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ULTRADIAN RHYTHMS IN EEG AND PERFORMANCE:
An assessment of Individual Differences in
the Basic Rest-Activity Cycle

by

ROSEANNE ARMITAGE

A thesis submitted to
the Faculty of Graduate Studies and Research,
in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

Department of Psychology

Carleton University
Ottawa Ontario
April 22, 1986

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submitted by

Roseanne Armitage

in partial fulfilment of the requirements for
the degree of Doctor of Philosophy.

.....
Chairman, Department of Psychology

.....
Thesis Supervisor

.....
External Examiner

Carleton University

April, 1986

ABSTRACT

The concept of the basic rest-activity cycle (BRAC) first introduced by Kleitman (1963), proposes that rhythmic oscillations in physiology and behavior are continuous throughout sleep and wakefulness. Since this time, several revisions and extensions of this theory have been offered. Most notably, it has been suggested that ultradian oscillations in physiology and behavior are coupled with rhythmic activation of the two cerebral hemispheres. Three studies were conducted to more fully investigate rhythms in electrocortical activity in sleep and in wakefulness. Two measures of interhemispheric EEG activity were used in each study. For each frequency band of EEG, relative right and left hemisphere ratios and absolute differences between right and left activity were calculated. The absolute difference measures were interpreted as an index of hemispheric balance.

In Study 1, 80-120 minute rhythms in EEG activity were investigated among males and females during task performance. Females showed 80 minute cycles in absolute difference measures of Beta and Sigma Power during task performance. Males showed ultradian variations in relative ratios of Delta Power. Correlations between EEG and performance variables indicated that hemispheric balance was associated with task performance among females. Males showed stronger correlations between relative ratio EEG measures and task performance.

Study 2 investigated 80-120 minute rhythms in EEG activity during sleep, among high and low frequency dream recallers. Low frequency recallers showed ultradian variations in relative ratio Beta Zero-Cross and Total Power, while high recallers showed 80 minute rhythms among a number of absolute difference EEG measures. Eighty minute rhythms in hemispheric balance were found among Delta and Theta Power and Total Power measures among high recallers.

Study 3 was undertaken to evaluate the BRAC hypothesis measuring EEG activity throughout sleep and wakefulness. Male and female high and low frequency dream recallers spent one night in the laboratory, EEG activity was recorded throughout sleep and during a two hour task performance session during wakefulness. Correlating rhythms in sleep EEG with rhythms during task performance, evidence of a BRAC was obtained in parietal Beta Power, Alpha Power and Alpha First Derivative balance EEG measures, attenuated among female high recallers. No evidence of a BRAC in relative ratio EEG was obtained. This study also showed stronger evidence of ultradian rhythms among high frequency recallers in hemispheric balance EEG measures compared to relative ratio EEG. Sex and frequency of dream recall were shown to moderate the expression of ultradian variation in EEG activity during task performance and also during sleep. It was suggested that high frequency dream recallers are better able to maintain the integrity of rhythmic cortical processes in the transition from sleep to wakefulness, than are low frequency recallers.

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INTRODUCTION

The concept of the basic rest-activity cycle (BRAC) as developed originally by Kleitman (1963), proposed an ultradian oscillation in physiology and behavior whose 90 minute period evolved to meet the gastric and consummatory needs of the organism. This theory, based on observations of infant feeding behavior and the cyclic occurrence of rapid eye movement sleep (REM) predicted a continuous oscillation of phasic ocular and myographic events during sleep, coupled with 90 minute rhythms in rest and activity in wakefulness. Despite a tremendous growth of interest in biological rhythms in the past three decades, research has added little to our understanding of the relationship between rhythms in sleep and wakefulness or provided conclusive evidence for a BRAC in humans.

In part the difficulty in evaluating the BRAC stems from inadequate theoretical development and from the methodological framework under which these research projects have been conducted. First, Kleitman's theory was never fully articulated. He did not speculate on the nature of mechanisms controlling BRAC oscillations nor did he suggest how the BRAC would manifest itself in wakefulness, beyond fluctuations in alertness.

Other researchers, most notably Broughton, Kripke and Lavie and their colleagues, have extended Kleitman's BRAC theory to predict waking variation in physiological and psychological function phase-locked to REM-NREM sleep

oscillations. Broughton (1975) has suggested that a rhythmic activation of the two hemispheres underlies the BRAC in sleep and wakefulness, predicting a 90 minute rhythm in interhemispheric EEG and information processing. Lavie has suggested that waking expressions of the BRAC include variations in perceptual processes and vigilance (Lavie, 1977; Lavie, Lord and Frank, 1974; Lavie, Levy and Collidge, 1974) while Kripke (1982) has emphasized physiological rhythms in heart rate, hormonal levels and urine flow.

There are several assumptions which have characterized all reformulations of the BRAC hypothesis and which have hindered an evaluation of this theory. Foremost is the conceptualization of REM and NREM sleep as opposite poles of the sleep continuum, diverging in function, physiology and associated mentation. There is a fundamental problem with this view of sleep, namely the failure to recognize significant differences among NREM sleep stages. Implicit in Kleitman's BRAC and recent extensions of his theory is the assumption that REM sleep is unlike all stages of NREM sleep. Electrophysiologically, REM and Stage 2 sleep are more similar than other sleep stages, characterized by the presence of desynchronous, fast frequency EEG activity (Rechtschaffen and Kales, 1968). Stages 3 and 4 are characterized by slow frequency, high amplitude EEG activity. Phenomenologically, dream recall rates are more similar among REM and Stage 2, especially among high frequency dream recallers, and there are more similarities in the structure and the content of dreams elicited from these stages of sleep

(Armitage, 1980). Estimates of dream recall rates from Stage 3 and 4 awakenings range typically between 0 and 40 percent (Armitage, 1980). By combining Stages 2, 3 and 4 to represent NREM sleep, the similarities in recall and electrophysiology between REM and Stage 2 are overshadowed, suggesting that contrasting REM against all NREM stages combined may overestimate physiological and phenomenological differences between REM and NREM as well as underestimating the differences among NREM sleep stages.

In a recent review of the ultradian rhythm literature Kripke (1982) has said:

Some time ago, I and other investigators thought we merely had to identify one 90 minute cycle during wakefulness to confirm the BRAC hypothesis, but the idea that any 90 minute waking cycle must be related to dreaming now proves to be a dream. Several cyclic processes must be distinguished, and none of the waking cycles has thus far been shown to have the same mechanism as REM-nonREM. With these considerations, I believe that the pursuit of the original BRAC hypothesis - at least by name - will prove unprofitable (p 29).

His comments pinpoint another major difficulty in ~~ultradian~~ rhythm theory: that is the assumption that the cognitive and neurological conditions which give rise to a dream experience are unique to REM sleep. Based on the original research which identified REM sleep, it has been suggested that rapid eye movements are the electrophysiological correlates of dreaming and that dreams only occur after the onset of REM. There is ample electrophysiological and phenomenological evidence to be reviewed in this paper which suggests this position is inaccurate and far too simplistic a view of cognition during sleep. Given that the distinctions between REM and other

stages of sleep were made on the basis of electrophysiological differences, attempts to provide evidence of a BRAC should focus on electrophysiological differences in wakefulness rather than searching for a waking analogue to dreaming.

Perhaps more importantly, the polarization of REM and NREM sleep has led researchers to speculate on the relationship between the unique specializations of the two hemispheres and the oscillation of sleep stages (Broughton, 1975; Goldstein, Stolzfuß and Gardocki, 1972). It has been suggested that dream content during REM more closely resembles the processing capabilities of the right hemisphere and that dreams elicited from NREM sleep stages bear a similarity to processing capabilities of the left side of the brain. Electrophysiological data suggesting greater activation of the right hemisphere suggested to Broughton (1975) that a rhythmic oscillation between the two hemispheres characterized both REM and NREM sleep cycles and waking expressions of the BRAC. Since this time, the attempt to demonstrate ultradian rhythms in cognitive and electrophysiological processes has been largely unsuccessful. Those studies which have demonstrated 80-120 min rhythms in sleep and wakefulness have been difficult to replicate. Part of this difficulty may stem from a continued reliance on the assumption that the two cerebral hemispheres are associated uniquely with REM and NREM sleep. Specifically it has been proposed that the onset of REM sleep is associated with increased activity in the right hemisphere while the left

increased activity in the right hemisphere while the left hemisphere is associated with NREM sleep (Broughton, 1975; Goldstein, Stolzfus and Gardocki, 1972).

Recent research has not been able to confirm the proposed association between REM sleep and the right hemisphere and NREM sleep and the left hemisphere (See Pivik, Busby, and Blysmas 1982 for a review). In fact it is becoming clear that there are few asymmetries in EEG in any stage of sleep (Bertini, Violani, Zoccolotti, Antonelli and DiStephano, 1983 ; Moffitt, Hoffmann, Wells, Armitage, Pigeau and Shearer, 1982). Thus if the mechanisms which control temporal variation in EEG during sleep also control rhythms in wakefulness then it seems likely that these too would display few asymmetries. The research projects to be presented in Chapters 3,4 and 5 of this paper support the view that 80-120 minute rhythms in unihemispheric EEG activity do not characterize sleeping or waking cycles. Rather it is an 80 minute rhythm in hemispheric symmetry or balance in EEG activity which characterizes ultradian rhythms in sleep and wakefulness.

One further issue is worthy of comment. Research projects in the past have investigated either rhythms in sleep or wakefulness, but not both. If significant 80-120 minute rhythms could be demonstrated in physiological or cognitive function they were taken as evidence of a BRAC. This represents far too liberal an interpretation of the data. In order to demonstrate the existence of a BRAC,

sleep and in wakefulness: Then it must be shown that these cycles are strongly correlated. In the absence of this analysis it is legitimate to conclude that there are ultradian rhythms in physiology or cognition but not that they are related to any rhythmic process continuous throughout sleep and wakefulness. This methodological and interpretational flaw has prohibited an accurate evaluation of the BRAC hypothesis. Given these methodological and theoretical difficulties, Kripke's (1982) conclusion that the search for a BRAC will prove unprofitable appears to be premature.

The purpose of this paper is to more fully investigate ultradian rhythms in electrophysiology during sleep and their relationship to EEG cycles during task performance in wakefulness. Since the research methodology and the analysis techniques necessary to detect periodicities in time series are relatively recent and new to psychology, they require a review before ultradian theory can be discussed. Chapter 1 of this paper provides a brief review of data quantification techniques and their application in biological rhythm research. Chapter 2 presents a detailed review of ultradian rhythm research from the discovery of REM sleep to recent explorations of physiological and cognitive variations in wakefulness. Finally this paper describes three research projects designed to investigate approximate 80 minute rhythms in electrophysiology during sleep and during task performance in wakefulness. These studies also determine the influence of sex and frequency of dream recall on ultradian

periodicities.

CHAPTER 1

DATA ACQUISITION AND ANALYSIS PROCEDURES FOR EEG AND BIOLOGICAL RHYTHM RESEARCH

The evaluation of human EEG activity involves the measurement, amplification and registration of differences in bioelectrical potentials in the brain, recorded through the use of Silver/Silver Chloride surface electrodes affixed to the scalp with electrolytic paste or jelly. Electrolytic compounds contain either sodium or calcium chloride to enhance conductivity and lower resistance between the scalp and electrode junctions.

At least two electrodes must be used to measure electrical potentials in the brain where the difference in voltage output at the two recording sites is taken as the electrical event. Either monopolar or bipolar electrode placements are used, where monopolar recordings are obtained by affixing one of the electrodes to an electrically inactive site such as the mastoid and the other affixed to an active site over the cortex. The difference between the output from the reference and active electrode is considered the bioelectrical event. In bipolar recordings both electrodes are placed over active sites and the difference between the two placements is measured. With the use of this type of recording procedure any information common to the two electrodes is lost. Monopolar montages avoid this disadvantage.

In order to promote comparisons across laboratories, electrode placement sites were standardized by the First International Congress of Electroencephalography in 1947, called to 10-20 system (Jasper, 1958). The most common sites for hemispheric research are parietal and occipital, best for detecting alpha (8-12 Hz) and for visual scoring of polygraph records. In sleep research central sites are more often used for the identification of sleep stages, although this more by convention than theory.

Once the electrodes are firmly in place the bioelectrical signal is amplified and usually filtered. High and low pass filters can be used to restrict the upper and lower response range to the frequency band of interest (Kamp and Lopes da Silva, 1982). Once filtered, the EEG may be traced on a polygraphic record for visual inspection, stored on tape for later analysis, or analyzed on-line with the aid of a computer.

Visual Scoring of Sleep EEG

Visual scoring of polygraphic sleep records generally follows the criteria outlined by Rechtschaffen and Kales (1968) standardized scoring system. This procedure assigns a single value for each epoch (time segment) identified on the basis of changes in eye movements and muscle tonus and the emergence of phasic EEG events. Epochs are classified as awake, Stages 1, 2, 3, 4 and rapid eye movement (REM) sleep. When the frequency of EEG activity is of interest the amplitude and number of wave form peaks per second are

measured, classifying EEG frequencies as delta (.5-2 Hz), theta (4-8 Hz), alpha (8-12 Hz), sigma (12-16 Hz) and beta (16-30 Hz). Rechtschaffen and Kales (1968) describe REM sleep as characterized by relatively low voltage, desynchronized, mixed frequency EEG accompanied by binocularly symmetrical eye movements with low voltage electromyographic (EMG) activity or muscle tonus. Low EMG indicates a suppression of gross muscle activity or muscle paralysis during this stage of sleep.

Relatively low voltage EEG in the absence of REM's, coupled with fast frequency EEG characterizes Stage 1 sleep often referred to as sleep onset. Stage 2 is associated with the presence of sinusoidal spindle activity (12-14 Hz) and higher voltage biphasic wave forms (K-complexes) with low voltage fast frequency EEG activity. Stage 3 sleep is characterized by moderate amounts (20-50 %) of high voltage slow wave synchronous EEG activity (delta), while a predominance (50 % or more) of delta marks the onset of Stage 4 sleep. Stages 3 and 4 are often referred to as deep sleep, based on higher auditory thresholds during these stages. Auditory thresholds from REM, Stage 1 and Stage 2 sleep are considered more similar to auditory thresholds in wakefulness and are therefore referred to as light sleep (Bonnet, 1982). Collectively Stages 1 through 4 represent non rapid eye movement (NREM) sleep (Rechtschaffen and Kales, 1968).

Sleep is typically organized such that individuals enter Stage 1 at sleep onset. After approximately 5-10 minutes spindles and K-complexes appear marking the onset of Stage 2.

Some time later (it varies among individuals) delta activity appears and Stages 3 and 4 begin. The first REM period (REMP) occurs during the second hour of sleep and subsequent REMPs occur on the average of 90 minutes from the end of the last REM in most individuals (Globus, 1966). The reader is referred to the section on REM-NREM cycle stability for a more detailed discussion of cycle measurement. Slow wave activity occurs predominantly in the first half of the night. The last half of the night is generally characterized by rhythmic oscillations between REM and Stage 2 and most individuals awaken from REM in early morning.

A major benefit of visual stage scoring is it does not require expensive materials nor equipment once the electrophysiological data have been recorded. However techniques of this type result in a great loss of information by assigning a single value to each epoch, combining information from EEG, EOG, and EMG rather than measuring each one directly. Hoffmann, Moffitt, Sussman, Wells and Shearer (1979) have pointed out that many tonic electrophysiological events remain undetected by the human eye and that visual scoring techniques do not permit an evaluation of the frequency characteristics of EEG activity. Thus visual scoring systems are more appropriate for immediate identification of sleep stages required while an experiment is on-going, for example during REM deprivation studies and when scheduling the sleep stage of experimental awakenings.

