session and performance after nocturnal awakenings. This stability in performance at such widely separated points on the presumed underlying circadian curve is truly remarkable.

Table 11. Standardized z-score means for LH (ZLEFT) and RH (ZRIGHT) tasks, their difference (ZDIFF) and their sum (ZSUM).

VARIABLE	WAKING	REM	STAGE 2
ZLEFT	+0.063	-0.032	+0.0002
ZRIGHT	-0.088	+0.038	+0.004
ZDIFF (CLQ)	-0.151	+0.071	+0.004
ZSUM (CPQ)	-0.026	+0.006	+0.005

Reliability Issues

Task Order

Order of individual tasks within the test battery was individually counterbalanced using a Latin Square design, randomized across subjects. This method is in contrast to that used by Lavie and his associates, who administered all tasks for a given hemisphere together, counterbalancing only the order of LH vs. RH tasks. The decision to counterbalance the tasks individually in the present study was taken so that the time course of decay of the putative carry-over effect could be more precisely ascertained. That is, if the carry-over effect is strongest immediately after awakening, then only the first or second task administered would be expected to show significant asymmetry effects. If the carry-over effect remains strong throughout the testing period, order within the task battery should have no effect on performance. A disadvantage with this particular method of task administration is, however, that LH and RH tasks are intermixed and switching rapidly from one type of cognitive processing to another may work against any existing bias for one type of hemispheric processing to be facilitated by a preceding sleep state.

Table 12. Mean z-scores by Stage for Individual Tasks as a function of Order of Administration within the Task Battery.

	TASK ORDER					
TASK	1	2	3	4	5	6
ANAGRAMS						
WAKING	+0.017	+0.594	+0.594	+0.189	+0.284	+0.051
REM	-0.293	-0.116	+0.816	-0.315	-0.067	-0.001
STAGE 2	-0.197	-0.182	-0.009	+0.124	+0.310	+0.097
DIGIT SPAN						
WAKING	+0.588	+0.019	-0.073	-0.331	+0.236	+0.072
REM	-0.208	-0.007	+0.071	-0.341	-0.070	+0.398
STAGE 2	-0.598	-0.089	+0.294	+0.114	+0.369	+0.107
POINT LOCALIZATION						
WAKING	-0.382	-0.419	-0.363	-0.387	+0.040	+0.238
REM	+0.297	+0.098	+0.448	+0.244	-0.462	-0.195
STAGE 2	+0.395	-0.104	+0.196	+0.708	-0.133	-0.231
PICTURE COMPLETION						
WAKING	+0.700	+0.631	-0.040	+0.032	+0.104	-0.087
REM	-0.471	-0.258	+0.204	-0.327	+0.277	+0.679
STAGE 2	-0.071	-0.371	+0.212	-0.286	-0.471	+0.320
TACTILE (RIGHT HAND)						
WAKING	-0.073	-0.263	+0.213	+0.450	+0.153	-0.358
REM	-0.263	+0.054	+0.009	-0.215	-0.263	+0.103
STAGE 2	-0.059	-0.210	-0.157	-0.176	-0.009	-0.176
TACTILE (LEFT HAND)						
WAKING	-0.148	-1.302	-0.407	+0.453	+0.547	+0.152
REM	-0.357	+0.453	+0.131	-0.073	+0.303	+0.048
STAGE 2	+0.561	+0.035	-0.132	-0.025	+0.303	-0.094
REACTION TIME (RIGHT HAND)						
WAKING	-0.048	-0.310	-0.048	-0.134	-0.167	-0.376
REM	-0.088	-0.082	-0.077	-0.222	-0.096	-0.011
STAGE 2	-0.048	-0.036	-0.033	-0.314	+0.060	-0.192
REACTION TIME (LEFT HAND)						
WAKING	-0.119	-0.193	-0.002	-0.115	-0.080	-0.141
REM	-0.128	-0.115	-0.081	-0.123	-0.098	-0.073
STAGE 2	-0.100	-0.053	-0.129	-0.207	-0.078	-0.170

Table 13. Correlations of task z-scores with order of task administration (from 1 to 6) for all conditions combined (Overall) and as a function of state of consciousness.

		STATE		
TASK	OVERALL	WAKING	REM	STAGE 2
ANAGRAMS	+.09	-.09	+.06	+.17
DIGIT SPAN	+.13	-.15	+.12	+.20
POINT LOC	-.08	+.22	-.19	-.15
PICTURE COMPLETION	+.09	-.29^	+.33*	+.05
TACTILE (rh)	-.05	-.02	+.12	+.01
TACTILE (lh)	+.11	+.35*	+.09	-.08
REACTION TIME (rh)	-.07	-.05	+.05	-.14
REACTION TIME (lh)	-.06	+.14	+.07	-.23^

p values:
^ $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

To evaluate the effects of task order within the task battery, mean z-scores for each task were derived as a function of task position within the battery. These mean values are presented as a function of prior state of consciousness in Table 12. Task z-score values were also correlated with order of task administration for each subject on each awakening, and are presented in Table 13. These correlations tend to be very close to zero in all but a few instances, indicating that for most tasks order of administration within the battery was not an important factor in the results. Left-handed tactile discrimination scores improved when the task was administered later in the battery, but only in the waking state. Since a similar trend was not seen for right-handed performance on this task, the correlation may be considered artifactual. The only other task to show a significant correlation with order of administration was Picture Completion. This RH task showed better scores after REM awakenings when the task came late in the battery; this result is contrary to the expectation of stronger RH bias immediately after awakening. Other RH tasks showed no significant relation to task order after either REM or Stage 2 awakenings.

For the two psychomotor tasks, Tactile Discrimination and Choice Reaction Time, left- and right-hand trials were administered sequentially. Order of starting hand was counterbalanced across subjects and awakenings. When all the data is combined across conditions, hand order emerges as a significant factor in scoring. Right-handed RT is shorter when the right hand went first (correlation RTrh and RTrh Order (1 or 2) = +.50, $p<.001$) and similarly the left hand is facilitated when it went first (correlation RTlh and RTlh Order (1 or 2) = +.34, $p<.001$). Left-handed Tactile Discrimination scores were higher when the left hand began the test series (correlation TAClh and TAClh Order (1 or 2) = -.26, $p<.001$). A reverse relationship was seen for the right hand on the Tactile Task, but only after REM sleep (correlation TACrh and TACrh Order (1 or 2) = +.32, $p<.05$). When considered separately by prior state of consciousness, the other tasks showed no relation to hand order. Thus the hand order effect appears mainly in the data considered globally, with 153 observations drawn from all subjects on all trials.

Reliability of Task Performance across Sessions

To obtain a measure of the reliability of subjects' task performance across experimental sessions, the Difference score ZDIFF (computed as ZRIGHT minus ZLEFT) was averaged across the two awakenings per night and correlated between the three experimental sessions: Waking Control, Night 2 and Night 3. The asymmetry score from the Waking Control (WDIFF) correlated well with the Night 3 difference score (r=+.43, p<.02) but less strongly with the asymmetry scores from Night 2 (r=+.23, ns). However, difference scores from Night 2 and Night 3 correlated well with each other (r=+.48, p<.01). The weak relationship between Waking Control difference scores and those from Night 2 may be caused by the longer interval between the Waking Control and Night 2 than between Night 2 and Night 3. (Remember that between the Waking Control session and Night 2 was an intervening adaptation night (Night 1) where mentation reports were solicited for use in another experiment.) Night 3 generally followed only 48 hours after after Night 2 and by then, experimental procedures and task performance were quite routine.

Task Intercorrelations

While each of the tasks used in the present study was selected as a good measure of lateralized cognitive processing (see Appendix 4), it is of interest to know how well the tasks correlate with each other. Ideally, purported measures of LH functioning should correlate highly with each other, and show a lack of relationship with measures of RH functioning. It is also of interest to examine the underlying factor structure of this task battery. Do all the tasks for a given hemisphere represent a unitary mode of cognitive processing; or do the more cognitive tasks (Anagrams, Digit Span, Point Localization and Picture Completion) differ from the more psychomotor tasks (such as Tactile Discrimination and Choice Reaction Time)? These questions were addressed by deriving a correlation matrix for all the tasks with each other, and with the summary scores for each hemisphere (ZLEFT and ZRIGHT). These correlations are presented in Table 14. Since ZLEFT and ZRIGHT did not differ significantly as a function of prior state of consciousness, Table 14 gives the overall correlations for Waking, REM and Stage 2 awakenings combined (*N* = 165 observations). For ease of inspection, the correlations have been divided into three groups: intercorrelations of ANA, DIG, LOC and PIC with ZLEFT and ZRIGHT; intercorrelations of TAC and RT with ZLEFT and ZRIGHT; and the correlations of the first group of tasks with the second.

Table 14 shows that the two cognitive LH tasks, ANA and DIG, correlate significantly with one another, and load highly on ZLEFT, while at the same time they show little, if any, relation to the RH measures LOC, PIC, and ZRIGHT. (The correlation between DIG and LOC (r=-.16, p<.04) is an exception to the above statement.) The two RH tasks LOC and PIC show a weak negative relationship to one another (r=-.14, p<.09) but both load strongly on ZRIGHT. LOC, in addition, shows a negative relationship to ZLEFT.

The correlations for the psychomotor tasks TAC and RT are presented for each hand separately. Left- and right-handed performance of the tactile task show a significant positive relationship, as do right- and left-handed RT scores. The intercorrelation between the two hands is stronger for the RT task than for the TAC measure. For each task, the individual hands load signficantly on ZLEFT and ZRIGHT as predicted by knowledge of the crossed neuroanatomical pathways. The two psychomotor tasks do not however show the expected relationship to each other; in fact for both pairs of variables (TACR and RTR, and TACL and RTL) the correlation is negative rather than positive. This finding indicates that these two psychomotor tasks reflect different processes. Perhaps the sensory input of the tactile discrimination task requires more elaborated processing than that of the RT task; whereas in the RT task the emphasis is on speed of motor output.