Visual scoring of polygraph records has also been used

to identify the frequency characteristics of waking EEG. Delta activity is generally associated with low levels of cortical arousal and is absent in waking EEG unless the individual suffers from a pathological disorder (Stevens, 1974), although investigation of waking EEG with computer techniques to be discussed below, indicates that delta is present in the EEG of individuals as they awaken (Pigeau, 1985) but not usually throughout wakefulness.

Waking EEG

According to the early literature theta activity is associated with the development of the cortex, present in abundance until the age of two and not usually associated with normal adult patterns of EEG activity in wakefulness (Lindsley and Wicke, 1974). In a review of the EEG literature however Schachter (1977) has pointed to evidence that theta may be associated with active and efficient information processing rather than reflecting an immature cortex. This evidence has included meditation studies indicating the higher the level of ability in meditating the more theta that is present in the EEG record. Ishihara and Yoshii (1972) have demonstrated that frontal theta is associated with performance on arithmetic tasks and the completion of intelligence tests although there are large individual differences. Pigeau (1985) has suggested that theta activity may be associated with sustained performance or vigilance and has reported data based on computer analysed EEG that the amplitude and the relative presence or absence of theta activity may reflect different underlying cognitive

processes. He suggested that the amplitude of theta activity reflects the degree of focussed attention while the presence or absence of theta reflects sustained attention.

* Alpha activity in wakefulness is perhaps the most studied frequency of EEG activity. It is most prevalent in parietal-occipital areas and is generally associated with relaxed wakefulness with closed eyes. Alpha activity is believed to decrease with heightened attention and information processing (Novikova, 1974). Alpha activity is generally assumed to bear an inverse relationship to beta activity (Neidermeyer, 1982).

Kuhlo (1976) has identified several types of beta rhythms present in adult EEG activity in wakefulness including those associated with cortical sensory-motor functions and a posterior rhythm that is blocked by mental activity and visual stimulation. EEG activity of this frequency band is generally divided into fast frequency (30 Hz and above) and slower frequency beta (13-30 Hz). Although Remond and Lèserve (1957) have suggested that beta activity is associated with aggressive and dynamic personality traits more recent research has been unable to substantiate this claim (Neidermeyer, 1982). This frequency of EEG activity is difficult to detect utilizing visual scoring techniques and thus must be studied through the use of data quantification procedures that are sensitive to the multifrequency components of EEG signals.

Computer Techniques:

Off-line computer analysis of electrophysiological data provides a more detailed description of bioelectric activity during sleep and wakefulness. The advances in computer technology over the past two decades have made this a feasible alternative to visual scoring of polygraph records. With computer analysis, analog EEG activity is digitized at a fast sampling rate through the use of analog to digital (A/D) convertors. The higher the sampling rate, the more accurately the digitized values approximate the analog signal. Maximum sampling rate is determined by the quality of the digital convertors and the computer memory size while the minimum sampling rate should not be less than twice the highest frequency of interest.

The length of the EEG sampling period, called the epoch, should not be less than one second or greater than one minute to ensure that slower frequencies (0.5 Hz) are measured and that EEG changes within the epoch are not masked.

After EEG signals are digitized they are subjected to an algorithm, the most common being fast Fourier transforms (FFT's), period analysis, and auto-regression. FFT's separate time series into harmonic sine and cosine components, yielding a power (area under the rectified curve) estimate for each frequency. A pure sine wave has a peak in spectral power at one frequency and zero at all others. When a sine wave does not fit the time series it is assumed the data are random. A random set of data has equal spectral power at all

frequencies. A plot of the FFT's at each frequency is called a periodogram or a power spectrum. If the FFT values are transformed by averaging power values at adjacent frequencies, the transformed power values are referred to as spectral density.

Fourier analysis of EEG data reveals the amount of variance which can be accounted for by each frequency band. To determine ultradian rhythms in EEG frequency bands a second spectral analysis is performed on each Fourier analysed EEG frequency band. Spectral analysis of behavioral or physiological data reveals the underlying periodicities in the data, the amount of variance which can be accounted for by each cycle length. If observations are made every ten minutes for ten hours, spectral estimates will be provided for one to 30 cycles in the test period. Power spectral density functions are more commonly found among behavioral research although Brillinger (1975) has suggested that since sampling rates are quite low under testing conditions that the periodogram (untransformed FFT) may provide a better estimate of the spectral characteristics of these time series. It should be noted that few studies report whether power spectra are periodograms or spectral density functions. To avoid confusion, this paper will refer to Fourier analysis to quantify EEG data as FFT's. Fourier analysis performed to determine periodicities or rhythms in data will be referred to as spectral analysis or spectral power values.

An alternative to FFT's, period analysis yields estimates of power, first derivative and zero-cross events.

The time interval between successive zero voltage crossings events is measured for each frequency of EEG activity, yielding percent time zero-cross and power estimates. First derivative values are based on the detection of negative inflections in the EEG signal regardless of whether they cross zero volts, and yield percent time estimates for each frequency band. Period analysis is simpler mathematically and faster than FFT's. Recent research has demonstrated that period analysis and FFT's share a large portion of the information gathered, having a canonical correlation of greater than .90 in sleep and waking EEG (Pigeau, Hoffmann & Moffitt, 1981). Spectral analysis may also be performed on period analysed EEG data if ultradian rhythms are of interest.

Auto-correlations correlate a segment of digitized EEG with itself or time series with themselves at a predetermined time displacement called a lag. This analysis is a time domain analysis, whereas frequency domain models utilize power spectral analysis or spectral density functions. The multiple correlations obtained from auto-correlations are then plotted to form a correlogram displaying the prominent wave forms. If the signal is comprised of random waveforms, the correlogram is flat. Cross-correlational analysis is an auto-correlation between two time series, using one to predict the other. Auto-correlations and cross-correlations are covariance estimates.

Coherence analysis is a correlation of two or more time

series, using a frequency domain model. Coherence analysis provides a single estimate of the correlation between two time series and is more sensitive to the phase relationship than the amplitude (Gottman, 1981). These techniques and those mentioned above are applicable to EEG, behavioral or physiological data. Cross-correlation and coherence analysis of EEG activity are of use when comparing EEG recorded from two different electrode sites. In coherence analysis, a low correlation is presumed to reflect different processes at two electrode sites although a single estimate of coherence is not sensitive to changes in the temporal relationship between time series whereas amplitude and phase spectra computed by cross-spectral functions are. Cross-correlations are more appropriate when biological rhythms are of interest as they provide estimates of the relationship between two time series at each periodicity. Fourier and spectral analytic techniques of EEG and behavioral time series are used typically in waking EEG and biological rhythm research. With this information in mind we will now review the literature relevant to the BRAC hypothesis.

CHAPTER 2

The Society for Biological Rhythms was founded in 1937 although research in this area did not experience a vigorous growth until the late 1950's (Webb, 1982a). The Physiology of Diurnal Rhythms, written by Harker in 1958, marked the first major publication in the area. Of primary interest to researchers at this time were rhythms in physiology and behavior which expressed an approximate twenty-four hour period, termed circadian (circa dies) by Halberg (1959). In the decade between 1960 and 1970, Bunning (1964), Cloudsley, Thompson (1960), Reinberg and Gata, Richter, and Sollenberg all published major works on circadian rhythms which have contributed to our understanding of fatigue effects, changes in performance and jet lag. This interest in circadian variations led to the development of research strategies, sampling less than once per hour over consecutive twenty-four hours, obscuring possible biological rhythms with shorter periodicities termed ultradian by Halberg (1973). Although chronobiological research continues to focus on circadian rhythms, interest in ultradian variations in physiology and behavior has grown substantially in the past decade.

Ultradian Rhythms in Sleep

Sleep is generally viewed as circadian, occurring once a day in adulthood, although one of the most influential sleep studies has identified the ultradian characteristics of sleep physiology. Aserinsky, one of Kleitman's graduate students,

observed the regular occurrence of periods of ocular motility in hospitalized infants during sleep. This finding prompted an investigation of adult sleep from which Aserinsky and Kleitman (1953) determined that these periods of ocular motility were concomitant with increases in heart rate, changes in muscle tonus, the presence of desynchronous electroencephalographic activity and an increase in the probability of obtaining a dream report following awakenings in the presence of rapid eye movements.

Aserinsky and Kleitman (1955) utilized visual scoring of EEG to further evaluate what was later called rapid eye movement (REM) sleep in neonates. They determined that REM sleep reappeared every 50-60 minutes throughout the day and night, coupled with a three to four hour gastric cycle and suggested that this cycle governed rest and activity in neonates throughout sleep and wakefulness. Fifty to sixty minute cycles were later shown in fetal motility suggesting an early ontogenetic development of sleep and waking cycles (Granat, Lavie, Adar & Sharf, 1979; Herman, 1972).

In observations of sleep cycles in older children, Kleitman (1963) determined that the REM-NREM cycle gradually lengthens to 90-100 minutes by early adolescence and remains relatively constant throughout adulthood (80-120 min, Dement & Kleitman, 1957). Based on these observations and the cyclic occurrence of REM periods associated with dreaming, Kleitman (1963) proposed the existence of a basic rest-activity cycle (BRAC) active throughout sleep and wakefulness expressing a

90 minute period in adulthood.

He further proposed that the BRAC emerged from a more primitive, phylogenetically older digestive rhythm adjusted to the organism's nutritional needs and environmental supply, hypothesizing that the association between dreaming and the emergence of REM sleep reflected cyclic fluctuations in mental activity which he believed to display a comparable 90 minute rhythm in wakefulness. As evidence for the BRAC Kleitman (1963) cited the continuation of cyclic sleep-waking patterns in decorticate dogs and the rhythmic occurrence of sleep in anencephalous children.

Kleitman (1963) did not however speculate on the nature of mechanisms which control ultradian rhythms. There are several possibilities: 1) a single mechanism controls rhythms in sleep and wakefulness 2) several mechanisms control harmonically coupled but independent rhythms in sleep and wakefulness 3) interdependent rhythms in sleep and wakefulness are controlled by separate mechanisms. As yet none of these alternatives has been fully investigated. Nevertheless the research conducted by Kleitman and his colleagues led to renewed interest in dreaming, an investigation of ultradian rhythms and a more complete description of the electrophysiological characteristics of REM and NREM sleep.

REM-NREM Cycle Stability

Hartmann (1968) measured inter-REM-intervals on eight nights in 15 young adults by calculating the length of time from the end of one REM to the end of the next REM. He

reported a mean cycle length of 95.8 minutes with a standard deviation of less than 10 minutes, well within the range originally reported by Kleitman and his colleagues.

Webb (1974) also investigated average inter-REM intervals among adults, reporting a mean of 93 minutes with extremely large variability prompting him to comment:

We all know that there is a 90 minute (circa) REM cycle. What we do not all seem to know is that this 90 minute cycle is a mean around enormous variability of onset times and that each episode is different in length (p. 485).

Similarly Feinberg and Floyd (1979) reported a mean REM onset time of 87 minutes with a standard deviation of 18.5 minutes among 33 adults. Other research projects have reported the period of the REM-NREM sleep cycle to be reasonably stable (Globus, 1970; 1972; Kripke, Reite & Pegram, 1968; Kripke, 1972). Lewis (1974) however has shown that the standard deviation of single cycles within a given night is approximately 20 minutes and that five percent of cycles fall outside the 50-130 minute range. According to Kripke (1982), little effort has been made to explain this unsystematic variance within subjects. Several researchers have attempted to demonstrate instabilities in REM-NREM cycles as a means of identifying variables which influence the sleep cycle. Naitoh et al (1973) showed, that significantly different period lengths could be obtained, depending on which sleep stage or physiological variables were emphasized in computation. Naitoh et al attributed this to the interaction

between within night instability of cycle period and the predominance of delta, early in the night and REM predominance, later in the night.

In a review of this literature Kripke (1982) has said:

"It seems difficult to grant any plausibility to any BRAC hypothesis which envisions an extremely stable or rhythmic periodicity (p 318)".

There are several factors which Kripke has not considered which may account for the presumed non-stationary components of REM-NREM cycles. First, there are some discrepancies among the studies reported above. Webb (1974) and Feinberg and Floyd (1979) measured inter-REM-intervals from the beginning of the first REM period to the beginning of the next while Hartmann (1968) measured REM intervals as the end of the first REM period to the end of the next. These differences in measurement procedure can produce vastly different REM-NREM cycle lengths. Several research projects do not specify the techniques used to calculate inter-REM-intervals making it difficult to compare results with other laboratories (Webb, 1982). Discrepancies of this nature have prompted the Sleep Research Society and the European Society for Sleep Research to publish standardized terminology for biological rhythm research (Sleep, 1980) recommending that details of methods used to measure REM-NREM cycle lengths be explicitly stated in all articles. The articles upon which Kripke's (1982) contentions are based may have relied on different procedures for calculating cycle lengths and thus artificially inflated variability in cycle lengths among laboratories. Recently Johnson (1982) has argued that simply providing estimates of

the temporal characteristics of REM-NREM sleep distributions does not adequately assess REM-NREM cyclicity and that statistical techniques amenable to the detection of periodicities, such as time series analyses, are more appropriate for evaluating REM cycle stability.

Furthermore biological rhythms are known to be influenced by environmental factors such as changes in lunar cycles and temperature, among others (Chovet, Emptoz, Burtschy, Routhier and Valatx, 1980). This susceptibility to environmental change may in part account for the variability in sleep cycles within subjects. From an evolutionary perspective, it would not be particularly adaptive if the organism could not adjust sleep periods and cycle lengths to meet environmental change. Kleitman's (1963) original hypothesis did not suggest that the BRAC was without variation or susceptibility to environmental change. In fact, Kleitman suggested that there were a number of zeitgebers exerting influence on biological rhythms and that sleep-waking cycles were controlled exogenously. Therefore if rhythms in wakefulness were part of an on-going BRAC they too would express inter- and intra-subject variability. Interest generated by Kleitman's (1963) proposal and the ensuing study of sleep led to the discovery of physiological rhythms of a similar periodicity as REM-NREM sleep oscillations.

Physiological Rhythms During Sleep

Heart Rate:

On the basis of Orr and Hoffman's (1974) suggestion of a 90 minute rhythm in cardiovascular function during sleep, Wilson, Kripke, McClure and Greenburg (1977) investigated cardiac rhythms in intensive care patients. Wilson et al measured heart rate, systolic, mean and distolic blood pressure from 1800 hours to 0600 hours in ten cardiac patients. Time series were constructed from these measures, taken at five minute intervals and variance spectra were obtained from three hour lag autocorrelations. After standardization the variance spectra were averaged and yielded no significant 72-102 minute cycles in either blood pressure or heart rate. Since EEG was not recorded, it is unclear whether subjects were sleeping or in which stage of sleep they were while being monitored. Thus it is not possible to evaluate the phase relationships between blood pressure and heart rate and sleep cycles in this study. Furthermore, all the subjects in this study were seriously ill, nine having undergone major surgery a few days prior to the study. Wilson et al also pointed out that there was considerable noise in the cardiac unit which may have influenced their data. Clearly, their results are generalizable to intensive care cardiac patients and should not be taken as evidence against the BRAC hypothesis in healthy individuals.

Urine Flow:

Mandell, Chaffey, Brill, Madell, Rodnick, Rubin and Sheff (1966) have shown that the urine flow of catheterized patients displays a 90 minute rhythm during sleep, and is in phase with REM and NREM cycles. These authors attributed this biological rhythm to the periodic secretion of antidiuretic hormone (ADH). This finding however, was only partially confirmed by the work of Rubin, Govin, Kales and Odel (1973), demonstrating an episodic secretion of ADH, but unrelated to the phase of the REM-NREM sleep cycle. Mandell et al (1966) also failed to provide statistical analyses of their data and their conclusions were based upon a visual inspection of peaks in urine flow in real-time.

In assessing renal excretion in dogs, Gordon and Lavie (1982) collected urine every ten minutes and analyzed samples for sodium (Na⁺) and potassium (K⁺) levels, volume and osmolality. EEG, EOG, EMG and ECG were monitored continuously. The six dogs were studied under normal hydration conditions and progressive dehydration. In the hydration condition, no significant differences were obtained between night and day readings on urine flow and osmolality. In the dehydration condition urine volume was higher during the day, while osmolality was higher at night. In both conditions daytime readings of concentration and excretion of sodium were higher than nighttime values. There were no significant differences in potassium recordings in the day or night in both groups of dogs.

Separate time series were constructed for each group of dogs and after removing linear trends from the data, autocorrelations were computed and the variance spectra were estimated. The spectra were smoothed, normalized and averaged, yielding an average power spectra for each of the variables measured. Significant spectral peaks were found at 7.2 cycles/day (180 minutes) in volume, osmolality and potassium concentration in the normal hydration condition. Volume showed a significant 14.4 cycle/day peak (90 minutes) during the day under normal conditions and a significant 7.2 cycle/day rhythm during the day in dehydrated dogs. No significant rhythms were detected in night time recordings with the exception of peaks in sodium for hydrated dogs and osmolality for dehydrated dogs, both showing significant peaks at 2.88 and 5.76 cycles/day. Gordon and Lavie (1982) attributed these longer rhythms to circadian variations in these electrolytes.

Gordon and Lavie (1982) also correlated urinary variables with sleep-wake stages. Volume was positively correlated with awake and negatively correlated with Stage 2 sleep in both groups of dogs throughout day and night recordings. The reverse trend was reported in osmolality. This measure was negatively correlated with wakefulness and positively correlated with Stage 2 sleep. All correlations were higher in normal dogs compared with the dehydration condition. The authors interpreted these results as reflecting the multi-oscillatory organization of the renal system with circadian and various ultradian rhythms governing

secretion, volume and electrolytic concentration. This study remains one of the most complete explorations of the relationship between ultradian variations in physiological function during sleep and wakefulness albeit among dogs.

Gastric Activity:

Gastric activity during sleep, measured through stomach contraction devices, does not appear to display a 90 minute ultradian rhythm, nor does it appear to be related in phase to REM and NREM alternations (Lavie, Kripke, Hiatt and Morrison, 1978). This study measured both duodenal acidity and stomach contractions. Studies in wakefulness have indicated a 100 minute cycle in gastric activity (Hiatt and Kripke, 1975), but indicate no relationship between stomach contractions and fantasy or EEG cycles (Hiatt, Kripke and Lavie, 1975).

Ruckebusch and his colleagues have studied gastric cycles extensively (Bueno, Fioramonti and Ruckebusch, 1975; Bueno and Ruckebusch, 1977; Grivel and Ruckebusch, 1972; Ruckebusch and Bueno, 1977; Ruckebusch and Fioramonti, 1975). Their results indicate that gut periodicity is initiated in the duodenum and spreads throughout the small intestine, expressing a similar periodicity as REM-NREM sleep cycles in humans. In other species however, such as rats and monkeys, Ruckebusch and his colleagues claim that sleep cycles and gastric cycles are independent, expressing dissimilar periodicities. They claim that in some species, gastric cycles are inhibited by large meals and function only as a means of

propelling food through the digestive tract. Their results suggest that if gastric cycles are expressions of the BRAC and are harmonically coupled with sleep cycles it is only among humans.

To summarize, the results from studies of ultradian rhythms in physiology during sleep have generally been taken as support for Kleitman's proposal of a BRAC, most strongly among humans. They do not however provide convincing support for his original contention that biological rhythms are governed by underlying gastric and consummatory functions nor do they address the issue of common mechanisms controlling ultradian rhythms in sleep. Nonetheless the variety of physiological functions displaying ultradian rhythms in sleep has prompted an investigation of variations in psychological function as well.

The discovery of REM sleep by Aserinsky and Kleitman (1953) also proposed that REM sleep was associated with dreaming suggesting that psychological or cognitive processes may display ultradian periodicities during sleep. Over the past three decades considerable effort has been devoted to the study of the cognitive dimensions of sleep. Some of this research has focussed on ultradian rhythms in cognition relating their findings to the BRAC hypothesis.

Rhythms in Sleep Mentation:

Aserinsky and Kleitman (1953) proposed that REMs were the electrophysiological correlates of dreaming, and that individuals only dreamed during REM sleep. Initial research tended to confirm this hypothesis, obtaining at least 80

percent dream recall following awakenings from REM sleep (Dement, 1955; Dement & Kleitman, 1957; Kales, Hoedemaker & Jacobson, 1967; Wolpert & Trossman, 1958 and Wolpert, 1960). This research, however, was flawed by a number of methodological problems such as subject selection, method of awakening, definition of dreaming and perhaps more seriously, combining NREM stages of sleep (see Armitage 1980 for a review). Later research which analyzed recall rates from all stages of NREM sleep indicated that dream recall from REM sleep reaches 80-100 percent, while Stage 2 and 4 awakenings yield 35-60 percent and 15-30 percent, respectively (Armitage, 1980). Clearly, recall rates are higher from REM awakenings "but dreaming can no longer be equated with REM sleep" (Broughton, 1975) although this notion still appears in the literature. Combining recall rates from Stage 2 and Stage 4 sleep results in an underestimation of the frequency of NREM dream recall.

Interestingly, research has tended to identify qualitative as well as quantitative differences between REM and NREM dreams. NREM dreams are preported to be "thought-like", boring and lacking in vividness, while REM dreams have been described as more visual and more bizarre experiences (Foulkes, 1972; Broughton, 1975). Armitage (1980) has suggested that the qualitative differences among REM and NREM experiences may lie along such dimensions as liklihood of the experience and number of people in the dream as well as vividness. However, this study has emphasized the importance

of identifying at home frequency of dream recall in subject populations. High frequency dream recallers in this study were shown to report more color and more people in their sleep experiences than low recallers, regardless of stage of awakening.

Despite ample evidence that dream reports can be elicited from NREM sleep stages there remains the pervading notion that the cognitive and neurophysiological conditions which mediate a dream experience are unique to REM sleep and cannot be accessed during other sleep stages. Significant differences in dream content have been substantiated (Foulkes, 1967; Armitage, 1980). However it is unclear whether these differences reflect a failure to recall or to generate a detailed dream. It is clear that REM sleep is unique in that it bears a marked similarity to waking EEG, memory processes and other aspects of cognition. It is not clear that dream generation is unique to REM sleep. Furthermore similarities between waking EEG and Stage 2 electrophysiology have been demonstrated (Moffit et al., 1982). Despite ample evidence of the similarities between REM and Stage 2 sleep contrasts continue to be made between REM and all NREM stages combined. This convention further enhances the notion that REM sleep is associated uniquely with cognitive processes during sleep and wakefulness. Nonetheless, comparisons between REM and NREM sleep have led to an investigation of the cognitive differences upon awakening from these sleep stages.

Lavie and Giora (1973) have investigated perceptual

differences in the spiral after effect (SAE) following awakenings from REM and Stage 4 sleep. The duration of the SAE is said to depend on the persistence of visual stimuli and the degree of cortical arousability. Lavie and Giora hypothesized that the duration of the SAE would be greater following REM than Stage 4 awakenings, due to the higher level of cortical arousal in REM. Each of their nine subjects was awakened five minutes after the beginning of the first or second REM and five minutes after the onset of Stage 4. The order, REM or Stage 4 first, was counterbalanced across nights. After a two minute light adaptation period the subjects were tested on the SAE. Subjects were also tested on the SAE prior to sleeping in the laboratory. Repeated measures analysis of variance (ANOVA) confirmed their hypotheses and revealed no significant differences in the duration of the SAE between REM and wakefulness. The authors concluded that perceptual abilities as measured by the SAE are similar in REM and wakefulness.

Lavie and Sutter (1975) also investigated perceptual phenomena following awakenings from REM and NREM sleep. Five subjects were awakened 20 minutes after the end of the first REM, or seven minutes after the beginning of the second REM, and tested on the phi phenomenon. They were also tested prior to sleeping in the lab. This procedure was repeated on a second non-consecutive night. Five additional subjects were tested under this procedure with awakenings ten minutes after the first REM and three minutes after the beginning of the

second REMP.

Lavie and Sutter (1975) reported that there was greater variability in perception of the phi phenomenon following Stage 4 awakenings compared to REM awakenings and wakefulness. Unpublished data from their laboratory demonstrated a significant 95 minute rhythm in variability of the phi phenomenon in wakefulness. On the basis of these findings, Lavie and Sutter (1975) concluded that the differences in responding to the phi phenomenon following awakenings from sleep reflected the continuity of a BRAC across sleep and wakefulness where oscillations in perceptual phenomena during sleep characterize variations in waking perception. Their view of REM and NREM sleep as opposite poles of a BRAC is supported by other researchers (Broughton 1975; Kripke, 1982) and is dealt with in greater detail below. Since spectral analyses were not performed on the perceptual data following awakenings from sleep this conclusion is unwarranted. Rather, their data indicate that there are differences in perceptual capabilities following awakenings from REM and Stage 4 sleep. Furthermore, the authors obtained significant differences between REM performance and wakefulness. Although performance was most similar between REM and wakefulness, Lavie and Sutter (1975) do not provide convincing evidence for a BRAC governing perceptual processes.

Broughton (1968) has provided evidence that visual evoked potentials (VEPs) following REM awakenings were similar to waking VEPs. Potentials taken from NREM sleep more

closely resembled the EEG characteristics of slow wave sleep. These results, and those from Lavie and Sutter (1975), do suggest that performance and brain activity during REM is more closely related to wakefulness than to some stages of NREM sleep.

The differences among REM and NREM dream content and the rhythmic oscillation of sleep stages has prompted Broughton (1975) to propose a biorhythmic variation in consciousness, which he claimed to be controlled by BRAC mechanisms. This theory is one of the few extensions of the BRAC hypothesis to be well articulated and to encompass recent advances (at the time of publication) in sleep electrophysiology. This theory is of import as it is representative not only of ultradian rhythm theory but of a major school of thought attempting to characterize the nature of variations in consciousness and perceptual awareness in terms of the unique specializations of the two hemispheres.

Broughton (1975) has suggested that rhythmic fluctuation in mental activity may be active throughout sleep and wakefulness, and that the phase of REM-NREM sleep cycles is related to oscillations in the activation or efficiencies of the two cerebral hemispheres. This suggestion is based on the assumption that more visual and bizarre dream experiences, which have been associated with REM sleep, involve right hemisphere processing strategies. More thought-like content, which Broughton claimed to be characteristic of NREM experiences, involves greater left hemisphere activation

according to his theory. He proposed that oscillations in REM-NREM sleep are phase-locked to activation of the right and left hemispheres respectively. Extending Kleitman's BRAC hypothesis Broughton suggested that variations in waking consciousness mirror the rhythmic changes associated with the REM-NREM sleep cycle. Thus a 90 minute rhythm in interhemispheric EEG activity should be evident in wakefulness. Psychologically, he proposed that the waking features of the BRAC should manifest themselves in an oscillation in information processing strategies associated with the two hemispheres. In his conceptualization the right hemisphere involves visuo-spatial and fantasy-intuitive functions while the unique specialization of the left hemisphere is reflected in verbal-analytical information processing..

In addition to the phenomenological features of sleep mentation outlined above, Broughton has also cited interhemispheric EEG amplitude differences during REM and NREM sleep in support of his hypothesis. As this research is pivotal to his argument it requires a close evaluation. Goldstein, Stolzhus and Gardocki (1972) investigated differences in EEG amplitude between homologous areas of the right and left hemispheres during REM and NREM sleep. They used monopolar parietal electrodes with linked ear reference in seven human adult males, four cats and five rabbits. EEG signals were rectified to yield integrated amplitude values of total EEG (not filtered for frequency) over two minute epochs. Integrated amplitude is a power estimate or the area

under the curve. Asymmetry coefficients were calculated using a left over right (L/R) ratio of integrated amplitudes. This ratio was transformed by removing the mean L/R ratio, and comparing individual deviations from the mean. Changes in the L-R ratios occurred concomitant with shifts from REM to NREM sleep in humans, cats and rabbits. EEG amplitude was significantly lower in the left than right hemisphere during NREM sleep and higher in the left during REM sleep. The assumption in EEG research is that greater amplitude or power reflects hemispheric deactivation as it is associated with slow frequency high amplitude EEG activity characteristic of deep sleep. It is assumed that the lower auditory thresholds obtained from Stages 3 and 4 sleep are associated with decreased cognition. The inference is then made that deactivation in one hemisphere reflects activation of the opposite hemisphere.

These results suggested to Goldstein et al (1972) that the right hemisphere is associated with REM sleep and that the left hemisphere is more activated during NREM sleep. The failure to produce comparable interhemispheric shifts in wakefulness (Sugerman, Goldstein, Marjerrison and Stolzfus, 1971) suggests that there was no waking analogue of interhemispheric amplitude shifts.

More recent research has failed to confirm the right-hemisphere-REM, left-hemisphere-NREM electrophysiological relationship (Bertini et al, 1985; Moffitt et al, 1982; Pivik et al, 1982). Furthermore, attempts at replicating Goldstein

et al (1972) have provided conflicting results. For example, Antrobus, Ehrlichman and Weiner (1978) reported that activity in the two hemispheres is balanced during NREM with mixed "dominance" in REM. Rosekind, Coates and Zarcone (1979) reported greater right hemisphere activity in both REM and NREM sleep stages while Hirshkowitz, Waele and Karacan (1980) and Goldstein (1979) replicated Goldstein et al's original findings. All of these studies utilized integrated amplitude techniques.

Using Fourier analysis of EEG data, Pivik et al (1982) failed to find significant hemispheric asymmetries during REM sleep among adolescents and supports Moffitt et al's (1982) period analysed data that the hemispheres are relatively balanced during REM and NREM sleep stages in all EEG frequency bands. Period analytic and spectral analytic techniques exemplify the complex electrophysiological macro- and micro-architecture of sleep and the cognitive processes associated with them. The methodological and theoretical difficulties with integrated amplitude techniques may explain the inconsistency among results in this area.