The third part of Table 14 presents the intercorrelations between all tasks used, regardless of task type or modality. The Anagrams and Picture Completion tasks show no relationship to the Tactile task, but correlate significantly with RT for both hands. Digit Span performance is not related to either of the two psychomotor tasks. Point Localization correlates only with TACrh; although the correlation is negative, this finding is surprising since it was expected that LOC would correlate instead with TAClh, both being purported measures of RH performance.

Table 14. Correlations between Individual Tasks and with Hemisphere Summary Z-Scores. Correlations are computed for Waking, REM and Stage 2 Sleep combined (*N*=165 observations).

A. LATERALIZED COGNITIVE TASKS

	ANA	DIG	LOC	PIC	ZLEFT	ZRIGHT
ANA	1.00	+.26***	+.03	+.02	+.53***	-.12
DIG		1.00	-.16*	+.12	+.68***	-.05
LOC			1.00	-.14^	-.17*	+.46***
PIC				1.00	+.02	+.43***

B. LATERALIZED PSYCHOMOTOR TASKS

	TACrh	TAClh	RTrh	RTlh	ZLEFT	ZRIGHT
TACrh	1.00	+.25***	-.16*	-.15^	+.52***	-.04
TAClh		1.00	-.24**	-.18*	+.02	+.46***
RTrh			1.00	+.67***	+.27***	+.17*
RTlh				1.00	+.10	+.38***

C. CORRELATIONS BETWEEN COGNITIVE AND PSYCHOMOTOR TASKS

	TACrh	TAClh	RTrh	RTlh
ANA	+.08	+.02	-.28***	-.28***
DIG	+.11	-.002	-.02	-.03
LOC	-.23**	-.07	+.03	+.003
PIC	+.06	+.05	-.16*	-.18*

p values:

^	*p* < .10
*	*p* < .05
**	*p* < .01
***	*p* < .001

In summary, it would appear that the tasks used do not all measure the same types of cognitive processing. As measures of LH function, ANA and DIG correlate well with each other and with ZLEFT. As measures of RH function, LOC and PIC are only weakly related to each other but both load strongly on ZRIGHT. While the performance of left and right hands on TAC and RT correlate with the appropriate hemisphere summary score, the two psychomotor tasks show little relation to each other. The tactile task seems to have little in common with the other four tasks, although RT of both hands is significantly related to ANA and PIC. This lack of strong interrelationship between measures which are all supposedly reflecting performance of a given hemisphere casts doubt on the validity of combining them into one measure such as ZLEFT or ZRIGHT. It would be more appropriate to inspect the results of individual tasks rather than to rely on these combined z-scores for meaningful conclusions.

III. Relationship between EEG and Behavioral Measures

The claim for carry-over effects in performance tasks rests on the assumption that EEG measures recorded during sleep bear some consistent and continuing relationship to performance for some time after awakening. To explore the nature of this relationship, total EEG power (0.5 - 32 Hz) at each electrode placement was correlated with standardized scores on the individual tasks. In addition, for both LH and RH a new EEG variable was constructed which summed power at the CN and the TP site (LEFTTOTL and RIGHTOTL). The difference between these two hemispheric EEG variables (HEMDIFF) and their combined sum (HEMSUM) were correlated with the task variables ZDIFF and ZSUM.

If the assumption of a carry-over effect is valid, significant correlations should be obtained between C3TOTAL and/or TP3TOTAL and ZLEFT task scores; between C4TOTAL and/or TP4TOTAL and ZRIGHT task scores; and between HEMDIFF and ZDIFF, and HEMSUM and ZSUM. In the results presented below, correlations are given separately for each state of consciousness (Waking, REM and Stage 2) as well as for the overall relationship, combining data across states. To allow for the possibility of overlap between the EEG variables, correlations of total power at each electrode location with the others were also evaluated. Since these intercorrelations may affect the interpretation of EEG relationships with performance measures, they will be summarized first.

Table 15 gives the intercorrelations between electrode sites for the combined database and for each condition separately. Correlations between C3TOTAL and C4TOTAL are significant in all states, but are noticeably lower in REM than in Waking or Stage 2. TP3TOTAL and TP4TOTAL are strongly interrelated in all states. C3TOTAL and C4TOTAL bear a strong relationship to both TP sites, but for C4 this relationship weakens considerably in REM sleep. While a simple correlation between EEG power at two electrode placements is not equivalent to a formal coherence analysis, these data may indicate a decrease in EEG coherence both within and between hemispheres during REM sleep. Previous studies provide conflicting data about hemispheric coherence in REM sleep.

Banquet (1983), with five right-handed subjects, reported that coherence values in REM sleep were intermediate between those of Waking, which were highest, and SWS, which were lowest. Barcaro et al. (1986), using 11 subjects, found the opposite relationship, with NREM coherence greater than in REM. Dumermuth and his colleagues originally reported that inter-hemispheric coherence was high in all sleep stages; in their six female subjects REM coherence was equivalent to that in SWS (Dumermuth et al., 1972). Later they replicated the study with six males and found that coherence was highest in SWS, except for the frontal lobes, where the highest coherence values were observed during REM sleep (Dumermuth et al., 1983). The present data seem to be consistent with those studies reporting somewhat lower inter-hemispheric coherence in REM sleep, at least at CN sites, and also may indicate a decrease in intra-hemispheric coherence for the RH.

As expected, the global power variable HEMSUM correlates strongly with total power values of each individual electrode. On the other hand, only the CN sites correlate with the global measure of hemisphere asymmetry (HEMDIFF). The nearly total lack of relationship with HEMDIFF at the TP sites may indicate that they are more synchronized than the CN sites. As noted earlier, the CN placements evidence more hemispheric asymmetry than is observed at the more posterior sites.

Table 15. EEG Total Power (0.5 - 32 Hz): Correlations between electrode site and EEG difference and sum variables, for all conditions combined (Overall) and as a function of state of consciousness.

	EEG VARIABLE					
	C3	C4	TP3	TP4	HEM DIFF	HEM SUM
TASK VARIABLE						
C3						
OVERALL	1.00	+.75***	+.72***	+.72***	-.21**	+.90***
WAKING	1.00	+.86***	+.73***	+.77***	-.49**	+.91***
REM	1.00	+.57***	+.70***	+.64***	-.30*	+.85***
STAGE 2	1.00	+.81***	+.68***	+.70***	+.02	+.91***
C4						
OVERALL		1.00	+.66***	+.70***	+.46***	+.88***
WAKING		1.00	+.79***	+.87***	-.01	+.94***
REM		1.00	+.58***	+.51***	+.59***	+.82***
STAGE 2		1.00	+.55***	+.71***	+.57***	+.88***
TP3						
OVERALL			1.00	+.91***	-.07	+.91***
WAKING			1.00	+.96***	-.24	+.93***
REM			1.00	+.89***	-.02	+.91***
STAGE 2			1.00	+.86***	-.07	+.86***
TP4						
OVERALL				1.00	+.13	+.90***
WAKING				1.00	-.10	+.95***
REM				1.00	+.06	+.84***
STAGE 2				1.00	+.31*	+.90***

p values:
^ *p* < .10
* *p* < .05
** *p* < .01
*** *p* < .001

Table 16. EEG Total Power (0.5 - 32 Hz): Correlations with task z-score hemisphere summary variables by electrode site for all conditions combined (Overall) and as a function of state of consciousness. (Note: Reported p values differ between conditions as a function of different numbers of observations used for the computations. Overall N=146; Waking n=29; REM n=57; Stage 2 n=60).

	EEG VARIABLE					
TASK VARIABLE	C3	C4	TP3	TP4	HEM DIFF	HEM SUM
ZLEFT						
OVERALL	+.10	+.12	+.13	+.16^	+.06	+.14
WAKING	+.02	-.10	+.06	+.06	-.27	-.001
REM	-.02	+.10	+.09	+.09	+.13	+.08
STAGE 2	+.22^	+.20	+.19	+.25^	+.08	+.23^
ZRIGHT						
OVERALL	-.11	-.08	+.03	+.004	+.02	-.05
WAKING	-.41*	-.36*	-.28	-.37*	+.12	-.38*
REM	-.16	-.08	+.05	-.08	-.02	-.07
STAGE 2	+.05	+.03	+.16	+.21	+.03	+.11
ZDIFF						
OVERALL	-.14^	-.13	-.08	-.12	-.04	-.13
WAKING	-.23	-.12	-.20	-.24	+.27	-.20
REM	-.08	-.12	-.04	-.12	-.11	-.10
STAGE 2	-.14	-.14	-.05	-.06	-.04	-.11
ZSUM						
OVERALL	+.005	+.04	+.12	+.13	+.06	+.08
WAKING	-.25	-.32^	-.13	-.19	-.17	-.24
REM	-.12	+.02	+.10	+.02	+.09	+.01
STAGE 2	+.19	+.17	+.24^	+.32*	+.08	+.25^

p values:
^ $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

In the present study, the possibility that the brain state of the prior sleep stage continues to exert an influence on brain functioning after awakening was not measured directly with EEG measures, due to the technical difficulties of recording EEG from an awake and moving subject. (It was feared that if we allowed the subject to lie quietly for say three minutes after awakening in order to record EEG in the transitional state between sleep and waking, that the very carry-over effect we wanted to demonstrate might dissipate before beginning task administration.) However the nature of this possible carry-over effect was explored indirectly by correlating sleep EEG power with the summary z-score variables for LH and RH task performance (ZLEFT and ZRIGHT respectively). These correlations are presented in Table 16, again for the combined database and for the three conditions separately.

It is clear from inspection of Table 16 that sleep EEG recorded from CN and TP sites bears little, if any, relationship to performance of lateralized tasks shortly after awakening. The few significant relationships that are seen are predominantly for the RH in the Waking condition. Central and temporo-parietal EEG power in REM sleep bears zero relationship to cognitive performance after awakening. In Stage 2, both C3 and TP4 power show a slight trend to correlate positively with ZLEFT; no relationship was seen with ZRIGHT.

Asymmetries in task performance scores (ZDIFF) bear no relationship whatsoever to any EEG variable, although the correlations are slightly higher (though still not significant) in the Waking state than in either sleep stage. The global EEG power measure HEMSUM was expected to correlate negatively with total task performance scores (ZSUM) but this relationship was not found. Indeed, there are indications that increased power in Stage 2 actually leads to improved task performance after awakening!