First, there is little convention in which sites are used for electrode placement. Asymmetry studies in wakefulness also report significant differences at one electrode site while no substantial asymmetries are reported at others (Ray and Cole 1985). It has been demonstrated that even those studies which do support asymmetrical activation of the hemispheres during sleep do not find significant differences in all electrode sites (Pivik, et al 1982;

Antrobus et al 1978 and Hirshkowitz, Turner, Ware and Karacan, 1979). Also, studies relying on integrated amplitude techniques infer activation of one hemisphere from higher amplitude or power estimates in the opposite hemisphere. The EEG techniques utilized by Moffitt et al (1982)-period analysis and by Pivik et al. (1982)-Fourier analysis, directly measure the EEG activity in both hemispheres, rather than inferring activation. Furthermore, Goldstein et al (1972); Goldstein (1979); Hirshkowitz et al (1979) and Hirshkowitz et al (1980) all used integrated amplitude of total EEG without filtering specific EEG frequencies. Antrobus et al (1978) and Rosekind et al (1979) filtered 2-12 Hz and 9-12 Hz frequency bands, respectively. Relying on integrated amplitude analysis rests on the assumption that higher amplitude reflects cerebral deactivation, an assumption which may be questioned. For example, in sleep detailed dream reports can be elicited from Stage 4 sleep where high amplitude delta activity predominates, and in wakefulness theta activity (relatively high amplitude) is associated with intense problem solving (Pigeau, 1985), hardly suggestive of cortical deactivation in the presence of high amplitude EEG activity. Utilizing total EEG amplitude values without filtering EEG frequency bands results in a bias against low amplitude, fast frequency EEG activity. The technique is dependent upon the presence of high amplitude activity and thus in sleep, is biased toward the presence of delta activity. In wakefulness, the technique is biased

toward the presence of alpha and theta frequencies. Estimates of the percent of activity within a frequency band, relative to tonic variation within an epoch are not provided by this method of analysis. Hence, the presence of high amplitude activity in epochs within which low amplitude, fast frequency predominates, will result in an integrated amplitude value not representative of overall EEG activity and may be misleading especially when hemispheric asymmetries are of interest. One hemisphere may display a predominance of alpha activity, while the other consists of mixed delta and beta activity, yet both produce comparable integrated total EEG amplitude values. These values would be interpreted inappropriately as reflecting hemispheric symmetry. Filtering for specific frequency bands overcomes some of the difficulties mentioned above. It is interesting to note that the studies which filtered EEG frequencies do not support Goldstein et al's (1972) study.

An additional problem in this research and other projects investigating physiological and behavioral differences among sleep stages, is the failure to separate stages of NREM sleep. This convention is based on the implicit assumption that REM sleep is unlike all other sleep stages. Electrophysiologically, REM and Stage 2 sleep are more similar than other sleep stages, characterized by the presence of desynchronous, fast frequency activity (Rechtschaffen and Kales, 1968). Dream recall rates are also most similar among REM and Stage 2 (Armitage, 1980). Based on the similarities and differences among sleep stages, it is

strongly recommended that each stage of sleep be analyzed and compared separately.

In summary, there is mixed support in recent EEG research for the notion of right hemisphere activation during REM sleep and left hemisphere involvement in NREM stages. Thus it is not clear that differential activation of the two hemispheres characterizes the sleep cycle as suggested originally by Broughton. However part of the difficulty in evaluating this hypothesis may stem from a general lack of knowledge about the nature of electrophysiological differences between REM and NREM sleep. The periodicity of REM and NREM cycles has been discussed earlier in this paper. However sleep research has not focused on an investigation of the frequencies of EEG activity which may differentiate between REM and NREM sleep stages. As sleep stages are usually evaluated using Rechtschaffen and Kales (1968) scoring system, assigning a single score for each of the REM and NREM stages, information concerning the EEG frequency characteristics is lost. There are however a number of behavioral studies which are also relevant to Broughton's hypothesis.

Behavioral Asymmetries During Sleep:

Lavie and his colleagues have investigated performance asymmetries and perceptual differences between REM and NREM sleep. Gordon, Frooman and Lavie (1982) tested 12 subjects on six tasks presumed to reflect differential hemispheric

involvement following REM and NREM awakenings. Left hemisphere tasks included digit span, serial ordering of familiar sounds and word fluency. Right hemisphere tasks included dot localization, form recognition and spatial orientation. Raw scores on the tasks were standardized and a composite was created for the left and right hemisphere tasks by averaging scores on each task. Gordon et al (1982) then calculated a cognitive laterality quotient by subtracting the left composite score from the right. Thus, a negative quotient reflected better performance on the left hemisphere tasks, while a positive value reflected better performance on the right tasks.

Gordon et al (1982) tested the difference between the laterality quotients and obtained significantly greater left hemisphere performance following NREM awakenings with virtually no bias in performance following REM sleep. The data presented in this study however, are extremely difficult to interpret. The authors present analyses of the composite scores, yet discuss performance on individual tasks for which the data are not reported. They report that performance on the dot localization task, considered under right hemisphere control, was most accurate following REM, and significantly worse following NREM awakenings. The serial ordering of environmental sounds, considered left hemisphere dominant, showed the greatest decrement following REM awakenings, but was not significantly different from NREM performance. Data for the other tasks were not provided in the paper.

Gordon et al (1982) concluded that their results

reflected a "shift in cognitive profile that appears time-locked to a biorhythm" (p 100). As the authors pointed out, more extensive studies supported by electrophysiological data and spectral analysis of changes in performance, are necessary to determine the relationship between the activation of the two hemispheres and sleep cycles. However, Gordon et al (1982) do not report whether performance estimates were based on percent correct, number completed or reaction time. Thus, it is difficult to compare these results with other behavioral assessments of lateralization. The authors also failed to report from what stage of sleep their NREM awakenings took place. Their data, despite the difficulties, are however, in agreement with some waking studies to be discussed in the following section of this paper.

Bertini, Violani, Zoccolotti, Antonelli and DiStefano (1983) have demonstrated a left hand superiority on tactile tasks upon awakening from REM sleep compared to NREM and waking performance on this task. Bertini et al interpreted this result as evidence for greater right hemisphere activation during REM sleep. However, they also obtained higher dream recall rates from those subjects who displayed small differences in right or left hand advantage upon awakening from REM, suggesting that dream recall should not be viewed solely as a right hemisphere process. They also provided evidence that a pattern of hemispheric balance in EEG mediates the recall of sleep experiences. We will return

to the issue of hemispheric balance-imbalance during sleep in chapter 5 of this paper.

In summary, there is some support for the notion of increased performance on visuo-spatial and perceptual tasks following REM awakenings and a relative deficit in performance on these tasks following NREM awakenings. While they do provide some support for the right hemisphere-REM, left hemisphere-NREM relationship, these studies do not address biological rhythms in performance during sleep or wakefulness. Spectral analyses of behavioral data during wakefulness have identified rhythms in performance relevant to both the BRAC hypothesis and Broughton's suggestion that interhemispheric oscillations underly ultradian rhythms.

Cognitive Rhythms in Wakefulness

Several researchers have pointed out the similarities between daydreams and night dreams (Armitage, 1983; Czsizentmihalyi, 1975; Piaget, 1962). In part based on the suggestion by Globus (1966), among others, that there is a waking analogue of dreaming and Kleitman's BRAC proposal, Kripke and Sonnenschein (1978) investigated ultradian rhythms in waking fantasy and the relationship between alpha activity and eye movements with the fantasy content of daydreams.

In the first part of this study subjects recorded their daydreams every five minutes while EEG and eye movements were recorded. The subjects were isolated and were not provided with any form of amusement. Each daydream was rated on a fantasy scale by the experimenters, and at a later date by

the subjects themselves. The amount of alpha activity and eye movements were scored visually for each five minute epoch from which time series were constructed. The scores on the fantasy daydream scales were averaged between experimenter and subject ratings and used to construct a time series. Lagged autocorrelations, power spectral density functions and cross spectral power were computed between each pair of variables.

Their results indicated significant spectral peaks in fantasy content at 16 cycles/day (90 minutes). Eye movement spectra also peaked at 16 cycles/day, significantly greater than mean variance at adjacent frequencies, but only marginally different from the average spectra. Alpha activity also showed a significant 90 minute rhythm. Increases in fantasy content were associated with increased alpha and a decrease in eye movements. All these correlations were significant. Furthermore, the mean coherence spectra, relating fantasy to alpha and eye movement spectra peaked at 16 cycles/day.

Kripke and Sonnenschein (1978) also investigated rhythms in daydreams in individuals allowed to maintain their normal daily habits, adding further support for the continuation of "dream-like" activity throughout sleep and wakefulness, as suggested by Broughton (1975). It should be noted however, that Kripke and his colleagues have been unable to replicate this finding (Kripke, 1982).

Lavie and his colleagues have conducted several research projects to investigate the persistence of rhythms in the

perception of the ~~spiral~~ after effect in wakefulness. Lavie, Levy and Colledge (1974) tested SAE durations throughout the day in a group of University students. One group of subjects were tested every five minutes from 8AM to 4PM and one from 12 midnight to 8 AM. Time series were constructed from the durations of the after effect and transformed to z scores. Lag autocorrelations and spectral analyses were then performed on the transformed data. Highest spectral peaks were obtained at approximately 100 minutes indicating an ultradian rhythm in the magnitude of the SAE, of a similar periodicity as sleep cycles.

Lavie, Lord and Frank (1974) replicated these results in a group of high school students, using a similar paradigm. The SAE was tested every five minutes from 4 PM until midnight on two consecutive days in the laboratory. Four subjects were tested twice, and four subjects tested three times during each five minute interval. Time series were constructed on the magnitude of the duration yielding 16 time series. Spectral density and autocorrelational analyses were performed after the data were smoothed. Of interest to Lavie et al were 66.7, 83.4, 100, 142.8 minute cycles, the normal range of the REM-NREM cycle. The authors reported that 62 percent of the time series (10/16) showed peak power in the 66.7-142.8 minute range although there was considerable variability between subjects. The median peak was 100 minutes. Of the eight subjects, three showed significant peaks in the predicted range on both days, three on the

second day alone and one on the first day alone. One subject did not show significant peaks in SAE duration on either day. Analysis of the pooled group data revealed one spectral peak at 100 minutes. It is unclear from their description whether Lavie et al (1974) tested the significance of spectral peaks at frequencies other than the four within the range of the REM-NREM sleep cycle. Had this analysis been performed, significant peaks reflecting circadian variations or additional ultradian rhythms may have been determined. These data nonetheless are suggestive of a BRAC involving perceptual processes.

Lavie (1977) has also investigated ultradian rhythms in the phi phenomenon in wakefulness. In this study, eight high school students were tested every five minutes on the SAE, testing the phi phenomenon every fourth trial (every 20 minutes). Testing sessions lasted from 4PM to midnight. An additional eight subjects slept in the laboratory and were tested after the morning awakening on both these phenomena every five minutes for eight hours. Two time series were constructed for each subject, one for the range of the phi phenomenon every 20 minutes, and one for the duration of the SAE, on the five minute trials. Autocorrelations and spectral analyses were then performed, yielding significant spectral peaks at 14.4 cycles/day (100 minute) in both perceptual phenomena. The 100 minute cycle was significantly greater than adjacent frequencies for both tasks using autocorrelational analysis. Lavie (1977) used a one-tailed t-test of significance. This author performed a two-tailed test

of significance and found that only the phi phenomenon showed a 100 minute spectral intensity significantly larger than adjacent frequencies. Cross-spectral analysis also revealed significant 100 minute peaks for both phenomena. Lavie obtained a low positive correlation ($r=.11$) between the SAE and phi phenomenon, from which he concluded that the same oscillatory mechanisms govern performance of these two tasks. He cited the 26 degree phase relationship as evidence for this. It should be noted however, the mean angular deviation was ± 66 degrees, suggesting that there is much variability in the synchronicity of the two perceptual rhythms. Performance on the tasks used in this study does appear to be related, but the data are not strong enough to warrant the conclusion that there are governed by the same oscillatory mechanisms. Lavie (1977) also concluded that performance on these perceptual tasks is phase-locked to REM-NREM oscillations. No direct support for this notion has been provided although night time research in his laboratory reported earlier in this paper is suggestive.

More recently Klein and Armitage (1979) have provided evidence for 90 minute ultradian rhythms in performance on tasks presumed to reflect the unique specialization of the two hemispheres, in support of Broughton's hypothesis that cyclic activation of the two hemispheres underlies cognitive aspects of the BRAC. This project tested five females and three males, all right-handed, on verbal and spatial tasks from 9 AM to 5 PM. The verbal task involved deciding whether

pairs of letters (one upper, one lower case) had the same name. The spatial task required subjects to decide if pairs of ~~random~~ dot patterns were identical. The tasks were presented in booklet form and subjects were tested on alternating booklets every three minutes. Performance was measured as the number of pairs correctly matched in each three minute period, yielding 32 scores for each task throughout the session. Scores were normalized and subjected to spectral analysis.

Significant spectral peaks were obtained at four hours, 96 minutes and 37 minutes and analysis of the phase relationship revealed that performance on the two tasks was 180 degrees out of phase. The authors interpreted these results as confirmation of Broughton's hypothesis that the efficiencies of the two hemispheres express a 90 minute periodicity, and suggested that this rhythm is a waking analogue of the REM-NREM sleep cycle. Although the authors did not comment, the significant spectral peaks obtained at other frequencies suggest that more than one biological rhythm related to performance is active during wakefulness. It is interesting to note that unpublished data from the Carleton University Sleep Laboratory suggests that four hour rhythms are discernable in the presence of delta activity in EEG recordings across the night. Should these rhythms be confirmed, it would add considerable support for a multi-oscillatory BRAC active throughout sleep and wakefulness. Kleitman (1963) has suggested that there are circadian influences on performance manifesting themselves in fatigue,

alertness and post-lunch dip phenomena. This suggestion would predict the four hour rhythms obtained in the Klein and Armitage (1979) study, although Kripke (1982) has interpreted significant spectral peaks at frequencies other than 90 minutes as evidence against a stable BRAC in performance.

Kripke, Fleck, Mullaney and Levy (1983) attempted to replicate ultradian rhythms in performance using similar tasks to Klein and Armitage (1979). Eleven subjects were tested for 10 hours on letter and dot matching task and the Wilkinson's Auditory Vigilance Task, adapted for computer presentation. Each subject was tested individually for three minutes on the letter task, three minutes on the dot task, three minutes on the vigilance task and one minute completing self-ratings on sleepiness and attention-fantasy scales, throughout the day. From the resulting 60 scores, time series were constructed and spectral analyses were performed on the smoothed data..

Kripke et al (1983) found no significant 90 minute peaks in performance and reported that performance on the letter and dot tasks was positively correlated ($r=.59$), in apposition to Klein and Armitage (1979). Results for the vigilance task were not reported. Kripke et al (1983) concluded that their results "...fail to confirm...Klein and Armitage. They lend no support whatsoever to the hypothesis that there is an about 90 min. cycle in performances modulated by alternating hemispheric dominance" (p 5).

There are a number of differences between Kripke et al

(1983) and Klein and Armitage (1979) which are worthy of note and may account for the discrepancies among these two studies. First, Kripke et al provided subjects with feedback on their performance throughout testing, with monetary rewards for high accuracy. This information was displayed after each trial and at the end of each ten minute session. They also provided strong negative auditory feedback for errors. This procedure which Kripke et al introduced to "control motivation", produced demand characteristics entirely different than the Klein and Armitage procedure. In a study investigating differences in ultradian performance rhythms where subjects were provided with knowledge of their results and in conditions where they were unaware of accuracy, Gopher and Lavie (1980) demonstrated that providing subjects with feedback suppresses performance cycles. This finding suggests that Kripke et al may have obscured the rhythms in their data by altering the demand characteristics and motivational features of their study. Their data analysis procedure also utilizes spectral density functions while Klein and Armitage (1979) computed periodograms without averaging spectral estimates. As suggested by Brillinger (1975), periodograms may be more appropriate with behavioral time series given the low sampling rate. This criticism is also relevant to other studies discussed in this chapter. Often the description of the analysis procedures do not specify whether periodograms or spectral density functions are performed on time series. Unpublished data from the Carleton University Sleep Laboratory suggest that under

conditions of a low sampling rate, spectral density power values differ substantially from untransformed FFT's (periodograms). Without a detailed description of the analysis procedures it is difficult to compare the results from different laboratories. A study comparing rhythms in performance under different demand characteristics may provide some explanation for the discrepancies among these studies. Still, Kripke et al (1983) did obtain a significant positive correlation between performance on the right and left tasks, contradicting Klein and Armitage (1979). With these considerations in mind, the results from Kripke et al may be interpreted several ways. These data may either reflect conditions under which ultradian rhythms may be masked by motivational changes and demand characteristics or that the ultradian variation in performance obtained in the study by Klein and Armitage (1979) was artifactual. Neither Kripke et al (1982) nor Klein and Armitage (1979) included corroborative EEG data and should therefore be viewed as assessments of ultradian rhythms in cognition rather than hemispheric asymmetries. If the assumption is made that performance on tasks of the type outlined above reflect the unique specialization of the two hemispheres then there is some support for Broughton's (1975) hemispheric hypothesis. However, recently it has been suggested that it may not be appropriate to conceptualize functional asymmetries as reflecting the unique processing capabilities of the two hemispheres (Allen, 1983).