In view of the generally low intercorrelations between the individual tasks included in the ZLEFT and ZRIGHT summary variables, as was discussed in the previous section, it may be more informative to inspect the correlations between EEG power measures and the individual performance tasks. Table 17 presents these correlations for the total power band as a function of electrode position and state of consciousness.

Table 17. EEG Total Power (0.5 - 32 Hz): Correlations with individual task z-scores by electrode site for all conditions combined (Overall) and as a function of state of consciousness. (Note: Reported *p* values differ between conditions as a function of different numbers of observations used for the computations. Overall *N*=146; Waking *n*=29; REM *n*=57; Stage 2 *n*=60).

	EEG VARIABLE			
	C3	C4	TP3	TP4
TASK VARIABLE				
ANAGRAMS				
OVERALL	+.06	+.11	+.11	+.08
WAKING	+.18	+.04	+.12	+.14
REM	-.08	+.06	-.12	+.02
STAGE 2	+.10	+.20	+.04	+.09
DIGIT SPAN				
OVERALL	+.08	+.20*	+.07	+.12
WAKING	+.04	+.03	-.06	-.03
REM	+.005	+.15	+.12	+.10
STAGE 2	+.14	+.28*	+.04	+.15
POINT LOCALIZATION				
OVERALL	-.22**	-.20*	-.04	-.11
WAKING	-.04	-.16	+.06	-.002
REM	-.27*	-.25^	-.10	-.21
STAGE 2	-.25^	-.18	-.01	-.03
PICTURE COMPLETION				
OVERALL	-.006	+.006	-.07	+.04
WAKING	-.36*	-.34^	-.44*	-.41*
REM	+.03	+.16	-.01	+.08
STAGE 2	+.09	+.08	+.006	+.14

p values:
^ $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

Table 17 (continued). EEG Total Power (0.5 - 32 Hz): Correlations with individual task z-scores by electrode site for all conditions combined (Overall) and as a function of state of consciousness. (Note: Reported p values differ between conditions as a function of different numbers of observations used for the computations. Overall N=146; Waking n=29; REM n=57; Stage 2 n=60).

	EEG VARIABLE			
	C3	C4	TP3	TP4
TASK VARIABLE				
TACTILE (right hand)				
OVERALL	+.11	+.04	+.15^	+.19*
WAKING	-.11	-.18	+.12	+.02
REM	+.02	+.03	+.01	+.12
STAGE 2	+.25^	+.10	+.29*	+.32*
TACTILE (left hand)				
OVERALL	+.06	+.12	+.15^	+.16^
WAKING	-.15	-.11	-.0004	-.07
REM	-.06	+.01	+.04	+.03
STAGE 2	+.18	+.23^	+.23^	+.27*
REACTION TIME (right hand)				
OVERALL	-.06	-.12	+.04	-.07
WAKING	-.27	-.23	-.15	-.12
REM	+.01	-.06	+.16	-.05
STAGE 2	-.06	-.16	-.01	-.07
REACTION TIME (left hand)				
OVERALL	-.02	-.09	+.02	-.08
WAKING	-.29	-.18	-.14	-.26
REM	+.04	-.04	+.13	-.03
STAGE 2	+.09	-.08	+.05	-.01

p values:
^ p < .10
* p < .05
** p < .01
*** p < .001

Unfortunately, few tasks show a significant relationship to any EEG site. The LH tasks were expected to correlate positively with RH power at C4 and TP4, and negatively with LH power at C3 and TP3; this general pattern was not seen for Anagrams or Digit Span. For the Digit Span task itself, there is a significant positive correlation at the RH C4 placement in the overall database (r=+.20, which becomes somewhat stronger in Stage 2 (r=+.28). These correlations are not inconsistent with the hypothesis: if an LH task is facilitated after NREM, then it should correlate positively with RH power if there is an asymmetric bias. Nonetheless these correlations of C4 power with Digit Span are not the crucial test of the hypothesis; better evidence would be provided if there had been a negative correlation of Digit Span scores with LH power at C3 or TP3.

Unfortunately, the relationships between EEG power in sleep and post-awakening performance are no clearer when one considers the RH tasks. For the RH task Point Localization (where high scores indicate greater errors in spatial orientation) the overall relationship is negative for both C3 and C4, while at the TP sites there is no relationship at all. The same trend is apparent in REM sleep. Thus lower power (i.e. more cortical activation) at CN sites in <u>both</u> hemispheres during sleep is associated with <u>impaired</u> performance of this RH task in the post-awakening period. This not at all the relationship that was predicted!

For Picture Completion, also a RH task, the overall data set reveals no relationship whatsoever with prior EEG power. Neither is there any effect of sleep EEG on waking performance after REM or Stage 2 arousals. However the strongest correlations of PIC scores with EEG power are seen in the Waking state, where they are uniformly negative at all electrode placements. Thus, for the awake state only, more activation in both hemispheres leads to improved performance on this RH task. In the pilot study (Reinsel, 1985b) this Picture Completion task was the only one to discriminate between REM and Stage 2 awakenings on the basis of task scores. In the present data this result was not confirmed in the performance data; and neither does sleep EEG power predict post-awakening performance of this RH task.

For the Tactile Discrimination Task, using both right and left hands, relationships are strongest after Stage 2 sleep and at TP placements. There is a slight hint of a (nonsignificant) trend towards a positive correlation with the CN electrode contralateral to the hand used for the tactile response, possibly reflecting the involvement of the contralateral sensory-motor cortex.

Finally, Choice Reaction Time, performed with the right or left hand, evidences no relationship to any EEG placement. The expectation was that RT would show a positive correlation to EEG power during the prior sleep stage, especially at electrode sites contralateral to the hand used for the RT response. In other words, shorter RTs would follow from a more activated brain state prior to awakening, and longer RTs would follow from less aroused states (indicated by higher EEG power). These expectations were not borne out. Even the opposite pattern of results reported by Rebert and Mahoney (1978) could not be replicated. These investigators had found signs of increased alpha power associated with shorter RTs. In the present data there is no sign of any relationship between RT and EEG power in the preceding sleep state, whether in the overall database or for any particular experimental condition.

Summary of Sleep EEG/Post-Awakening Task Correlations

The data of the present study do not support the claims for the existence of a carry-over effect of prior sleeping brain state on post-arousal cognitive functioning. Correlations between ZLEFT and LH EEG power are notably absent. Correlations between EEG power and ZRIGHT are found only in the Waking state, and then in the same direction for both hemispheres. Differences in performance between LH and RH tasks (the ZDIFF variable) bear no relationship to EEG asymmetry (except possibly in the Waking state, where r=+.27, ns).

Also damaging to the hypothesis of the carry-over effect is that the combined measure of task performance (ZSUM) is not related to the combined measure of cortical power (HEMSUM), where there was expected to be a significant negative relationship.

In hindsignt it is clear that we should have continued to record EEG through the sleep/wake transition and also during post-awakening task performance. For technical reasons this was not possible. These results might have shown that while there is no prominent hemispheric asymmetry in any sleep state, the appropriate task-specific asymmetries would appear during performance of the lateralized tasks themselves. In the absence of such data we can only say that the lack of stage-specific asymmetry in the sleeping brain is followed by an absence of stage-specific asymmetries in lateralized task performance. Performance of cognitive tasks in the post-awakening period is not influenced by brain state in the prior sleep stage (as measured by EEG total power at CN and TP sites). What relationships emerged in these EEG/task correlations were mainly for the Waking state, where the brain state during EEG recording and during task performance would be expected to be more similar.

In view of the strong intercorrelations between individual CN and TP electrode placements (as shown in Table 15), it might be expected that any relationship between one EEG variable and a given performance variable would also hold true (at least to some degree) for the other EEG variables. This is not generally the case in the present data. Relationships may be found for one electrode but not the others, or bilaterally for one cortical region but not for another. In the few instances of the latter case, these bilateral relationships are generally in the same direction, reflecting the underlying coupling of both cortical areas which is evidenced by the intercorrelations between electrode placements shown in Table 15.

The lack of global relationships between task performance and EEG power measures in the combined database suggests that any residual influence of prior EEG on waking performance is best examined on a stage by stage basis. Notably the trends are stronger for the waking state, where the brain state between EEG recording and task performance is presumably most similar. It is unfortunate that due to the smaller number of observations in the Waking condition (only one data point per subject, as opposed to two in each sleep stage) the smaller sample size does not allow these correlations to reach significance at the .05 level.

Increased power at C4 and TP4 correlates negatively with RH task scores, as might be expected (after all, an activated hemisphere would surely do better on lateralized tasks). But at the same time, RH task performance declines as power increases in the LH. In the laterality literature, it is often assumed that an increase in power in the LH during a lateralized task indicates a simultaneous decrease in power in the RH ("activation" of the RH). In the present study, the significant positive relationships betwen bilateral homologous recording sites shown in Table 15 point to a relatively tight coupling of the hemispheres, such that when one increases in power, so does the other. Conversely, if one hemisphere were to become activated, the other would also show a decrease in power. Since EEG was not recorded during the performance of the tasks themselves, EEG asymmetries specific to the tasks being performed are not observed. Instead, in these normal subjects with an intact corpus callosum, the hemispheres covary closely, responding to the rising and falling tides of cortical arousal.

DISCUSSION

Overall, the results of this study show a disappointing failure to confirm the five hypotheses set forth in the Introduction. Neither task performance nor cortical EEG activity show the predicted stage-specific asymmetries. These results seriously question the assumptions of RH dominance in REM, and by extension, RH primacy in the dream production process. The failure to find stage differences in task performance gives no evidence for the existence of a lateralized stage-specific carry-over effect.

Findings relating to each of the five hypotheses will be briefly summarized below.

Hypothesis 1. The crucial variation in cerebral laterality as a function of stage of sleep was not demonstrated. Task performance was close to the theoretical mean of zero after all awakenings. Hemisphere differences (HDs) were no different in REM than in Stage 2; and in fact, both showed a predominant LH bias in all conditions of sleep and waking.