There are several other methodological difficulties in those studies assessing performance cycles which are worthy of note. The tasks employed by Klein and Armitage (1979) and Kripke et al (1983) share a common information processing component which makes it difficult to conceive of these tasks as reflecting unique asymmetry of function. Both the letter and the dot tasks require a same/different comparison. It is probable that processes required to perform a same/different comparison are not unique to one hemisphere. Thus the tasks in these studies differ on stimulus characteristics and they require subjects to name the letters while the visuo-spatial task requires a pattern comparison in the absence of a linguistic code. There is also an inherent bias in degree of difficulty between these tasks, with the spatial task being considerably more difficult than the letter matching task. In Klein and Armitage (1979) subjects correctly matched an average of 182 letter pairs and only 115 patterns. Since stimulus characteristics alone are not sufficient to predict functional asymmetries and a number of studies suggest the right hemisphere can recognize simple linguistic code (cf Armitage, 1981) it is suggested that these tasks should not be viewed as 'hemisphere-specific'. None of the studies discussed in this paper ensured lateralization of presentation to the right or left visual fields and do not include corroborative EEG data. Periodicities in behavioral data of the type outlined above should be interpreted as aspects of a performance cycle. The tasks need not be viewed as dependent upon processes unique to the two hemispheres.

Tasks which require different processing strategies may just as well characterize ultradian rhythms in cognition without the constraints of lateralization theory. There is at present no evidence that suggests differential activation of the two hemispheres is in phase with performance cycles and the oscillation of sleep stages. Therefore the behavioral data reported in the previous chapter should not be taken as an assessment of the BRAC hypothesis or Broughton's cerebral activation proposal. There have been a few studies which have characterized the nature of EEG rhythms in wakefulness, among them Study 1 presented in the next chapter of this paper. Although they do not assess the BRAC hypothesis they do suggest the frequency bands of EEG activity which may display BRAC oscillations.

Chapter 3

Study1: Ultradian Rhythms in EEG Activity and Performance

There have been a few studies which have investigated ultradian rhythms in waking EEG activity (Manseau and Broughton, 1984; Okawa, Matousek and Petersen, 1984) although they have not focused on EEG periodicities during task performance. Nonetheless they are of relevance to the BRAC hypothesis.

Okawa et al (1984) recorded five seconds of parietal and occipital EEG activity in nine subjects every twenty minutes for eleven hours. During the recording interval subjects were required to lie down, close their eyes and relax. In the intervening periods when EEG activity was not being recorded the subjects were permitted to engage in "light" activities such as reading, handicrafts and writing. This procedure was repeated one week later. Okawa et al (1984) analysed the EEG using a computerized method for "vigilance assessment", a technique for measuring alertness based on the presence of fast-frequency desynchronous EEG and the absence of slow frequency high amplitude wave forms. Time series were constructed from the vigilance EEG profile and autocorrelational analyses were performed to determine the sine wave frequency which best approximated the vigilance profile throughout the testing session. The results from their study conform to the general pattern of performance fluctuations (Kleitman, 1963) indicating more variability in the morning, a large "post-lunch dip" and relative stability

in the afternoon. In addition Okawa et al (1984) reported significant 60-110 minute rhythms in 16 of the 19 analyzable vigilance time series with 12 of the 19 recordings displaying significant 80-110 minute rhythms. They concluded that EEG vigilance displays an ultradian variation in wakefulness but stressed the large intra- and inter-subject variability obtained in this data set.

Manseau and Broughton (1984) have also investigated ultradian rhythms in waking EEG, focusing on hemispheric differences from frontal and parietal recording sites. The eight subjects in this study were not required to perform tasks during the testing session but were required to write down their thoughts after EEG samples were recorded every 15 minutes. Every 45 minutes subjects completed a mood questionnaire and received two personality inventories upon completion of the test session. FFT's were performed on each EEG lead and spectral density functions were computed in addition to cross-spectral analysis comparing left and right hemisphere activity at frontal and parietal recording sites. Predominant 16 c/day rhythms were obtained in frontal but not parietal theta amplitude measures while the cross-spectral analysis indicated bilaterally synchronous ultradian theta cycles. These results do not confirm Broughton's (1975) hypothesis of unihemispheric fluctuations in wakefulness but do indicate rhythms in theta activity of a similar periodicity to the REM-NREM sleep cycle. Manseau and Broughton (1984) do point out however that their research methodology allowed an investigation of phase shifts in

hemispheric EEG rather than amplitude differences between the two hemispheres relative to overall EEG activity.

Study 1, presented below, investigated rhythms in interhemispheric EEG activity while subjects were engaged in mathematical and visuo-spatial tasks (Armitage, Hoffmann, Moffitt and Pigeau, 1985). The intent was to determine which EEG frequency bands, if any, display ultradian variations during task performance. This study included two sets of interhemispheric EEG values: a ratio of the difference between the two hemispheres relative to overall EEG activity and a set values reflecting the absolute value of the difference between the two hemispheres. Due to the exploratory nature of this research, no specific hypotheses concerning EEG frequency bands were generated.

METHOD

Subjects

Three right handed male and four right handed female volunteers between 22 and 30 years were chosen as subjects. All were university undergraduates and none suffered from known medical or psychological disorders nor were they taking medication at the time of this study. All subjects were asked to refrain from consuming alcohol or drugs 24 hours prior to participating.

Apparatus

Subjects performed visuo-spatial and mathematical tasks in an anechoic chamber measuring 10'x6'x8', equipped with an intercom for communication. Subjects were seated at a table

equipped with a chin rest and a head brace. A 15" video screen, used to display the stimuli was located three feet in front of the subject's chair. Presentation of the mathematical and visuo-spatial stimuli was controlled by an Apple II + microcomputer located outside the chamber.

The physiological equipment consisted of four Grass (P511) EEG amplifiers with power supply, a Beckman (RN) dynograph, a dual beam Textronix oscilloscope, a Vetter (Model 1) FM tape recorder and a square wave signal generator. EEG, EOG and EMG were recorded at 15/16 ips. The electrophysiological data were subsequently quantified using an LSI-11/23 computer with A/D converters, real-time clock and discs for mass storage. After quantification using fast Fourier transforms (FFT's) the EEG data were transmitted to the Carleton University (Honeywell) CP-6 computer for spectral and subsequent statistical analyses. EOG and EMG data were used for selecting artifact-free EEG epochs from polygraph records but were of no subsequent interest in this study.

The Tasks

The subjects, tested individually, were presented with two tasks requiring different processing strategies. The pattern task required a comparison to set strategy with one of four possible solutions. The mathematical task had a range of 90 possible answers between 10 and 99 and required the addition and subtraction of four double digit numbers.

Pattern Task

For this task four random asterisk patterns, each composed of six asterisks, were displayed one in each quadrant of the video screen for five seconds followed by a three second delay. A single asterisk pattern then appeared in the center of the screen and subjects were required to indicate in which quadrant of the screen the target stimulus had appeared originally. Subjects responded by saying "upper left", "upper right", "lower left", "lower right". The target pattern remained in view until a verbal response was made.

Mathematical Task

For this task four numbers were presented in equation form requiring additions and subtractions of the following type:

$$45+73-69+13=?$$

The equation, containing either two additions and one subtraction or two subtractions and one addition, was presented in the center of the video screen for ten seconds or until subjects had solved the equation. The subjects were instructed to provide a verbal solution as quickly as possible while still maintaining accuracy.

Procedure

Each subject entered the laboratory at 8 a.m. for electrode placement. EEG recordings were made from sites P3 and P4, referenced to linked ears at sites A1 and A2 with Beckman AgCl electrodes. A pair of submental electrodes were

used for EMG recordings and a bipolar array at sites E1 and E2 was used for EOG recordings. A gain of 10,000x was used for EEG and EOG with filter settings at 0.3 Hz and 100 Hz. The EMG amplifier was set to produce a voltage excursion of 2v peak to peak at the start of the experimental session. An automatic event timer used to signal A/D conversion was recorded simultaneously with the electrophysiological measures on FM tape. After electrode placement the subject was seated at the table in the anechoic chamber and two minute eyes open and eyes closed baselines were recorded.

The test sessions began with the presentation of either spatial or mathematical stimuli counterbalanced among subjects, consisting of multiple trials approximately ten seconds in length for three minutes. As the inter-stimulus interval was controlled by the length of time subjects required to solve the mathematical problem some trials were longer than ten seconds in length. This interval was followed by a three minute interval on the alternate task and a four minute rest interval in which subjects were requested to sit quietly and relax. This procedure continued for four hours yielding 24 trials for the mathematical and spatial stimuli.

On average subjects received eight pattern stimuli and ten equations during each trial. Electrophysiological data were not recorded during rest intervals and no food, beverages, or time cues were permitted for the duration of the experimental session.

Time series were constructed from the percent correct

estimates on each of the 24 trials on the spatial and mathematical tasks upon which FFT's were performed to determine periodicities in performance. An additional analysis was performed on the behavioral data. A ratio of the relative difference in performance on the two tasks of the type:

$$\frac{\% \text{ Correct Spatial} - \% \text{ Correct Math}}{\% \text{ Correct Spatial} + \% \text{ Correct Math}} \times 100$$

was calculated and subjected to Fourier analysis.

EEG Analysis

Following the experiment the FM tape was replayed for EEG quantification. The recorded event timing signal activated the A/D converter linked to the LSI-11/23 computer. The first four seconds of each ten second trial were sampled at a rate of 64 samples/second (64 Hz) after which FFT's were performed. The four second segment was chosen for analysis as it recorded the interval during problem solving before a solution had been generated and as it was free of response artifact. Gevins and his colleagues have suggested that hemispheric asymmetries during task performance are an artifact of the motor response component of problem solving (Gevins, Zeitlin, Doyle, Schaffer and Calloway 1979a; Gevins, Zeitlin, Doyle, Yingling, Schaffer, Callaway and Yeager, 1979b).

The FFT routine provided a power estimate for each EEG frequency band categorized as delta (0.5 to <4.0 Hz), theta (4.0 to <8.0 Hz), alpha (8.0 to <12.0 Hz), sigma (12.0 to <16.0 Hz), beta (16 to 30 Hz) as well as a total power

estimate. The power values from left and right recording sites were used to calculate relative interhemispheric ratios ($(\text{left-right}/\text{left} + \text{right} \times 100)$) for each EEG frequency band on each ten second trial. The relative ratios were then averaged across the three minute task intervals producing a 24 point time series of interhemispheric EEG ratios in each frequency band and a left-right total power estimate for the mathematical task and the visuo-spatial task. The use of relative ratios is however suspect to artifact. The following examples illustrate this point. If an EEG value for a given frequency band is 40 from the left recording site and 10 from right recording site the relative ratio produces a value of 60 ($(40-10/40+10 \times 100)$). If an EEG value from the left recording site is 4 and 1 from the right, the relative ratio also produces a value of 60 ($(4-1/4+1 \times 100)$). The relative ratio from the second example suggests large interhemisphere differences when in fact the differences between right and left values are quite small.

To compensate for the possible artifact produced by the relative ratios, time series were also constructed from the absolute value of the difference between the two hemispheres without regard to overall EEG activity. These absolute difference measures were also averaged across the three minute task intervals producing a 24 point time series for each EEG frequency band for the two tasks. Spectral analyses on EEG and performance data were computed using BMDP-1T univariate and bivariate routines providing a spectral

resolution from 1 cycles per unit time (cut.) a 320 minute rhythm, 2 cut (160 minutes), 3 cut (107 minutes) 4 cut (80 minutes), 5 cut (64 minutes), 6 cut (53 minutes), 7 cut (46 minutes) 8 cut (40 minutes), 9 cut (36 minutes), 10 cut (32 minutes), 11 cut (29 minutes), 12 cut (27 minutes), 13 cut (25 minutes), 14 cut (23 minutes), 15 cut (21 minutes) and 16 cut (20 minutes). It should be noted that all spectral analyses were performed on individual subjects' time series and not on group averages. After spectral analysis, group differences were tested with analysis of variance of the power spectral values. This procedure was followed to compensate for the possibility that individual cycles may not have been synchronized.

RESULTS

1.1 Performance Data

To remind the reader, the performance data were analyzed in three different ways. For each subject time series were constructed from percent correct estimates on the pattern task, percent correct estimates on the mathematical task and finally from a ratio of the percent correct scores on both tasks reflecting the relative difference in performance. Thus three performance time series were constructed for each subject.

1.1.1 Spectral Analyses of Performance Data

Spectral analyses were then performed on these time series to determine the frequency of ultradian variations in task performance. Average performance on the mathematical

task was 71.8 % and 65.3 % on the visuo-spatial task.

Figures 1 and 2 present the power spectra for performance on the mathematical task and the spatial task respectively. From examining Figure 1 it can be seen that males display 27, 32 and 53 minute rhythms in mathematical performance. Females show peak power at 80 and 25 minutes. Repeated measures analysis of variance (ANOVA) indicated no significant periodicity main effect but a significant sex x periodicity quadratic trend interaction was obtained ($F=7.24$ $df=1,5$ $p=.036$) indicating multiple periodicities that differ among males and females. In spatial task performance, as seen in Figure 2, females show a 53 and a 29 minute rhythm while males show 20, 46 and 40 minute performance cycles. Neither sex nor periodicity main effects were significant with ANOVA although a sex x periodicity trend interaction was obtained ($F=6.59$ $df=1,5$ $p=.04$), also indicating multiple ultradian rhythms which differ among males and females.

A significant main effect for periodicity in the relative performance ratios ($F=3.20$ $df=15,75$ $p=.003$) was obtained from ANOVA, indicating 107 minute rhythms in this performance measure. There were however no interactions with sex (See Figure 3).

1.1.2 Correlations of Performance Data

Pearson product moment correlations were calculated on the percent correct estimates to determine the relationship between performance on the spatial and the mathematical tasks. The results, presented in Table 1, indicate high positive correlations between mathematical and spatial

Figure 1: Power spectra of performance on the mathematical task for males and females.

Figure 2: Power spectra of performance on the visuo-spatial task for males and females.

Figure 3: Power spectra of relative performance ratios collapsed across sex.

Table 1: Correlations between average percent correct mathematical and spatial scores (Coherence Index).

	FEMALES	MALES	COMBINED
Math with Spatial	$r = .39$	.99	.50
	$p = .61$	.03	.25
	$n = 4$	3	7

performance for males ($r=.99$, $n=3$, $p=.03$) suggesting that the two tasks are in phase. Correlations are not significant for females ($r=.39$, $n=4$, $p=.61$), or collapsed across sex ($r=.50$, $n=7$, $p=.25$).

1.2 EEG Analyses

Only the EEG measures displaying 80-120 minute rhythms supported by a significant main effect for periodicity or a sex x periodicity interaction from repeated measures ANOVA are reported here.

1.2.1 Relative Ratio EEG Measures

The power spectra for the relative ratio of Delta Power during the mathematical task is presented in Figure 4, indicating 80 and 36 minute rhythms among males during this task. During the spatial task males showed a 20 minute rhythm while females showed no spectral peaks during either task. ANOVA supported these findings revealing a significant task by sex by periodicity interaction ($F=2.15$, $df=15,75$ $p=.010$). None of the remaining relative ratio EEG measures showed 80-120 minute cycles.