Hypothesis 2. No support was found for the predicted change in EEG or task performance as a function of time of night. However, weak two or three way interactions of time of night with placement, stage and gender emerged for both hemisphere differences and hemisphere sums.

Hypothesis 3. The GILD hypothesis (Cohen, 1977) was tested and disconfirmed for both EEG and tasks. A time of night effect was not found for the hemisphere differences. Although there was a prevailing LH bias in both REM and Stage 2, it apparently did not vary between early and late awakenings. For the tasks, the z-score summary variable ZLEFT showed no variation between early and late awakenings.

Hypothesis 4. The predicted stage of sleep by time of night interaction was indeed found for cerebral asymmetry (as measured by the HDs) in the delta and beta bands, with marginally significant trends for spindles and total power. However, neither combined cortical power (hemisphere sums) nor the cognitive task battery showed such effects.

Hypothesis 5. No evidence whatsoever was found for gender differences in cerebral asymmetry or lateralized task performance. However, when considering combined cortical power across both hemispheres, a significant stage by gender interaction appears for EEG delta, theta, beta and total power. Time of night x gender interactions are weaker trends in the theta, alpha, spindle and total power bands. The interaction of electrode site with gender and stage of sleep is a strong effect in all bands. Thus gender appears to be a moderator variable, apparent in the global distribution of cortical activity, and significant only in combination with other effects. The complexity of these interactions would invite further study; but also discourage facile interpretations. The discrepancies in the literature on task-related gender differences or male/female differences in EEG measures of laterality are only to be expected when such a variety of other (usually uncontrolled) sources of variance are present in the measurements.

In summary, the results reported in this study do not support the claims of hemisphere asymmetry in sleep and the existence of carry-over effects in performance. Total EEG power during sleep had very little success in predicting performance in the post-awakening period. Several conceptual and methodological issues are relevant to the interpretation of the present findings. These issues will be reviewed in the same order as in the previous section, i.e. first EEG, then issues raised by the behavioral cognitive tasks, then the questions about the interrelation between the cortical electroencephalogram and psychological performance behavior.

EEG Issues

State Differences

For all bandwidths, Waking was found to differ significantly from the combined mean of both stages of sleep. Within sleep, REM was significantly different from Stage 2 on all combined power measures and on none of the hemisphere difference measures.

It has generally been assumed that REM, as a state of sleep, should have more overall EEG power than Waking, due to the predominance of low frequency, high voltage activity in sleep. This assumption is not supported by the present study. These data show Waking power to be considerably higher than in REM sleep, due primarily to the greater power in the alpha, spindle and beta bands. REM had low power in the higher bandwidths, where we expected to see signs of increased activation as compared to NREM sleep.

Itil (1970) found the most striking characteristic of REM sleep to be slow wave activity with superimposed fast activity (>40 Hz). In contrast, Buchsbaum et al. (1982) found EEG power above 30 Hz to be minimal. In the bandwidth from 16-32 Hz, my data show beta power ranking highest in Waking and least in REM. The one study to have compared phasic REM (with eye movements) to tonic segments found no difference in spectral characteristics (Dumermuth, Walz, Scollo-Lavizarri, and Kleiner, 1972).

Hemisphere Asymmetry

Confirming the findings of previous studies (Ehrlichman et al., 1985; Gaillard et al., 1984; Moffitt et al., 1982; Pivik et al., 1982; Rosekind et al., 1979;

Violani et al., 1984) the magnitude of hemisphere differences were found to be quite small, though quite variable (especially at CN sites). Only for the delta band are Waking HDs greater than sleep, with the difference maximal at CN sites; the other bands do not differ in hemisphere balance between states. The orthogonal contrasts between REM and NREM show that hemisphere differences are not present.

Contrary to the original claim of RH dominance in REM sleep made by Goldstein et al. (1972), the present data show a consistent LH activation in all bandwidths and in both stages of sleep, as well as in Waking. Pilot data from ten subjects (Reinsel, 1985b) also showed LH activation in both stages of sleep. These findings disagree with Murri et al. (1982), even though the measure used here (Log L - Log R) is essentially equivalent to the ratio R/L used in their study.

The Concept of Activation as Reflected in the Scalp EEG

Increased EEG activation is generally defined as a decrease in low frequencies and an increase in high frequencies. However, the same interpretations of EEG activity do not necessarily hold across states. As Johnson (1970) has convincingly argued, the definition of relatively greater or less activation must be expressed for each individual state. For instance, in Waking, increased alpha is considered to be a sign of decreased attention and alertness; whereas in sleep, increased alpha signals a movement toward a more highly aroused and alert state of consciousness.

It is argued here that in the case of a band like beta, where power is generally very low, more power in a given hemispehre is actually indicative of greater activation in that same hemisphere, rather than on the contralateral side, as in the case of alpha or delta. In the cases of negative (fractional) CCP values for LH spindles and beta in REM, the larger positive values in the RH surely mean more high-level cognitive activity in the RH which may possibly be associated with dreaming mentation.

Time of Night

The failure of the predicted time of night effect to emerge in the data is surprising in view of the well-established circadian rhythms in both cognitive and motor performance in human subjects (Colquhoun, 1981; Monk et al., 1983; Moore-Ede, Sulzman & Fuller, 1982; Webb, 1982). Under conditions of sleep deprivation (Johnson, 1982; Naitoh, 1976) these rhythms have been observed to show depressed performance in nocturnal hours when subjects would normally be asleep, and improved performance in diurnal period when Ss would normally be awake and active; even though sleep deprivation had by then gone on for a longer total duration. In such studies, the effect of the underlying physiological rhythm is confounded with sleep deprivation. In this study, where sleep was disturbed as little as possible apart from the requirements of awakening Ss to get performance measures, the influence of the time of night manipulation is not visible in the data.

One possible methodological reason for the lack of a time of night effect is that there were no true "early" awakenings. Perhaps both awakening conditions should be considered "late" inasmuch as they did not sample the first REM cycle, and there were few in the first three hours of sleep. Even early awakenings were 3-5 hrs after sleep onset, and late awaks 5-7 hrs. Alternatively, in the absence of temperature data on these subjects, it is difficult to evaluate the placement of the awakenings on the underlying circadian curve. It is not clear where the turnaround point (trough) would fall in the nocturnal temperature rhythm. One might conjecture that the absence of a time of night effect in performance is due to the possible positioning of the awakenings at equivalent levels on the descending and ascending arms of the circadian oscillator. (It was not considered worthwhile to attempt to collect temperature data in this study, since two data points per night over 2 nights are not sufficient to detect a circadian periodicity.)

The failure to find differences in hemisphere asymmetry between early and late awakenings is also a crushing blow to the Gradual Increase in Left Dominance (GILD) hypothesis proposed by Cohen (1977), which would have predicted more LH dominance on late awakenings. Other EEG studies by Rosekind, Coates and Zarcone (1979), Violani, DiGenarro and Capogna (1984) and Armitage, Hoffmann, Moffitt and Shearer (1985) also disconfirm the GILD hypothesis.

Electrode Placement

The finding of consistently greater amplitude at TP sites is not surprising since posterior placements usually show higher amplitude. The lesser variability at TP sites as compared to CN electrodes is notable; the combination of higher amplitude and decreased variability is a characteristic of synchronized EEG activity. Overall coherence has been found to be highest in occipital and parietal regions (Dumermuth et al., 1983). One might speculate that the posterior cortex is more subject to the synchronizing influence of subcortical structures (e.g. the thalamus, via nonspecific thalamocortical projections) than are frontal regions, which are more variable in their activity.

On the other hand, the finding of greater HDs at CN sites conflicts with the report of Ehrlichman & Weiner (1979) that the largest asymmetries were found at TP3 & TP4. There is considerable evidence that involvement in specific tasks may increase asymmetry at particular scalp locations. The use of covert imagery tasks involving affect, visual imagery, and verbal or spatial abilities, may be responsible for the TP asymmetries observed by Ehrlichman and Weiner (1979).

The importance of TP sites in detecting asymmetry may be due to the neuroanatomical substrate. Below the TP positions lies the angular gyrus region of cortex, at the point of convergence of the temporal, parietal and occipital lobes (TPO junction). Greenberg and Farah (1986) have found the TPO junction of both hemispheres to be particularly implicated in dream generation and recall in brain damaged patients.

The lack of hemisphere differences in the present study may be due to the lack of control over cognitive variables during sleep EEG recording. Even in the Waking control condition the subjects were in relaxed wakefulness and not performing any specific task. Since mentation reports were not collected in the present study this issue cannot be addressed further.

Stationarity of the EEG

The use of parametric statistical analyses on EEG measures presumes that the underlying distributions are normal. (i.e. follow a Gaussian distribution). The issue of whether or not the EEG is "stationary" refers to whether it can be considered a fundamentally random process across time. If it is not random, then averaging over epochs of varying lengths would significiantly obscure meaningful fluctuations in neural activity. Elul (1969) took amplitudes of successive two second epochs of EEG activity from one normal adult and used a chi-squared goodness of fit function to evaluate the probability that each sample was drawn from a Gaussian distribution. With the subject awake, relaxed and cognitively "idle", the distribution of EEG amplitudes was effectively random. When the subject was alerted or during performance of a mental arithmetic task, there was a sharp decrease in the Gaussian activity; more than twice as many samples of EEG activity, up to 70%, were determined to violate the Gaussian assumption under these conditions.

Cohen and Sances (1977) used a nonparametric sign test to test the randomness of digitized EEG samples from 104 normal individuals. Recording from bipolar temporal electrodes, they used both mean amplitude and average half-period (interval between successive baseline crossings) to evaluate the stationarity (or randomness) of the scalp EEG. They conclude that, on the basis of the mean amplitude data, the EEG may be considered to be a stationary random process for epoch lengths up to 24 seconds. When considering the half-period measures, stationarity extends only up to 12 second epochs. For epochs of 64 seconds in length, the null hypothesis of randomness was rejected in 35% of the cases based on mean amplitudes and in 60% of the samples based on half-period measures.