1.2.2 Absolute Difference EEG Measures

The absolute difference in Beta Power indicated small 320 and 80 minute rhythms for females with a 64 and 32 minute rhythm among males during spatial task performance. See Figure 5. Repeated measures ANOVA confirmed these differences indicating a significant sex by periodicity interaction ($F=2.50$, $df=15,75$ $p=.005$). Females also showed peak spectral power in the absolute difference in Beta Power at 80 minutes

Figure 4: Power spectra of relative ratio Delta Power for male and females during the mathematical task.

Figure 5: Power spectra of absolute difference BETA POWER during the visuo-spatial task

during the mathematical task although ANOVA indicated no significant main effects or interactions.

Figure 6 presents the power spectra for absolute difference in Sigma Power during the spatial task where it can be seen that females showed largest spectral power at 107 minutes. Males showed a 320 minute rhythm in this EEG measure. Repeated measures ANOVA indicated a significant sex by periodicity interaction in support of these differences ($F=1.95$, $df=15,75$ $p=.030$). During the mathematical task both males and females showed multiple peaks in the absolute difference Sigma Power which failed to reach significance with ANOVA.

Alpha Power absolute difference measures during the spatial task showed 320 minute rhythms for both males and females which approached significance in ANOVA ($F=1.74$, $df=15,75$ $p=.061$ periodicity main effect).

1.3.1 Correlations Between EEG and Performance Measures

To determine the relationship between the relative EEG ratios, absolute difference EEG measures and performance, Pearson product moment correlations were computed between the average relative ratio of each EEG frequency, average absolute difference values and average performance on the two tasks. These correlations may be viewed as analogous to a coherence index, providing a single estimate of the overall relationship among EEG and performance variables (prior to spectral analysis). The correlation matrices for males and females respectively are presented in Tables 2 and 3.

Figure 6: Power spectra of absolute difference SIGMA POWER during the visuo-spatial task.

Table 2: Correlations between absolute difference and relative ratio EEG measures and percent correct performance for males (Coherence index).

Absolute Difference EEG measures with Performance

Beta with Math	r = -.526 p = .647	Beta with Spatial	.023 .985	Sigma with Math	.996 .060	Sigma with Spatial	.901 .286
Alpha with Math	.929 .241	Alpha with Spatial	.648 .551	Theta with Math	.822 .386	Theta with Spatial	.864 .336
Delta with Math	.763 .448	Delta with Spatial	.251 .839	TotPow with Math	.219 .860	TotPow with Spatial	.341 .778

Relative Ratio EEG measures with Performance

Beta with Math	.977 .137	Beta with Spatial	.961 .179	Sigma with Math	.999 .030	Sigma with Spatial	.999 .030
Alpha with Math	.984 .113	Alpha with Spatial	.729 .479	Theta with Math	.974 .147	Theta with Math	.955 .191
Delta with Math	.993 .077	Delta with Spatial	.998 .042	TotPow with Math	.972 .151	TotPow with Spatial	.979 .131

Table 3: Correlations between absolute difference and relative ratio EEG measures and percent correct performance for females (Coherence Index).

Absolute Difference EEG measures with Performance							
Beta with Math	r= .690 p= .030	Beta with Spatial	-.807 .193	Sigma with Math	.664 .336	Sigma with Spatial	-.780 .220
Alpha with Math	.494 .506	Alpha with Spatial	-.738 .262	Theta with Math	.470 .530	Theta with Spatial	-.775 .225
Delta with Math	.154 .846	Delta with Spatial	-.413 .586	TotPow with Math	.569 .431	TotPow with Spatial	-.618 .382
Relative Ratio EEG measures with Performance							
Beta with Math	.933 .067	Beta with Spatial	.311 .689	Sigma with Math	.916 .084	Sigma with Spatial	.259 .741
Alpha with Math	.548 .452	Alpha with Spatial	.371 .629	Theta with Math	.331 .679	Theta with Spatial	-.914 .086
Delta with Math	.787 .213	Delta with Spatial	.191 .809	TotPow with Math	.971 .029	TotPow with Spatial	.295 .705

Table 2 presents the correlation matrix among EEG and performance measures for males where it can be seen that males showed few significant correlations between the absolute difference EEG measures or the relative ratio measures and performance. The absolute differences in Sigma and Alpha Power are positively correlated with performance on the mathematical task, indicating that as performance improves there is a greater absolute difference between the two hemispheres. A similar pattern was obtained for the absolute difference in Sigma Power and spatial task performance.

In terms of the relative ratio EEG measures, Sigma Power was correlated significantly with performance on both tasks, indicating that greater amounts of Sigma Power in the left hemisphere is associated with accuracy on both tasks. Relative ratios in Delta Power show a similar pattern. Although there are only three males in this group, the high positive relationship between greater left hemisphere power and task performance is evident in all relative ratio EEG measures and is consistent among these subjects. Performance on the spatial task does not appear to be associated with an increase in right hemisphere activity as would be predicted by the hemispheric asymmetry literature.

The relationship between EEG and performance cycles among females differs substantially from that of males as can be seen in Table 3. All correlations between absolute difference EEG measures and performance are included in Table 3 as they demonstrate a consistent trend across frequency

bands which may have reached significance had more subjects been included. All absolute difference EEG measures are negatively correlated with performance on the spatial task, ranging from $-.413$ for Delta to $-.807$ for Beta. A negative correlation reflects an increase in performance associated with smaller absolute differences between the hemispheres. Performance on the mathematical task is associated with larger absolute differences, as the positive correlations suggest. The interhemispheric EEG measures suggest that an increase in left hemisphere Beta, Sigma and Total Power is associated with increased mathematical performance.

1.3.2 Correlations Among EEG Measures

Due to the small number of subjects in each group, only correlations exceeding $\pm .997$ (for males) and $\pm .950$ (for females) reached a .05 level of significance. For illustrative purposes only those correlations exceeding $\pm .900$ are included in Tables 4 and 5.

The correlations among EEG measures for males, as seen in Table 4, indicate that an increase in the relative ratio of Alpha Power is associated with an increase in relative ratios of Beta Power. This finding is contrary to accepted notions of the interrelationship among EEG frequencies which suggest that Beta is inversely correlated with Alpha. The absolute difference measures also show positive correlations among EEG frequency bands but less pronounced than the relative ratio measures.

The correlational pattern for females, presented in

Table 4: Correlations among absolute difference EEG measures and relative ratio EEG measures for males.

Absolute Difference EEG Measures					
Beta Math		Theta Math		Beta Spatial	
with	r= .945	with	.995	with	.962
TotP Math	p= .212	Delta Math	.061	Delta Spatial	.176
Beta Spatial		Sigma Spatial		Sigma Spatial	
with	.932	with	.914	with	.997
TotP Spatial	.237	Alpha Spatial	.265	Theta Spatial	.050
Alpha Spatial		Alpha Spatial			
with	.943	with	.937		
Theta Spatial	.215	TotP Spatial	.227		
Relative Ratio EEG Measures					
Beta Math		Beta Math		Beta Math	
with	.964	with	.999	with	.999
Sigma Math	.170	Alpha Math	.024	Theta Math	.024
Beta Math		Beta Math		Sigma Math	
with	.996	with	.999	with	.974
Delta Math	.060	TotP Math	.024	Alpha Math	.146
Sigma Math		Sigma Math		Sigma Math	
with	.960	with	.985	with	.958
Theta Math	.180	Delta Math	.110	TotP Math	.184
Theta Math		Theta Math		Delta Math	
with	.994	with	1.00	with	.993
Delta Math	.070	TotP Math	.004	TotP Math	.074
Beta Spatial		Beta Spatial		Beta Spatial	
with	.968	with	.977	with	.997
Sigma Spatial	.161	Delta Spatial	.137	TotP Spatial	.048
Sigma Spatial					
with	.999				
Delta Spatial	.024				

Table 5: Correlations among absolute difference EEG measures and relative ratio EEG measures for females.

Absolute Difference EEG Measures					
Beta Math		Beta Math		Beta Math	
with	r = .965	with	.965	with	.915
Sigma Math	p = .035	Alpha Math	.035	TotP Math	.085
Sigma Math		Sigma Math		Sigma Math	
with	.962	with	.969	with	.986
Alpha Math	.038	Theta Math	.031	TotP Math	.014
Alpha Math		Alpha Math		Theta Math	
with	.961	with	.949	with	.992
Theta Math	.039	TotP Math	.051	TotP Math	.007
Beta Spatial		Sigma Spatial		Sigma Spatial	
with	.984	with	.902	with	.949
Sigma Spatial	.016	Alpha Spatial	.098	Theta Spatial	.051
Alpha Spatial		Alpha Spatial		Alpha Spatial	
with	.992	with	.908	with	.986
Theta Spatial	.008	Delta Spatial	.092	TotP Spatial	.014
Theta Spatial		Delta Spatial			
with	.972	with	.949		
TotP Spatial	.028	TotP Spatial	.050		
Relative Ratio EEG Measures					
Beta Math		Beta Math		Delta Math	
with	.948	with	.992	with	.952
Delta Math	.052	TotP Math	.008	TotP Math	.048
Beta Spatial		Beta Spatial		Beta Spatial	
with	.934	with	.986	with	.985
Sigma Spatial	.066	Alpha Spatial	.014	TotP Spatial	.015
Sigma Spatial		Alpha Spatial			
with	.973	with	.945		
Alpha Spatial	.027	TotP Spatial	.055		

Table 5, differs substantially from the male subjects. Females show few correlations among the relative ratio EEG measures, displaying strong correlations among the absolute difference EEG measures. For these subjects an increase in faster frequency bands such as Beta and Sigma is associated with an increase in slower frequencies such as Theta and Delta, among the absolute difference measures. This pattern is evident to a lesser degree among relative ratio EEG measures. Again, these findings are discordant with accepted notions of the functional correlates of EEG frequency bands discussed in Chap 1 of this paper.

DISCUSSION

To summarize, males showed 80-120 minutes in relative ratios of Delta Power during task performance. Females showed stronger evidence of ultradian variation in the absolute difference measures than males, demonstrating 80-120 minute cycles in Beta Power and Sigma Power especially during performance on the spatial task.

Spectral analysis of performance data indicated multiple rhythms in performance on both the visuo-spatial and mathematical tasks of periodicities shorter than 80-120 minutes. Only females showed 80 minute variations and only during the mathematical task.

Correlations between EEG measures and performance suggested that mathematical tasks are associated with greater relative left hemisphere activity, especially among males. Spatial task performance appears to be associated with small

absolute differences between the hemispheres among females and greater relative left hemisphere power among males. Taken together, the results from this study suggest that ultradian oscillations in performance and their electrophysiological correlates are clearly more complex than originally suggested by Broughton (1975) and Klein and Armitage (1979). There is little evidence in this study that an oscillation in right and left hemisphere EEG activity mediates performance and expresses a periodicity similar to REM-NREM sleep cycles. Rather the results from this study suggest that absolute differences in EEG activity display 80-120 minute variation especially among females. The proposed association between spatial performance and the right hemisphere and mathematical performance and the left hemisphere is not well supported. Only males show a significant positive relationship between greater left hemisphere relative ratios and performance on the mathematical task.

The results from this study are not however completely discordant with the hypothesis that oscillations in interhemispheric EEG underlie variations in performance. Females appear to show ultradian variations in the absolute difference EEG measures. These findings suggest that rhythms in interhemispheric EEG activity may best be described as an oscillation from small to large differences between the two sides of the brain. This pattern is attenuated among females.

There are however a number of methodological difficulties with this study that require discussion. It has

been demonstrated recently that high and low frequency dream recallers, that is individuals who remember their dreams regularly and those who report dream recall rarely, differ on a variety of phenomenological and electrophysiological dimensions as well as correlations among these two sets of variables (Moffitt et al., 1982). Specifically among high recallers it is relative ratios of interhemispheric Beta activity which correlates with subsequent dream content of color, vividness, the number of scenes and active-passive participation. Low recallers show significant negative correlations between likelihood of the experience and relative ratio EEG measures. When examining the relationship between the verbal characteristics of the dream report and pre-awakening EEG activity, Moffitt et al. (1982) found that high recallers showed a significant positive correlation between Beta activity averaged across the two hemispheres (rather than relative ratios) and the number of words in the dream report. Low recallers showed a strong negative relationship between relative ratios of interhemispheric Beta and Sigma activity and report length. Thus, if high and low recallers show a dissimilar relationship between EEG and verbal descriptions of dream reports, it is conceivable that they may differ in their relationship between EEG and other cognitive activities such as task performance during wakefulness. In comparing the correlations between pre- and post-awakening EEG measures among the two recall groups, Moffitt et al. reported more significant correlations among EEG measures averaged across the two hemispheres in high

recallers, while lows showed significant pre- and post-awakening interhemispheric EEG ratio measures. Given these differences, it is likely that high and low dream recallers would display different ultradian variations in electrophysiological measures during sleep and perhaps during wakefulness. The subject selection procedures in the present study did not allow an assessment of frequency of dream recall. The possible confound between sex and frequency of dream recall in the present study may have resulted in artifactual sex differences. It is interesting to note that the males in the present study showed a stronger relationship among relative ratios of interhemispheric EEG activity than among absolute difference measures. The low recallers in Moffitt et al. (1982), all males, showed a stronger relationship among relative EEG ratios than EEG measures averaged across the two hemispheres, suggesting that the males in the present study may have been low frequency recallers. The Moffitt et al. study did not however investigate ultradian rhythms in EEG activity, nor did it include absolute difference interhemispheric EEG measures.

There are several other issues in the present study which are worthy of note. This study utilized Fourier analyses to quantify EEG, providing only power estimates for each frequency band. Period analytic techniques of the type outlined in Hoffmann et al. (1979) and utilized by Moffitt et al. (1982) provide percent time first derivative and zero-cross measures in addition to power estimates. The additional

information provided by period analysis may reveal ultradian characteristics of EEG to which FFT analyses are not sensitive.

An additional difficulty in subject selection in this study and others reviewed in this paper are the disparate number of males and females chosen as subjects. Three male and four female subjects were used in this study while Manseau and Broughton (1984) included six female and two male volunteers. Okawa, Matousek and Petersen (1984) recorded EEG in six females and three males while Kripke et al (1983) used eight males and three females as subjects. It is generally presumed that females display a less complete lateralization of function than males (Springer and Deutsch, 1981) although EEG data suggests that females show more EEG asymmetries during task performance than males (Pigeau, 1984). Given the disparate interpretation of laterality data and the suggestion from this study that there may be sex differences in the relative ratio and absolute difference in interhemispheric EEG activity, it is clear that a sufficient number of males and females should be included in future research to permit a reasonable comparison by sex.

Finally this study has assessed interhemispheric EEG activity during wakefulness, but has not evaluated the BRAC hypothesis nor have any of the studies reviewed in this paper. Analysis of the absolute differences in interhemispheric EEG measures suggest that there are ultradian variations in wakefulness of a similar periodicity as REM-NREM sleep although frequency of dream recall may be

confounded with sex in this study. A first step in assessing the BRAC hypothesis and the degree to which such variations may be moderated by subject selection procedures is to demonstrate that rhythms in interhemispheric EEG measures of the type outlined in the present study occur during sleep. The following chapter of this paper describes a research project investigating rhythmic variation in EEG during sleep.

One more issue is worthy of note. It can be argued that the rhythms in balance EEG obtained in this study may be due to an overall variation in EEG activity in both hemispheres. To compensate for this possibility, analyses of average EEG measures were performed. These analyses provided no evidence that average EEG measures display predominant 80-120 minute rhythms and thus they are not reported in this study or the subsequent studies in this paper.