Cohen and Sances (1977) suggest that in patients with neurological damage, stationarity would be even greater and over longer intervals due to the diffuse synchronised slow activity characteristically seen with brain damage. On a related issue, Berkhout and Walter (1968) found that the temporal stability of EEG segments (as measured by the standard deviations of normalized power spectra) from 47 normal males was a significant element in the discriminability of EEG samples from different individuals.

The issue of temporal stability within individuals was empirically examined by Johnson, Lubin, Naitoh, Nute and Austin (1969). For each of their thirteen subjects, they compared two one-minute segments separated by over 60 seconds. "The average correlations for the 1 min (sic) periods were all highly significant and indicate considerable stability" (p. 366) For five subjects, the correlation between power spectra of two one-minute segments separated by between 6-194 minutes (mean 80 minutes) was evaluated. The average correlations between REM and Stage 2 were above .90 and indicate considerable spectral stability over time. These results lend confirmation to the reliability and stability over time of repeated measurements of EEG activity from the same individual, which form much of the data base of the present study.

Comments Relating to Individual EEG Bandwidths

Delta. In their study of daytime naps in four individuals, Buchsbaum et al. (1982) report low delta power in Waking and REM, with power highest at Cz and lowest over temporal cortex. These findings are not confirmed by the present study. Delta power is nearly as high in Waking as in REM or Stage 2, and is slightly higher at the TP placement than at CN. The different results perhaps reflect the differences in depth of sleep between daytime naps and nocturnal sleep.

The possibility that eye movement artifact may contribute to the high delta values in Waking is considered unlikely. First, the electrodes were not positioned at frontal or pre-frontal sites, which are the most vulnerable to this kind of artifact, but rather were at more posterior placements. The bandwidth analysis eliminated 0-0.5 Hz, which is the source of much DC shift artifact. Movement artifact was further controlled by careful visual screening of the EEG samples while recording, and was supplemented by computer artifact rejection during the Fast Fourier Transform process.

Theta. In the study of daytime napping by Buchsbaum et al. (1982), theta was the only band which showed no variation with sleep stage or topography. In the current study, CCP in the theta band varied significantly between CN and TP placements and discriminated REM from Stage 2, as well as Waking from the combined sleep stages.

In the sleep literature there are few studies of the psychological significance of theta activity. Hayashi et al. (1983) presented a paper at the Bologna International Congress of Sleep Research in Bologna, Italy showing that frontal midline theta was more frequent in REM than in Waking or NREM. In their fifteen subjects, theta correlated negatively with dream recall; when present, theta was associated with hypnagogic images. Lehman, Lange, Meier, and Dumermuth (1982) also reported significant differences in 6-8 Hz power between REM epochs with and without subsequent dream recall.

In his valuable review article, Schachter (1977) summarizes the conflicting findings about the role of theta activity as follows:

> "On the psychological side, the literature indicates that at least two grossly different processes are related to EEG theta activity. In hypnagogic and sleep deprivation states (and to some extent the REM state), theta activity was seen to accompany a generally low level of pre-stimulus alertness which results in impaired processing of various kinds of information. In studies of problem-solving and perceptual processing, theta was seen to accompany relatively active and efficient processing, which was discussed in terms of selective and intensive components of attention. ... It is not yet known whether the two 'classes' of psychological events related to theta activity are essentially different processes, or whether they are different aspects of the same process ... "
>
> (Schachter, 1977, p. 74)

Alpha. Johnson, Lubin, Naitoh, Nute and Austin (1969) report a correlation of +.75 between waking and REM alpha intensity. In their study of 13 high and low alpha subjects, these authors found that the two groups were sharply differentiated in Waking, but became more similar as they progressed through the stages of NREM sleep. High alpha subjects showed a marked change in EEG with sleep onset and had a low correlation between alpha power in Waking and in Stage 1 sleep; the reverse was true for the low alpha group.

Dumermuth Walz, Scollo-Lavizzari and Kleiner (1972) reported high bilateral coherence during REM for all frequencies; a followup study found high REM coherence for all frequencies except alpha and spindles (Dumermuth, Lange, Lehmann, Meier, Dinkelmann and Molinari, 1983). Within REM itself, coherence was maximal over frontal cortex. Dumermuth et al. (1983) also comment on the "remarkably stage-independent" spectral power levels of alpha in parietal and occipital areas.

Synchronized EEG activity is defined as waveforms of similar amplitude, frequency and phase in different regions of the cortex. Upon stimulation the higher amplitude synchronized activity is replaced by desynchronized (low voltage fast) activity. In waking this situation, termed "alpha blocking", is a hallmark of the orienting response. In sleep, however, even a much more intense stimulus produces neither alpha blocking nor alpha enhancement. Therefore, as Johnson (1970) puts it, "... the REM state with alpha appears to have different response characteristics which are not predictable from other states with similar alpha activity." (p. 503)

Spindles. Several studies using power spectral analysis have reported finding spindle activity in all stages of sleep, including REM (Dumermuth et al., 1972, 1983; Johnson et al., 1969).

This study failed to find a time of night effect in the spindle band, in spite of previous reports of differential spindle production in the first vs. the second half of the night (Goetz et al., 1983; Myslobodsky et al., 1976). Additionally, a RH advantage in spindle production had been reported by Myslobodsky et al. (1976), particularly in the first third of the night. Such an asymmetry was not found in the present data. Differences in methodology may be responsible; simply counting the number of spindles per epoch may well give different results than a Fast Fourier Transform, which averages frequencies over relatively long time periods (in this case 60 seconds).

Beta. In Waking, high frequency EEG activity is associated with higher levels of cognitive performance. As expected, the current study finds very low levels of beta power overall. The ranking of Waking > Stage 2 > REM confirms the findings of Buchsbaum et al. (1972) and

Dumermuth et al. (1983). Previously Dumermuth et al. (1972) had reported a negative correlation between beta activity and depth of sleep.

The fact that beta power was lowest in REM is contrary to the assumption that beta is correlated with the production of dreaming mentation. The fractional beta power in the LH (indicated by the negative mean in Table 6 contrasts with the much greater beta power in the RH. Again this brings up the question of the definition of hemispheric differences in activation. When overall power levels for beta are so low, higher power means *more* activation, (not less, as would be the case for delta and alpha activity).

It is interesting to note that in their use of parietal EEG to discriminate waking and the five stages of sleep, Lubin, Johnson and Austin (1969) observed that the beta band made no contribution to the classification of any sleep stage, nor could it differentiate between selected pairs of stages in their thirteen subjects. In contrast, in the present findings, while there was no asymmetry between stages, beta power significantly discriminated between Waking and both sleep stages in the measure of global power (CCP).

Behavioral Measures

The failure to find stage-specific fluctuation in the performance of the lateralized cognitive and psychomotor tasks employed in the current study does not support the conclusions of five other behavioral studies (Bertini et al., 1984; Gordon et al., 1982; Lavie and Tzinschinsky, 1984; Lavie et al., 1984; Violani et al., 1983). While this failure to replicate does not invalidate the previous investigations, the large sample size in this study argues that if there is a relationship, it should have been detected.

<u>Statistical Power.</u> According to the power analysis (Cohen & Cohen, 1975) an N of 30 gives an 80% probability of detection of a moderately strong effect (for example, one with an effect size of .5). An effect size of this magnitude is indicated by the significant differences in task performance found between sleep stages by Gordon et al. (1982), Lavie et al. (1984), and Bertini et al. (1984). On the other hand, if the effect size is assumed to be much smaller (for instance, .2) a sample size of 196 subjects would be required to give an 80% detection probability with the standard significance level of alpha=.05.

Thus, the failure to find differences in task performance between REM and NREM awakenings indicates that the lateralized cognitive effect, if present, is too weak to be considered either reliable or robust.

The present failure to replicate increases the caution with which we must view the assumption of RH dominance in REM sleep, and the persistence of this asymmetry as lateralized performance carry-over effects. In an attempt to account for these conflicting results, several types of procedural and statistical differences between these studies and the present work will be considered.

<u>Testing Conditions.</u> The procedures in this study were chosen to be as similar as possible to those of the other studies: only two awakenings per night, testing durations of similar lengths, etc. Wherever possible, the performance tasks used were identical to those used in the previous studies; if they differed (e.g. *Verbal Fluency vs. Anagrams), the differences were not felt to be substantial. Care was taken in selecting subjects to insure that they were right-handed, and normal sleepers, free from excessive use of caffeine, drugs or alcohol.

<u>Trial Duration and Response Modality.</u> A methodological difference also exists in the procedures used on the tactile task. Subjects in this study had 15 seconds to perform each trial, and during this time the standard as well as the comparison stimuli were available for palpation. In the Bertini et al. (1984) study, though total trial duration was the same, subjects had only seven seconds for tactile palpation of the stimulus, the rest of the trial being given to

response selection. A comparable increase in the haptic exploration time for the standard stimulus from 4 to 16 seconds has been shown by Davidson, Abbott and Gershenfeld (1974) to significantly increase accuracy of response selection. A further difference in the tactile procedure involved response modality; the verbal response used here may be less sensitive to hemispheric asymmetries than the manual pointing response used in the original study (Gardner et al., 1977; Milner and Lines, 1982).

Memory Load. Violani (personal communication, December, 1986) has suggested that the minor difference in tactile task instructions adds a memory dimension to the lateralized processing of the tactile information. Since, in the Bertini et al. (1982) study, subjects were not allowed to go back to the standard stimulus to verify the similarity, they had to maintain a memory representation of the test stimulus while comparing it with the three distractor items. Such memory loads were not imposed in the present work. The ability to recheck the original stimulus while comparing it with the distractor items may have raised accuracy levels to the point where minor carry-over effects were masked.