Chapter 4

Study 2: Ultradian Rhythms in EEG Activity During Sleep

In the previous chapter it was suggested that the temporal organization of EEG during sleep may differ among high and low frequency dream recallers, based on the significant differences in the relationship between electrophysiology and subsequent dream content in these two recall groups (Moffitt et al., 1982). To determine the ultradian characteristics of EEG activity during sleep and to investigate the degree to which frequency of dream recall moderates the expression of ultradian rhythms, the EEG data were analysed from a night in which no experimental awakenings took place (Armitage, Hoffmann, Moffitt and Shearer, 1985). This night was the second of three consecutive nights spent in the laboratory as reported in Moffitt et al. (1982).

As described in the previous chapter of this paper both the relative ratios of interhemispheric EEG and the absolute difference between the right and left hemispheres were included for analysis.

METHODS

Subjects

Eight right-handed males, ranging in age from 18-38 years served as subjects. The group consisted of four high frequency dream recallers who reported spontaneous morning

recall five times a week or more, and four low frequency recallers who reported morning recall once a month or less. None of the subjects were known to suffer from sleep or medical disorders, nor were they taking medication at the time of the study.

Apparatus

The equipment consisted of four Grass (P511) EEG amplifiers with power supply, a four channel Beckman (RN) dynograph, a dual beam Tektronix oscilloscope, a Vetter (Model 1) FM tape recorder and a square wave signal generator. EEG, EOG, EMG were recorded on FM tape at 15/16 ips. EEG data were quantified using a PDP 8/F computer with A/D convertors and real-time clock with cassettes and discs for mass storage. The electrophysiological data were transmitted to a Honeywell CP6 computer for statistical analysis. The subjects slept in an anechoic chamber measuring 10'x6'x8', equipped with an intercom for communication with the subjects.

Procedure

EEG recordings were made from Beckman Ag/AgCl electrodes at sites C3 and C4 referenced to A1 and A2 linked ear sites. Two submental electrodes recorded EMG and a bipolar array was used for EOG. A gain of 10,000x was used for EEG and EOG with filter settings at 0.3 and 100 Hz. The EMG amplifier was set to produce a 2v peak to peak voltage excursion at the start of the night. A 30 sec timing signal was also recorded on FM tape and the polygraph records. EEG amplifiers were counterbalanced within subjects and across nights.

Each subject spent approximately eight hours in bed each night for three consecutive nights. Experimental awakenings took place on Nights 1 and 3 and the details of the procedure and the analyses of this data are reported in detail in Moffitt et al (1982). The second night consisted of uninterrupted sleep and the electrophysiological data collected in this time period are reported here.

Digital period amplitude analyses of the type outlined in detail in Hoffmann, Moffitt, Shearer, Sussman and Wells (1979) were performed on the electrophysiological data. Three different analyses were performed on each EEG lead for 25 sec of each 30 sec epoch. Each analysis evaluated period in five frequency categories: delta (0.5 to < 4.0 Hz), theta (4.0 to < 8.0 Hz), alpha (8.0 to < 12.0 Hz), sigma (12.0 to < 16.0 Hz) and beta (16.0 to 30.0 Hz). Two half-wave zero cross analyses produced values for percent time and power in frequency band per epoch with a sampling rate of 1000 Hz. The third analysis was a full-wave first derivative analysis producing percent time in frequency band per epoch based on negative inflections in the EEG signal. EOG counted both the number of eye movements above 50 μ v and the integrated amplitude of all eye movements. The EMG analysis provided an integrated EMG value for each epoch.

Prior to statistical analysis the two channels of period analysed EEG were converted to two sets of values in each frequency band for each of the zero-cross, first derivative and power measures, along with a total power estimate. The

first set consisted of relative ratios of interhemispheric EEG ratios calculated as $((L-R/L+R) \times 100)$ indicating the magnitude and the sign ($+ = L > R$, $- = R > L$) of the difference between the two recording sites. The second set of values consisted of the absolute value of the difference between right and left recording sites in each frequency band for each EEG measure. Thus 35 variables were analysed for each epoch: EOG count, EOG and EMG power, beta to delta zero-cross, beta to delta first derivative, beta to delta power and total power for the relative ratio and absolute difference measures between the hemispheres.

RESULTS

2.1 Rhythms in Relative Ratio Interhemispheric EEG Measures

To evaluate the ultradian characteristics of interhemispheric relative EEG ratios, time series were constructed for each subject from the relative ratios in each period analyzed EEG frequency band and the power spectra were computed utilizing BMDP-1T univariate and bivariate spectral routines. These routines provided a spectral resolution of 1 cut (480 minutes), 2 cut (240 minutes), 3 cut (160 minutes), 4 cut (120 minutes), 5 cut (96 minutes), 6 cut (80 minutes), 7 cut (68 minutes), 8 cut (60 minutes), 9 cut (53 minutes), 10 cut (48 minutes), 11 cut (43 minutes), 12 cut (40 minutes), 13 cut (37 minutes), 14 cut (34 minutes), 15 cut (32 minutes), 16 cut (30 minutes), 17 cut (28 minutes), 18 cut (27 minutes), 19 cut (25 minutes) and 20 cut (24 minutes).

2.1.1 Relative Ratios in Interhemispheric Zero-Cross:

Of the zero-cross measures only Beta Zero-Cross relative ratios showed a substantial peak at 80-120 minutes, and only among low frequency dream recallers (See Figure 7). High recallers showed an approximate 4 hour Beta rhythm. Analysis of variance indicated a significant recall x periodicity interaction ($F=2.75$, $p<.05$, $df=19,114$). None of the other zero-cross relative ratio measures showed substantial 80-120 minute rhythms among high or low recallers. For the purposes of graphic illustration, ANOVAS significant at .05 are included. The exact probabilities of each analysis are reported to aid in the detection of potential Type 1 errors.

2.1.2 Relative Ratios in Interhemispheric First Derivative:

None of the first derivative interhemispheric ratios showed significant 80-120 minute rhythms during sleep.

2.1.3 Relative Ratios in Interhemispheric Power:

Figure 8 indicates differences among high and low recallers in relative ratios of interhemispheric Total Power, where high recallers show greatest power at 80 minutes and lows show no substantial ultradian rhythms in this EEG measure. These findings were confirmed by a significant recall x periodicity interaction from ANOVA ($F=1.82$, $df=19,114$, $p=.005$). None of the other interhemispheric power measures showed substantial ultradian variation.

2.2 Absolute Differences in Interhemispheric EEG Measures

Time series were also constructed from the absolute difference EEG measures and the power spectra were computed. These analyses were based on an FFT routine provided by

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Figure 7: Power spectra of relative ratios of Beta Zero-Cross among high and low recallers.

Figure 8: Power spectra of relative ratio Total Power during sleep for high and low recallers.

Ahmed-Rhao (1975), providing a spectral resolution of 1 Hz (255 minutes), 2 Hz (127 minutes), 3 Hz (85 minutes), 4 Hz (64 minutes), 5 Hz (51 minutes), 6 Hz (42 minutes), 7 Hz (38 minutes), 8 Hz (32 minutes), 9 Hz (28 minutes) and 10 Hz (26 minutes). The reader is referred to the previous section for a description of the spectral resolution provided by BMDP-1T routines.

2.2.1 Absolute Differences in Interhemispheric Power:

Of the power measures, Delta Power, Theta Power and Total Power showed large approximate 90 minute EEG rhythms, attenuated among high frequency recallers. Repeated measures ANOVA of Delta Power indicated a significant periodicity main effect ($F=3.26$, $df=9,54$, $p=.003$) and a marginally significant recall $\times$ periodicity interaction ($F=1.75$, $df=9,54$, $p=.099$). Mean spectral power, collapsed across groups is presented in Figure 9. Absolute differences in Theta power showed a similar pattern with a marginally significant recall $\times$ periodicity interaction ($F=1.83$, $df=9,54$, $p=.084$). The average power spectra is presented in Figure 10. Analysis of variance of absolute differences in Total Power indicated significant main effects for frequency of dream recall and periodicity ($F=6.53$, $df=1,6$ $p=.043$; $F=2.14$, $df=9,54$ $p=.040$ respectively). These results are presented in Figure 11.

2.2.2 Absolute Differences in Interhemispheric First Derivative:

Of the absolute differences first derivative measures, Beta First Derivative showed a 90 minute rhythm among both

Figure 9: Power spectra of absolute difference Delta Power collapsed across frequency of recall.

Figure 10: Power spectra of absolute difference Theta Power collapsed across frequency of recall.

Figure 11: Power spectra of absolute difference Total Power collapsed across frequency of recall.

high and low recallers, as seen in Figure 12, supported by a significant main effect for periodicity from repeated measures ANOVA ($F=3.65$, $df=9,54$, $p=.001$) and no recall x periodicity interaction. Absolute differences in interhemispheric Sigma Derivative measures showed a 4 hour rhythm among highs with a secondary peak at 90 minutes, while low recallers showed an approximate 40 minute rhythm in this measure as seen in Figure 13. These findings were supported by a significant recall x periodicity interaction ($F=3.01$, $df=9,54$, $p=.006$) from repeated measures ANOVA. High and low recallers also showed a 4 hour rhythm in the absolute difference in interhemispheric Theta Derivative although the high recall group displayed a secondary peak at 90 minutes, supported by a significant recall x periodicity interaction ($F=2.05$, $df=9,54$, $p=.050$) with no main effects See Figure 14. Substantial 90 minute rhythms were found in Delta Derivative among both recall groups, confirmed by a significant periodicity main effect ($F=4.70$, $df=9,54$, $p=.001$). See Figure 15.

2.2.3. Absolute Differences in Interhemispheric Zero-Cross:

In Delta Zero-Cross absolute value measures, both high and low recallers showed peak spectral power at 90 minutes. These findings are supported by ANOVA, indicating a significant main effect for periodicity ($F=2.46$ $df=9,54$ $p=.020$) with no interactions, as seen in Figure 16.

Figure 12: Power spectra of absolute difference Data First Derivative collapsed across frequency of recall.

Figure 13: Power spectra of absolute difference in Sigma First Derivative for high and low recallers.

Figure 14: Power spectra of absolute difference Theta First Derivative for high and low recallers.

Figure 15: Power spectra of absolute difference Delta First Derivative collapsed across frequency of recall.

Figure 16: Power spectra for absolute difference Delta Zero-Cross collapsed across frequency of recall.

Discussion

In general, relative ratios of interhemispheric EEG measures failed to show significant rhythms of a similar periodicity as the REM-NREM sleep cycle. The exceptions may be relative ratios of Beta Zero-Cross and Total Power. The Beta Zero-Cross relative ratio measure indicated 80-120 minute rhythms among low recallers but not among highs while relative ratios of Total Power suggested the opposite pattern. These results do not provide striking evidence for the hypothesis that activity in the two hemispheres oscillates with a periodicity similar to REM-NREM cycles. The fact that the absolute difference EEG measures provide clearer evidence of ultradian oscillations suggest that Broughton's hypothesis as conceived initially (Broughton, 1975; Klein and Armitage, 1979; Kripke, 1982) does not adequately describe the complex oscillatory systems which govern electrocortical events in sleep and as shown in the previous study, in wakefulness.

Specifically, absolute difference values for hemispheric Delta and Theta Power and Total Power all showed approximate 90 minute rhythms among high recallers but not among lows. Both recall groups showed 90 minute oscillations in absolute difference measures of Beta and Delta First Derivative. These results suggest that ultradian variation in the absolute difference in hemispheric activity may better characterize the nature of rhythmic EEG activity during sleep. Furthermore, significant 4 hour rhythms in Sigma First

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Derivative, absolute difference measures support Lavie's (1983) multioscillatory view of physiological processes and argue against unioscillatory control mechanisms related to lateralization. The differences among high and low recallers in this study argue in favor of the inclusion of individual differences in frequency of dream recall in subject selection procedures. Research projects which confound frequency of recall may conclude artifactually that there are no ultradian cycles in EEG activity. Furthermore the inclusion of only those measures which quantify relative differences between the two hemispheres or interhemispheric ratios risks oversimplifying the nature of rhythmic electrocortical activity during sleep. The results from this study suggest it is the absolute interhemispheric difference and not the relative ratio of interhemispheric EEG measure which display 80-120 minute oscillations.

This study however was based on period-analysed EEG data rather than FFT quantification procedures. As shown by the rhythms in First Derivative and Zero-Cross measures in this study, period analysis provides an alternative description of changes in EEG wave forms and as such may be more amenable to the detection of ultradian rhythms. The results reported here and those from the previous study suggest that both frequency of dream recall and sex may moderate ultradian periodicities, although the reader is reminded that in Study 1 EEG was quantified using FFT's rather than period analytic techniques. Nonetheless these studies do indicate approximate 90 minute rhythms in sleep and wakefulness in absolute

differences in interhemispheric EEG of a similar periodicity to REM-NREM cycles attenuated among high frequency dream recallers. The results from these two studies indicate a rhythmic alternation between periods of large interhemispheric difference to periods of small interhemispheric difference characterizes the nature of 90 minute rhythms in electrophysiology rather than an cycle where unihemispheric activity predominates for 90 minutes followed by a period of greater activity in the opposite hemisphere. However, neither of these studies has assessed the basic rest-activity cycle. Absolute differences in interhemispheric EEG have been shown to display an 80-120 minute rhythm but whether they are controlled by similar oscillatory mechanisms has not been ascertained.

There is one remaining interpretation that requires discussion. The predominant ultradian rhythms among high frequency dream recallers may be a response to sleeping in the laboratory. Alternatively, ultradian rhythms of low frequency dream recallers may be disrupted by the laboratory environment. The analyses presented in this study were based upon a second night of uninterrupted sleep, preceded by a night in which experimental awakenings took place. Thus this second night may constitute a "recovery" period. Whether it is the high or low recallers who display alterations in ultradian periodicities as a result of sleeping in the laboratory has not been determined by this study. One method to determine whether ultradian variation in EEG activity among

high recallers is a response to sleeping in the laboratory is to evaluate daytime fluctuations among high and low recallers. The following chapter of this paper presents a research project which investigates more fully interhemispheric EEG cycles in both sleep and wakefulness and the degree to which these cycles are moderated by sex and frequency of dream recall.

CHAPTER 5

Study 3: Electrophysiological Evidence for the Basic Rest-Activity Cycle

This research project was designed to investigate a number of hypotheses. Foremost was the evaluation of Kleitman's (1963) BRAC hypothesis that ultradian rhythms in physiology and behavior are continuous throughout sleep and wakefulness and are controlled by the same or similar oscillatory mechanisms. On the basis of the results of Study 1 and Study 2 a number of specific hypotheses were generated. It was proposed that high cross-spectral correlations at 80-120 minutes would be obtained between sleep and waking EEG (Hypothesis 1), among the absolute difference EEG measures rather than relative ratios. High positive correlations would indicate that two time series had a similar spectral profile, displaying peak periodicities in the same frequencies. Specifically, it was expected that rhythms in the absolute difference between the hemispheres in Delta, Theta and Total Power, Beta and Delta First Derivative and Sigma and Delta Zero-Cross would show strongest cross-spectral correlations between waking and sleeping EEG (Hypothesis 2). Based on the significant differences in periodicity between high and low recall groups, it was hypothesized that high recallers would show strongest correlations between waking and sleeping EEG at 80-120 minutes (Hypothesis 3). Low frequency recallers were expected to show high coherence at 80-120 minutes, but

only among Beta and Delta First Derivative absolute difference measures (Hypothesis 4). Of the relative interhemispheric EEG ratios, evidence of an 80-120 min BRAC was expected to occur for low recallers in Beta Zero-Cross relative ratios (Hypothesis 5).