Certain studies show that laterality effects are most clearly seen when a memory load is imposed on the task (Dee and Fontenot, 1973; Jason, 1983; Oscar-Berman, Rehbein, Porfert and Goodglass, 1978; Young and

Ratcliff, 1983). This hypothesis is also relevant to Lavie's studies, since the two tasks in the CLB that showed the greatest asymmetries with sleep stage both involved a memory load (Point Localization for the RH and nonverbal serial recall for the LH). This interpretation is not supported by the results from the *Serial Numbers (Digit Span) task in the present study. Digit Span is the prototypical short-term memory task, yet the data showed no significant differences between sleep stages. Further, Violani (personal communication, July, 1987) has also suggested that the memory factor only becomes relevant when task stimuli are presented to the subject in a lateralized fashion - which was not done in this or the Lavie et al. studies.

Data Transformation. Other variations in method involve the statistical treatment of the data. In the CLB studies the data were standardized by conversion to z-scores on the basis of normative responses from large numbers of normal individuals. In other words, they derived waking norms from a very large number of adult controls on these same tasks, and then used the waking norms to score the sleep data.

The present data were standardized by computing z-scores from the pool of all available data for each task. This method is preferable to the use of a normative data base collected under other (waking) conditions, inasmuch as the distribution of post-sleep scores may lie outside the range of the waking scores. If waking and post-sleep performance may lie on different portions of the distribution, reference to the waking mean and standard deviation might yield a biased and truncated distribution for the sleep scores. Using the full range of behavioral scores, obtained across states, to generate the normal distribution seems to introduce less possible distortion into the data. In hindsight, this concern was not necessary, since the REM and Stage 2 data fell very close to the waking mean on most tasks.

General Comments

<u>The Appropriate Baseline for Comparison.</u> A crucial issue in the study of psychophysiological variation across states concerns the choice of control condition against which to evaluate experimental findings. Few studies in the past have used a Waking Control condition; thus conclusions about relative hemispheric dominance between sleep states are limited in their generality.

Variations in statistical treatment of the data can also change the basis of comparison between studies from absolute power measures (as in the present experiment) to relative deviations from a grand mean, as was used in the influential early report by Goldstein, Stoltzfus and Gardocki (1972). Using integrated amplitude measures of EEG (bandwidth unspecified), they encountered problems of subject variability and small variations in amplifier calibration between nights and subjects. Rather than re-recording the data, they used a statistical transformation: the grand mean for the entire night was calculated, then individual epochs were expressed as deviations from this overall mean. On balance, the values of the R/L ratio in REM showed higher amplitudes in the LH while NREM showed lower amplitudes, and thus more activation, in the LH.

Goldstein (1980) later noted, using data from a waking individual, that if means are derived for each condition (REM, 2, waking) separately, results may fail to show the lateralized shifts which are apparent when computed with deviations from the night's grand mean for all stages. In attempting to replicate Goldstein's work, Murri et al. (1982) used absolute power values in the R/L ratio on an epoch by epoch basis. In contrast to Goldstein et al., Murri and his associates found a RH activation for all stages of sleep. They note that if they had used Goldstein's method of relative deviations, the data would have shown lateralized shifts between REM and NREM. Thus the baseline for comparison of REM/NREM shifts in cerebral dominance assumes a critical importance in determining the nature and interpretation of the results.

Subject Variation

Entirely apart from questions of procedural variations and statistical treatment of the data, variability among subjects poses problems for interpretations of laterality in performance. Important sources of variability include gender and handedness.

There were no differences between right-handed males and females in this study on either the EEG or performance measures, which agrees with the finding of Lavie, Metanya and Yehuda (1984). However, these results conflict with the conclusions of Trotman and Hammond (1979), McGlone (1980) and Bryden (1982) that males are more lateralized than females for verbal and spatial processes. Similarly, Beaumont, Hayes and Rugg (1978) found that females showed greater coherence (i.e. less asymmetry) between hemispheres than did males. It must however be recognized that the literature on gender differences in EEG and performance is inconsistent; such differences appear most often in task by hemisphere interactions which are very dependent on particular stimulus parameters and methodological conditions (Bryden, 1982; McGlone, 1980). In the present study gender differences appeared in the EEG measures in interaction with the electrode placement and time of night manipulation (for the HDs) and in interaction with electrode placement and state of consciousness (for the CCP variables). It appears then that whether or not gender differences are found in the EEG depends largely on which cortical regions are studied and under what physiological conditions.

Left-handed subjects were not assessed in the current study, though 3 right-handed individuals had a left-handed relative in their immediate family. Performance data from these subjects, who seemed to be LH dominant in waking and both sleep stages, was not entirely consistent with the pattern from the majority of other subjects. Similarly, Murri et al. (1982) report on one subject with two left-handed relatives: this subject had LH activation throughout the night. In contrast, the one truly left-handed subject they described had predominant RH activation in all sleep stages, similar to the right-handed subjects. It is worth noting that Davidson et al. (1980), in their study of 12 right-handed subjects with familial sinistrality (left-handed relatives), found <u>greater</u> EEG asymmetries at parietal electrodes induced by lateralized task demands in these individuals than in subjects with no left-handed relatives.

The original report of Gordon, Frooman and Lavie (1982) on stage-specific carry-over effects gives evidence of fairly large individual differences in prevailing patterns of interhemispheric relationships. A careful reading of the Gordon et al. paper tempers the initial impression of an RH advantage after REM and a LH advantage after NREM. In this study, REM awakenings did not, on the average, result in a performance bias for either hemisphere. The difference between the sleep stages is contributed entirely by the NREM awakenings, which lead to a significant advantage for LH tasks. However, there is considerable variability among individuals. In the 12 subjects studied, a variety of patterns of cerebral dominance were shown. Judging by the CLB task performance, 4 subjects were RH dominant in both stages, but less so after NREM. Another 4 subjects were LH dominant in both REM and NREM, but more so after NREM. Only 3 subjects actually showed LH dominance after NREM and RH dominance after REM, and these asymmetries were of quite small magnitude.

Conclusion

It should be clear from the above discussion that a reassessment of the nature of cerebral dominance during sleep is in order. While shifts in cerebral asymmetry may occur between sleep states and wakefulness, especially when coupled with performance of cognitive tasks, it is not clear that there are any consistent differences in lateralization between REM and NREM sleep. This being so, the present failure to document carry-over effects lateralized by prior sleep stage is not too surprising. The two studies which have recorded

EEG continuously across the state transition do not provide convincing evidence that such lateralized carry-over effects persist in the brainwaves for any appreciable time after awakening. Thus, if the carry-over effects are not present in the EEG, how then can we expect to find them in post-awakening behavioral measures?

In summary, in a careful attempt to replicate two previous bodies of research, with a larger sample size and nearly identical procedures, we have failed to demonstrate the performance asymmetries that have been previously reported. One might conclude therefore that these effects are not as robust and long-lasting as has been previously claimed. Secondly, we must bear in mind that apparently minor variations in task instructions and experimental procedures may either obscure behavioral effects, or perhaps even induce effects which are not normally present.

The lesson to be learned here is that the time has come to reevaluate our current assumptions about cerebral hemispheric asymmetries in visual imagery and dreaming. Recently evidence has accumulated to suggest that the LH may play a larger role in these activities than previously suspected (Antrobus, 1984, 1987; Greenberg and Farah, 1986). Notions of laterality derived from studies of split brain patients (see, for example, Kinsbourne and Smith, 1974; Sperry, 1982) may not be entirely applicable to a neurologically normal population. (Patients who undergo callosal section for intractable epilepsy may have unusual brain organization even prior to split-brain surgery; afterwards, the cut callosal fibers do not allow the kind of hemispheric interaction that would normally occur in the intact brain.) Obviously, in the normal individual, both cerebral hemispheres are functioning interactively at all times and contribute jointly to perceptual and mental experience.

Allen (1983) has analysed the variety of ways the cerebral hemispheres might interact. Unilateral models assert that a given type of processing can be accomplished only by the preferred hemisphere. Bilateral models, in contrast, posit an interaction between both hemispheres. Depending on the type of information processing task, interaction may be positive (facilitatory) or negative (inhibitory). On the other hand, allocation models suggest that both hemispheres are capable of performing the task, but that normally only one does so at a time. Thus, task processing may be allocated differentially to one hemisphere or the other, either at some relatively early stage in the process (an input model) or near the end of it (an output model). A further possibility is that of switching between the hemispheres at various stages during task performance, with the contributions from both hemispheres being integrated at some higher level of processing. If such a complex switching is advocated, one must consider difficult questions such as, what is the nature of the control mechanism that governs switching? Under what circumstances does switching occur? And how is this alternation of control between the hemispheres coordinated? So far, these questions remain unanswered, although several recent studies have addressed these issues. (See, for example, LeDoux, 1983; Liederman, Merola and Martinez, 1985; Sergent, 1982; Wyke, 1982).

One way to approach these questions might be to focus on the degree of intercorrelation or coherence between brain regions, rather than on their differences. Shaw, O'Connor and Ongley (1978) have proposed that measures of EEG coherence within and between hemispheres can help to illuminate the functional relations between brain states and behavior. Several studies have assessed interhemispheric coherence during sleep (Banquet, 1983; Barcaro, Denoth, Murri, Navona & Stefanini, 1986; Dumermuth et al., 1972, 1983). Unfortunately, those who might hope for clear and consistent findings will be disappointed. Results of these studies tend to be somewhat contradictory, with sleep stages varying in coherence depending on the brain region or EEG bandwidth considered. This issue remains open for future investigation.

In their report on interhemispheric EEG synchrony during and after sleep, Armitage, Hoffman and Moffitt (1988) suggest that it is not the degree of asymmetry after awakening which determines aspects of dream reporting and performance , but rather the degree to which both hemispheres are in synchrony. Extreme imbalances between the hemispheres may be an abnormal condition, whereas balance and synchronized functioning may be characteristic of the most efficient information processing. In the present study, the cerebral hemispheres showed no significant hemisphere differences between REM and Stage 2 sleep, and in the Waking state asymmetry was notably different from sleep only for the delta band. HDs in REM in particular tended to be very small, indicating a condition of increased equilibrium between the hemispheres. Thus, a focus on cerebral asymmetry as a determinant of performance may in fact be missing the most important and interesting aspects of interaction and cooperation between the cerebral hemispheres.

APPENDIX ONE

Review of Methodological Aspects and Findings of Selected Studies in the Area of EEG Asymmetry during Sleep
(Studies are grouped by type of method used)

STUDY	SAMPLE SIZE	SLEEP STAGE	ELECTRODE PLACEMENT	METHOD	ASYMMETRY RATIO	EPOCH	BAND	FINDINGS
Goldstein, Stoltzfus & Gardocki (1972)	7 rh M 5 rabbits 4 cats	R N	P3,P4/A1,2	Integrated Ampl	L/R	2 mins	?	RH > in REM
Rosekind, Coates & Zarcone (1979) ●	8 adults	W,R,2	?	Integrated Ampl	L-R/L+R	?	?	RH > in R than W. No diff R vs. 2. No time of night effect
Herman, Roffwarg & Hirshkowitz (1981) ●	?	W, R	T,P,TP, C,O bipolar?	Integrated Ampl.	?	1 sec	alpha	RH > in R than W. transient, small magnitude shifts in asymmetry
Hirshkowitz & Karacan (1981) ●	22 rh (11 M, 11 F)	R,1,2,3,4	T3,T4/Cz	Integrated Ampl	L-R/L+R	60 sec	?	RH > in REM for males only
Gaillard, Laurian & Le (1984)	17 Ss (3 lh)	W,R,1,2, 3,4	T3,T4/Cz	Integrated Ampl	L/R	60 sec	0-70 Hz	For rh Ss, no diff between sleep stages
Ehrlichman, Antrobus & Weiner (1985)	18 rh	R, 2	TP3,TP4/Cz	Integrated Ampl	L- R/L+R	60 sec	2-12 Hz	No diff in AR between R & 2. LH > for visual & verbal imagery
Moffitt et al (1982)	8 rh M	R, 2, 4	C3,C4/A1,A2	Period Analysis	L-R/L+R	30 sec	0-30 Hz	RH > for all stages; No diff R vs. 2.
Murri et al (1982)	13 M (1 lh)	1,2,3,4 Rt , Rp	F3 / C3 F4 / C4	FFT	R/L	5 sec	.5 - 30 Hz	RH > all stages of sleep, highest in R. No diff tonic vs phasic REM
Violani et al. (1984)	5 rh M	W, R, 1, 2, 3, 4	T3,T4/A1,A2	FFT	R-L/R+L	60 sec	.5 - 18 Hz & alpha	No consistent asymmetry. No time of night (GILD) effect
Banquet (1983)	5 rh M	W,R,1, 2, SWS	C3,C4,O2, F1,F2/A1,A2	FFT, coherence	N/A	25 sec	0-25 Hz	Coherence lowest in SWS. W> R, 1, 2 All bands show high corr betw hems. Asymmetry not evaluated directly
Dumermuth et al. (1972)	6 F	R, 1, 2, 3, 4	F, C, P, O bipolar, within hem	FFT, coherence	N/A	40 sec	.25-40 Hz	Coherence high in all sleep stages. coherence in R = SWS; asymmetry not evaluated directly
Dumermuth et al. (1983)	6 M	W, R, 1, 2, 3, 4	F, T, P, O /Cz	FFT, coherence	N/A	20 sec	.4 - 30 Hz	Coherence > in SWS posteriorly REM coherence > in frontal lobes; Asymmetry not evaluated directly
Barcaro et al. (1986)	11 M	W, R, N	F3/C3, F4/C4	A/D, cross-correlation	N/A	60 sec	1-20 Hz	NREM coherence > R; low in W Time of night diff in coherence across REM cycles; 1st REMP anomalous Asymmetry not evaluated directly

Notes and Abbreviations

Column	Symbol	Explanation
Study	@	Abstract only
Subjects	M	Male
	F	Female
	rh	right-handed
	lh	left-handed
Sleep Stage	W	Waking
	1	Stage 1
	N	NREM
	SWS	Slow Wave Sleep (Stages 3 & 4)
	R	REM
	Rt	REM tonic
	Rp	REM phasic
	REMP	REM period
Findings	LH >	LH dominant
	RH >	RH dominant
	diff	difference
	corr	correlation
	betw	between
Throughout	?	No information given
	N/A	Not applicable

Additional note:

The study by Pivik et al. (1982) was inadvertently omitted from the literature review table in Appendix One.

Pivik et al. studied 6 intellectually gifted adolescent males, all right-handed, in Waking, REM and Stage 2 sleep. They recorded EEG from C3 and C4 referenced to linked ears and computed spectral power in multiple bandwidths. Laterality effects were assessed using the ratio L-R/L+R. Pivik et al. found no consistent pattern of hemisphere asymmetry; dominance of one hemisphere over the other varied within subjects by frequency band and electrode site studied. They continued their EEG recording into the post-awakening period but found no consistent relationship between pre- and post-awakening EEG asymmetry in the six subjects.

APPENDIX TWO

THE CITY COLLEGE
OF
THE CITY UNIVERSITY OF NEW YORK
NEW YORK, N.Y. 10031

DEPARTMENT OF PSYCHOLOGY
(212) 690-6700/5397

SLEEP LABORATORY

VOLUNTEER RESEARCH SUBJECT AGREEMENT

I hereby volunteer my services as a research subject in the Sleep Laboratory of the Psychology Department of the City College of New York. This research is being conducted under the supervision of Professor John Antrobus, Ph.D. and Ms. Ruth Reinsel, M.A.

I understand that the research involves no pain or major discomfort and will not be harmful to me in any way. My privacy will be respected and the information I provide will remain confidential.

The procedures have been explained to me. They involve placing electrodes on my head and face to measure brain waves, eye movements and muscle activity. My brain waves will be recorded for computer analysis.

On other awakenings, I will be asked to engage in a variety of simple and brief cognitive tasks which measure the functioning of the left and right hemispheres of the brain. These tasks are not personality or IQ tests, and their results cannot be used against me in any way.

I understand that the experiment requires 4 sessions: one afternoon session and three nights. The afternoon session will be scheduled first, followed by three nights which I will spend sleeping at the laboratory. These nights will not be all in a row, and they will be scheduled at a mutually convenient time.

I will be paid $20 for my participation in the experiment, which I receive upon completion of all 4 sessions. If I discontinue participation before the end of the experiment, I will forfeit the right to be paid for the sessions I have completed up to that point.

I understand that I am free to quit the experiment at any time, should I so desire, and that this will have no harmful effects upon my academic standing or on my relationship with the experimenters.

NAME: (Print) ____________________
SIGNATURE: ____________________
ADDRESS: ____________________
____
TELEPHONE: ____________________
SOCIAL SECURITY NUMBER: ____________________
(For accounting purposes)
DATE: ______________

Parent or Guardian consent when research subject is under 21 years old:
NAME: (Print) ____________________
SIGNATURE: ____________________
ADDRESS: ____________________
____
TELEPHONE: ____________________
DATE: ____________________

Researcher's Signature: ____________________

APPENDIX THREE

SLEEP HABITS QUESTIONNAIRE

NAME ______________________ AGE _____ SEX M F

ADDRESS ______________________

____

TELEPHONE: (Daytime) ( )
(Evenings) ( )

What is generally the best time to call you?

____

INSTRUCTIONS: Please answer the questions below as honestly as you can. Some questions leave a blank for you to fill in your answer. Other questions can be answered by circling YES or NO in the right margin. If there are questions which you would like to answer in more detail, feel free to use the reverse side of this page.

This information will be kept confidential, and used only for the purposes of this experiment.

PART I. SLEEP/WAKE SCHEDULE

1. Do you feel that you usually get enough sleep at night? YES NO

2. What time do you usually go to bed and get up on weekdays?

   Go to bed _____ AM / PM Get up _____ AM / PM

3. What time do you usually go to bed and get up on weekends?

   Go to bed _____ AM / PM Get up _____ AM / PM

4. Would you describe yourself as someone who has trouble sleeping? YES NO

5. On the average, how long do you actually sleep at night? (that is, how much of the time in bed is spent actually sleeping?) _____ hrs _____ mins

6. What is the average amount of sleep you need to feel alert and refreshed?
____ hrs ____ mins

7. On the average, how long does it take you to fall asleep at night after you turn out your bedroom lights?
____ mins

8. Do changes in your sleeping routine (e.g. different bedtime) markedly affect the quality of the sleep you get?
YES NO

9. On the average, how many times do you wake up during the night?
____

Do you get out of bed at these times? YES NO

How long do you generally stay awake at these times? ____ mins

How long does it generally take you to return to sleep? ____ mins

10. Do you often wake up too early in the morning and have trouble returning to sleep? YES NO

11. How do you usually feel when you wake up in the morning after a typical night of sleep? (circle one of the answers below)

1. Completely rested and refreshed
2. Somewhat rested and refreshed
3. Somewhat tired and groggy
4. Very tired and groggy
5. Feel like you haven't slept at all

12. Do you feel that you get too little sleep at night? YES NO

13. Are you bothered by sleepiness during the day? YES NO

14. Do you nap or return to bed during the day? YES NO

If yes, how many times per day? ________

Average length of sleep per nap?
____ hrs ____ mins

15. Do you find yourself falling asleep at inappropriate times, even when you have slept well the night before? YES NO

(If you answered yes to this question, please describe on the reverse side of this page.)

PART II. DREAMS

16. Do you often feel you go into a dream immediately when you fall asleep at night, or when you nap? YES NO

17. Do you frequently have frightening or disturbing dreams? YES NO

18. Are you troubled by recurrent dreams? YES NO

19. Have you ever had a lucid dream? YES NO
(That is, know that you are dreaming, while still experiencing the dream going on?)

20. How frequently do you remember your dreams?
(Circle one)

    1. Never, or very infrequently
    2. Rarely (about once a month)
    3. Sometimes (a few times a month)
    4. Frequently (once or twice a week)
    5. Very often (almost daily)

21. How would you describe your dreams, compared to daydreams you have while you are awake?
(Circle one)

    1. Dreams are more intense, vivid
    2. Dreams are about the same as daydreams
    3. Dreams are not as intense, vivid as daydreams
    4. Don't know

22. Do you have any comments about your dreams that you would like to share with us?
(Please use the space below and the back of this page, if you wish.)

PART III. "THINGS THAT GO BUMP IN THE NIGHT"

23. Have you been told you snore loudly while asleep? YES NO

24. Do you toss and turn a lot at night? YES NO

25. Have you ever been told that you talk in your sleep? YES NO

26. Have you ever had trouble with sleepwalking? YES NO

27. Do you often awaken during the night with headaches? YES NO

28. Have you been told that you make unusual movements while apparently asleep? YES NO

29. Do you ever grind your teeth while apparently asleep? YES NO

30. Do you find that you have trouble sleeping when away from home? YES NO

31. Does being in a small, enclosed room make you feel very uncomfortable? YES NO

PART IV. DIET AND HEALTH

32. How much of these beverages do you consume?

			After 6 pm	
Coffee	______	cups/day	______	cups
Decaffeinated coffee	______	cups/day	______	cups
Tea	______	cups/day	______	cups
Carbonated drinks (soda)	______	cans or bottles	______	cans
Beer/wine/liquor	______	drinks/day	___	drinks

33. Do you have any medical problems for which you are taking medication? YES NO
(If yes, please describe the problem and the medication on the reverse side of this sheet.)

34. Please describe your use of the following substances by placing a check mark in the appropriate column:

	Never or Very Rarely	Occasionally	Frequent	Heavy
Cigarettes	______	______	______	______
No-Doz, etc.	______	______	______	______
Sleeping Pills	______	______	______	______
Marijuana	______	______	______	______
Cocaine	______	______	______	______
LSD, PCP, etc.	______	______	______	______
Other non-prescription drugs	______	______	______	______

APPENDIX FOUR

DESCRIPTION OF TASKS

Several factors were considered in selecting tasks for this study. First, it was felt advisable to use tasks that had been used in similar studies before, in order to facilitate comparison of results. Secondly, in view of the within-subject design, a task should have numerous items, so that six equivalent forms of the task could be constructed for the six experimental conditions (1 waking and 4 post-sleep conditions, plus a practice session). Thirdly, several trials of each task should be conducted on each awakening, to increase the reliability of the final score. Thus, tasks were favored wherein several trials could be conducted within one or two minutes. Lastly, but certainly not least, the tasks should be sensitive measures of lateralized cognitive abilities. The tasks described below were finally selected for the current study.

*Serial Numbers, from the CLB, is a modified digit span (forward) task. Digit strings are presented orally and the subject is requested to recall them on a prepared answer sheet. Strings vary in length from 3 to 9 digits with no repeated digits in a given string. The strings are incremented by one digit on each trial up to the maximum length of 9 digits, then are decreased by one digit to the final length of 6 digits. Scoring of recall is not done on an all or none basis; rather, points are given for subsections of the digit string which are recalled in the correct sequence. The scores may range from a low of zero for total absence of recall to a maximum of 378 for perfect performance on all nine trials. Further details on scoring of the *Serial Numbers task are given in Table A-1, which presents the maximum possible scores for each trial, and the total score that can be achieved.

The Serial Numbers task of the CLB is considered to reflect LH functioning, not because the stimuli are digits, but because of the sequential requirement in recall (Bradshaw and Nettleton, 1981). In addition, impaired performance on forward Digit Span was found in patients with focal brain damage to the LH (Newcombe, 1969; De Renzi & Nichelli, 1975) and in learning disabled children with indications of left hemisphere dysfunction (Rudel and Denckla, 1974).

Anagrams. The subject is given a page with a 10 letter word on it. He/she is asked to form as many smaller words (of at least 3 letters) using only the letters provided in the stimulus word. A point is given for each word formed, provided it is a correctly spelled English word. This task is similar to the verbal fluency measure used in the Gordon CLB, which was found to be sensitive to differences between REM and NREM sleep. However, verbal fluency measures may be unduly influenced by differences in vocabulary extent between subjects. It was hoped that the Anagrams task would be less sensitive to these extraneous subject differences, since Anagrams only requires verbal processing of visually presented stimulus material.

Previous studies of a variety of verbal tasks, such as Vocabulary tests (Lansdell, 1968; Warrington and Rabin, 1970); Analogies (Spydell, Ford and Sheer, 1979; Loring and Sheer, 1984) and Synonyms (Ornstein, Johnstone, Herron and Svencionis, 1980) have all found the LH to be primarily involved in processing these kinds of tasks, in both brain-damaged and normal subjects.

*Form Completion is a version of the Gestalt Picture Completion task, which involves the part-whole integration ability of the RH. Subjects are shown drawings of common objects, where part of the drawing has been erased, and they are asked to guess what the whole picture is. Six pictures are shown in a single slide, with the subject having 60 seconds to name the six stimuli.

This test has the most subjective scoring. The principle is that one point is given per item if the subject can correctly identify it. If the item is only partially identified, 1/2 point is given. If the item is ambiguously or wrongly identified, no points are given. The CLB scoring manual gives some guidelines to correct, partial or incorrect answers. For a given trial where 6 pictures are presented, the maximum score is 6 points.

In pilot work (Reinsel, 1985a,b) the Form Completion task was the only one to significantly differentiate between REM and Stage 2 awakenings, with better scoring after REM sleep. Performance on this task also showed a significant interaction between stage of sleep and time of night ($p = .03$).

This type of task was shown to be sensitive to RH insult by De Renzi and Spinner (1966) and Lansdell (1968). Although an earlier study by Warrington and Rabin (1970) found no significant differences between normal controls and patients with LH or RH damage, Ornstein et al. (1980) were able to show slight EEG asymmetry favoring the right parietal lead in 20 right-handed normal subjects performing this task. Additionally, Nebes (1971, 1972) showed the RH to be superior in part-whole integration. More recently, Wasserstein, Zappulla, Rosen and Gerstman (1987) demonstrated that these kinds of closure tasks are factorially complex, but involve the RH ability to perceive subjective contour illusions, probably based on depth perception cues.

Point Localization. This task presents the subject with a randomly positioned dot within a rectangular field. The subject is provided with an answer sheet on which to indicate from memory the position of the dot. Scoring is accomplished by measuring the distance in millimeters between the actual position and the indicated position of the dot. A transparent plastic template is provided which indicates the position of the actual stimulus within a frame of reference of concentric circles marked off in one-millimeter increments. The score for each trial is the linear distance from the correct location to the center of the subject's "X" mark. The total score is the average of the 8 trials. This is the only test where the higher the score, the poorer the performance. Theoreticallly, a perfect performance on this task would yield a score of 0 mm deviation from the correct positon of the stimulus.

In Gordon et al.'s (1982) study, the Point Localization task showed the most powerful asymmetries between REM and NREM conditions. Warrington and Rabin (1970) used a dot position matching task with brain damaged patients, and found that patients with damage to the RH showed the worst performance (especially if the damage was to the parietal region). LH lesioned patients performed at a level comparable to the normal controls.

Tactile Recognition. The tactile task is a variation of that used by Bertini et al. (1984). They have developed a plastic belt which rotates around 2 flywheels. On the belt are affixed plexiglass shapes which the S is asked to explore with the first two fingers of each hand, without looking at the stimuli. A matching to sample response is required. The task is first performed with one hand for 8 trials, then again with the other hand for 7 trials. (The initial trial performed with the first hand is considered a warm-up trial, and is not scored.) Each trial is allotted 15 seconds, so completion of the entire task requires four to five minutes. The order of left hand/right hand starting the task was counterbalanced within subjects and randomized across subjects. This task is considered lateralized since when tactile stimulation is received from the index and middle fingers of each hand, the sensory input is processed entirely by the contralateral hemisphere (Brinkman and Kuipers, 1972; Ghez, 1981, p. 283). Previous work presenting tactile stimuli and requiring selection of the identical stimulus from a visually presented array found this task to involve RH abilities in brain damaged patients (DeRenzi, 1978) and in split-brain patients (Nebes, 1972, 1978).

Choice Reaction Time (RT). A Choice RT device was employed which presented the subject with stimulus lights on either side of a central "warning" indicator.

The left-side or right-side light was illuminated in random sequence. The subject was instructed to press the response button on the same side as the illuminated stimulus light. The subject's response stopped a clock which indicated reaction time to the nearest hundredth of a second. Six trials were conducted with each hand, of which the last 5 were averaged to provide a mean score for each hand. The order of starting hand was counterbalanced. RT scores were log-transformed and averaged to remove skew before being entered in the data analysis.

Neural control of motor responses is crossed such that right-handed responses are controlled by the LH and left-handed responses are controlled by the RH. RTs to lateralized stimuli are generally fastest when the response is made with the contralateral hand (Broadbent & Gregory, 1965; Filbey & Gazzaniga, 1969). When verbal and nonverbal tasks have been compared, RT scores have been found to be fastest when the hand used for responding is contralateral to the hemisphere presumably most relevant for the task (Milner and Lines, 1982; but see Rebert & Mahoney, 1978). However, some studies have found that the hand which is on the same side as the stimulus has an advantage in simple RT (Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977; Berlucchi, Heron, Hyman, Rizzolatti, & Umilta, 1971; Berlucchi, Crea, DiStefano & Tassinari, 1977).

Table A-1. Maximum possible points for individual trials, and cumulative scoring for the *Serial Numbers Task.

Length of Digit String	Maximum Possible Score on String	Cumulative Score (if Perfect Performance)
4 digits	14	14
5 digits	22	36
6 digits	32	68
7 digits	44	112
8 digits	58	170
9 digits	74	244
8 digits	58	302
7 digits	44	346
6 digits	32	378

Table A-2. Stanford Sleepiness Scale

(see Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973)

Instructions: Choose the statement below which best describes your state of sleepiness. Then give the number corresponding to that statement as your answer.

1	Feeling active and vital; alert; wide awake
2	Functioning at a high level; but not at peak; able to concentrate
3	Relaxed; awake; not at full alertness; responsive
4	A little foggy, not at peak; let down
5	Fogginess, beginning to lose interest in remaining awake; slowed down
6	Sleepiness; prefer to be lying down; fighting sleep, woozy
7	Almost in reverie, sleep onset soon; lost struggle to remain awake

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