The two studies reported previously in this paper are suggestive of an interaction between sex, frequency of dream recall and EEG periodicities. Study 1 suggested that females show clearer evidence of 80-120 minute EEG rhythms in wakefulness among Beta and Sigma Power and Total Power absolute difference measures. If Kleitman's BRAC hypothesis is correct, females should show high cross-spectral correlations at 80-120 minutes between waking and sleeping EEG among these measures (Hypothesis 8). Given that high recall males show clearer evidence of rhythms in absolute difference EEG measures during sleep than do low male recallers (Study 2) and the suggestion that males show fewer 90 min rhythms in waking EEG than females (Study 1), it is hypothesized that high recall males and females will show stronger evidence of an 80-120 minute BRAC among the absolute difference EEG measures than low recall males (Hypothesis 9). There are no data to suggest the degree to which high and low frequency recall females may differ in EEG cycles or in the relationship between waking and sleeping ultradian rhythms. Therefore no specific hypotheses concerning frequency of dream recall among females were generated.

To test the hypotheses outlined above, subjects were

awakened from Stage REM after approximately eight hours of sleep and were tested for two hours on mathematical and visuo-spatial tasks while EEG activity was recorded throughout.

METHOD

Subjects: Twenty-four right-handed volunteers, who slept eight hours a night regularly, spent one night in the laboratory. Subjects were asked to maintain a regular sleep schedule two weeks prior to participating in the study and to report any changes in their sleep habits. None of the subjects reported a substantial change. One half of the subjects were males and one-half were females with no history of familial left-handedness. They were selected on the basis of response to the Carleton University Frequency of Dream Recall Questionnaire (Appendix 1) such that six high recall males, six high recall females, six low recall males and six low recall females were recruited as subjects. High frequency of dream recall was determined as five recalls a week or more, while individuals were considered low frequency recallers if they recalled one dream a week or less at home. Subjects were asked to refrain from consuming alcohol or drugs 48 hours prior to participating in this study.

Apparatus and Tasks: The apparatus and tasks used in this study were identical to those described in Study 1 of this paper.

Procedure: Subjects entered the laboratory for electrode placement approximately one and one-half hours prior to normal bedtime. EEG recordings were made from site P3-P4 and F3-F4, referenced to linked ears at sites A1-A2 using Beckman AgCl electrodes. A pair of submental electrodes were used to record EMG and a bipolar array at sites E1 and E2 was used for EOG recordings. A gain of 10,000x was used for EEG and EOG with filter settings at 0.3 Hz and 100 Hz. The EMG amplifier was set to produce a voltage excursion of 2v peak to peak at the start of the experimental session. An automatic event timer used to signal A/D conversion was recorded simultaneously with the electrophysiological measures on FM tape.

After electrode placement the subject entered the anechoic chamber in preparation for sleep and electrophysiological recordings began. Subjects slept for at least eight hours and were awakened from Stage REM, with the exception of two subjects who awakened spontaneously from Stage 2 sleep. Upon awakening the subjects were seated in front of the video screen in preparation for task presentation. Two minute baseline EEG recordings were made while the subject sat quietly and looked at the video screen and under eyes closed conditions after which the subjects were permitted three practice trials on the mathematical and visuo-spatial stimuli.

The performance testing session began with the presentation of either visuo-spatial or mathematical stimuli

for three minutes, counterbalanced among subjects, followed by a three minute trial on the alternate task and a four minute rest interval. This procedure continued for two hours yielding 12 trials on each task.

EEG Quantification Procedures

Digital period amplitude analyses of the type described in Study 2 of this paper were used to quantify electrophysiological measurement during sleep and wakefulness. On sleep EEG data two different analyses were performed on each EEG lead for 25 seconds of each 30 second epoch at a sampling rate of 1000 Hz. Each analysis evaluated period in delta, theta, alpha, sigma, and beta frequency bands. One half-wave zero cross analysis produced percent time and power in each frequency band. The second analysis produced percent time first derivative in each EEG frequency band.

Prior to statistical analyses the four channels of period analysed EEG were converted to two sets of values in each frequency band for zero cross, first derivative and power. The first set of values consisted of interhemispheric ratios $(L-R/L+R) \times 100$ reflecting the relative difference between the left and right recording sites. A set of EEG measures $([L-R])$ reflecting the absolute value of the difference between right and left EEG leads were also calculated for each frequency band on zero-cross, first derivative and power measures. These values were then used to construct time series, yielding 64 time series per subject,

upon which FFT's utilizing subroutines (Ahmed-Rao, 1975) on an LSI 11/23 computer were performed to determine ultradian rhythms in EEG activity throughout sleep.

Period analyses were also performed on the EEG activity collected during task performance. Zero-cross, first derivative and power values were computed for the first five seconds of each 10 second trial on the mathematical task. These values were then summed and averaged across the three minute trial and used to construct 12 point time series for beta, sigma, alpha, theta and delta frequency bands on the relative ratios of interhemispheric EEG and the absolute difference EEG measures. This procedure was also followed to quantify EEG collected during performance on the spatial task. Thus, sixty-four 12 point time series were constructed for each subject, for each task.

To determine the relationship between EEG during task performance and preceeding sleep, the period analysed EEG from the last two hours of sleep were used to construct time series comparable to the waking EEG quantification procedures outlined above. Specifically, the 25 second period analysed EEG measures were averaged across ten minute segments producing 12 point time series for each of the 64 EEG measures. Spectral analyses, utilizing BMDP-1T univariate and bivariate routines, were computed on all 12 point EEG time series with Carleton University's Honeywell CP-6 computer system. FFT algorithms produce more stable and more reliable and more accurate estimates when spectral computations are

based on a power of two (Gottmann, 1981). Thus all 12 point time series from both electrophysiological and performance data were padded with four zeros and tapered prior to computation to produce spectral power estimates for 160 minute, 80 minute, 53 minute, 40 minute, 37 minute, 27 minute, 22 minute and 20 minute periodicities.

Performance Data

Percent correct estimates ($\# \text{ correct} / \# \text{ completed} \times 100$) were calculated for each trial on the mathematical task and the pattern task. These values were then be used to calculate relative performance ratios of the type outlined in Chapter 3 of this paper using the formula :

$$\frac{\% \text{ correct pattern} - \% \text{ correct math}}{\% \text{ correct pattern} + \% \text{ correct math}} \times 100$$

producing three separate 12 point performance time series for each subject. Spectral analyses using BMDP 1-T univariate and bivariate routines (FFT's) were performed to detect underlying periodicities in performance. For the purpose of graphic illustration, ANOVA's significant at .05 are presented in the following sections. The exact probability of these analyses are reported to aid in the reader's assessment of potential Type 1 errors.

RESULTS

3.1 Performance Data:

To remind the reader, power spectral analyses were performed on each individual subject's performance data: percent correct on the spatial task, percent correct on the mathematical task and the relative performance ratio. To

compensate for the possibility that subject's cycles might have been out of phase, the power spectra were computed on individual subject's time series rather than average performance for each group. Computing group power spectra might mask periodicities unless subject's cycles were synchronized. Computing FFTs on individual time series avoids this problem and permits group comparisons once the power spectra have been computed.

To determine the relationship between frequency of dream recall, sex and cycles in performance, repeated measures analyses of variance were computed on both the percent correct performance estimates and on the power values from spectral analysis.

3.1.1 Analysis of Percent Correct Data Prior to Spectral Analysis

Repeated measures ANOVA indicated no significant interactions with sex or frequency of recall but a main effect for performance measure (mathematical, spatial or ratio) and trials was obtained ($F=28.41$ $df=1,19$ $p=.000$; and $F=2.14$ $df=11,209$ $p=.019$ respectively). The main effect for trials suggests there is temporal variation in performance. This finding is supported by the ANOVA based on the spectral analyzed performance data reported in Section 3.1.2 below.

Pearson product moment correlations were computed between the percent correct performance scores on the two tasks. These results, reported in Table 6 indicate few significant correlations in performance for any group. The general trend however indicates a positive correlation

Table 6: Correlations between percent correct estimates on the mathematical and spatial tasks for all subjects.

Trials	Females		Males	
	High	Low	High	Low
1	r= .283 p= .587	.323 .596	.216 .680	-.174 .742
2	-.032 .953	.875 .052	.473 .343	.651 .161
3	.804 .054	-.087 .890	.192 .715	-.339 .511
4	.606 .202	-.483 .410	-.046 .931	-.201 .703
5	.589 .218	.220 .722	.654 .159	.115 .828
6	.383 .453	.598 .287	-.003 .996	.753 .084
7	.388 .448	-.097 .876	.543 .266	-.365 .476
8	.711 .113	-.174 .780	-.578 .229	.014 .979
9	.078 .883	.707 .182	.231 .660	.194 .713
10	.018 .973	.270 .661	-.260 .619	-.575 .232
11	.819 .046	.659 .226	.220 .675	.014 .979
12	.655 .158	-.042 .946	.869 .025	-.596 .212

n= 6/group

between the two tasks, contrary to Klein and Armitage (1979) but in agreement with Kripke et al (1982).

A second correlation coefficient was computed on the average mathematical and spatial percent correct values. These correlations, presented in Table 7 are single estimates of the overall relationship between performance on the two tasks and may be taken as a coherence index. Here it can be seen that males show stronger positive correlations between the tasks than do females, in agreement with the results presented in Study 1 of this paper.

3.1.2 Analysis of Spectral Analyzed Performance Data

Repeated measures ANOVA of the performance power spectra indicates a significant interaction between sex and frequency of recall ($F=6.15$ $df=1,19$ $p=.022$), a performance measure x sex x recall interaction ($F=4.56$ $df=2,40$ $p=.016$) and a performance x periodicity x sex x recall interaction ($F=1.86$ $df=14,280$ $p=.030$). Performance on the spatial task did not indicate 80 minute rhythms among any of the groups.

Figures 17 and 18 present the spectral profile of performance on the mathematical task. Figure 17 shows two major spectral peaks for high recall females at 160 minutes and 80 minutes. Low recall females show a 22 minute cycle in this performance measure. By examining Figure 18 it can be seen that low recall males show a 160 and a 53 minute rhythm while high recallers demonstrate a 40 minute cycle in mathematical performance.

Only high recall females showed an 80 minute rhythm in

Table 7 : Correlations between average mathematical and spatial percent correct.

F E M A L E S		M A L E S	
HIGH	LOW	HIGH	LOW
.2987 (.565)	-.1612 (.760)	.7371 (.095)	.9488 * (.014)

* $p < .05$

Figure 17: Power spectra of mathematical performance for high and low recall females.

Figure 18: Power spectra of mathematical performance for high and low male recallers.

the relative performance ratios while low recall females showed 20 minute rhythms in this measure as seen in Figure 19. High and low frequency male recallers display 22 minute cycles in relative performance ratios (See Figure 20).

To determine the relationship between performance cycles, cross-spectral correlations were computed between the power spectra on the mathematical task and the power spectra on the spatial task. Separate correlations were computed for each group as a result of the significant four way interaction between periodicity, sex, frequency of recall and task obtained in ANOVA and reported above. The correlation matrices are presented in Table 8. None of these correlations were significant, suggesting that the spectral profile for performance on the two tasks differs substantially. These results coupled with the zero-order correlations on percent correct estimates reported in Section 3.1.1 suggests that although there is a performance component common to the two tasks, temporal variation on these tasks is largely unrelated.

3.2.1 Ultradian Rhythms in the Absolute Differences in Interhemispheric EEG During Task Performance

Due to faulty electrode placement and experimenter error two subjects, one low and one high male recaller, were excluded from the analysis of all daytime EEG. Thus all analyses reported below are based upon 22 subjects. Several EEG measures displayed ultradian rhythms at frequencies other than 80 min, most notably at 160 min. Although these periodicities require a complete exploration to determine

Figure 19: Power spectra of relative performance ratios for high and low female recallers.

Figure 20: Spectral profile for relative performance ratios for high and low male recallers.

Table 8: Cross-spectral correlations between the mathematical and spatial power values.

CYCLE LENGTH	F E M A L E S		M A L E S	
	HIGH	LOW	HIGH	LOW
160	-.2025	.0534	.1817	.0719
80	.1756	-.3903	-.1372	.2729
53	-.2548	.4774	-.2140	.3435
40	-.2889	-.4718	.2542	.0954
37	-.5959	-.4640	-.0530	-.4368
27	-.0254	.1657	-.1280	-.1523
22	.2781	-.3364	.4593	.6618
20	.2024	-.2856	.5670	-.0853

ultradian rhythms in EEG outside the range of the REM-NREM sleep cycle, this task is beyond the scope of the present study. Thus the results reported in this paper will focus on those EEG measures which are of relevance to an 80 minute BRAC.

3.2.2 Frontal EEG Leads

3.2.2.1 Absolute Difference Power Measures

Figures 21 and 22 illustrate ultradian variations in Alpha Power for females and males respectively, during performance on the spatial task. Both female recall groups and low recall males show 80 minute rhythms in Alpha Power. High recall males display 20 min variations in this EEG measure. These results are supported by ANOVA indicating a significant periodicity main effect ($F=2.21$ $df=7,126$ $p=.042$) and a periodicity x sex x recall interaction ($F=2.17$ $df=7,126$ $p=.047$). None of the groups showed substantial spectral peaks at any frequency during the mathematical task supported by no significant interactions or a task main effect in ANOVA.

3.2.2.2 Absolute Difference Zero Cross Measures

Of the Zero Cross measures, the absolute difference in interhemispheric Alpha Zero Cross revealed an 80 minute rhythm among males during performance on the spatial task and among females during the mathematical task. These results can be seen in Figures 23 and 24. Females display a 53 minute rhythm in this EEG measure while performing the spatial task and males show a 22 minute cycle during the mathematical task. These results are supported by ANOVA indicating a

Figure 21: Power spectra of absolute difference frontal Alpha Power during the visuo-spatial task for high and low female recallers.

Figure 22: Power spectra of absolute difference frontal Alpha Power during the visuo-spatial task for high and low recall males.

Figure 23: Power spectra of absolute difference frontal Alpha Zero-Cross during the visuo-spatial task for males and females.

Figure 24: Power spectra of absolute difference frontal Alpha Zero-Cross during the mathematical task for males and females.

significant periodicity, $\times$ task $\times$ sex interaction ($F=2.10$ $df=7,126$ $p=.048$).

Absolute differences in Sigma Zero Cross showed an 80 minute rhythm during both tasks, supported by a significant periodicity main effect with no interactions from repeated measures ANOVA ($F=3.02$ $df=7,126$ $p=.009$). The spectral profile of Sigma, collapsed across sex and frequency of dream recall is presented in Figure 25.

None of the remaining frontal absolute difference EEG measures showed significant temporal variation during task performance.

3.2.3 Parietal EEG Leads

3.2.3.1 Absolute Difference First Derivative Measures

As seen in Figure 26 female high recallers show an 80 minute rhythm in Alpha First Derivative absolute difference EEG measures during spatial task performance. Low recall females display a 32 minute cycle in this EEG measure. Male low recallers show 53 minute cycles during the spatial task while high males express a 160 minute Alpha First Derivative rhythm, as seen in Figure 27. From comparing Figures 28 and 29 it can be seen that high recall males and females show a 53 minute rhythm in Alpha during the mathematical task. Female lows show a 20 minute cycle while male low recallers display a predominant 160 minute rhythm. Repeated measures ANOVA indicated a significant periodicity $\times$ sex $\times$ recall interaction ($F=2.12$ $df=7,126$ $p=.047$) and a marginally significant periodicity $\times$ task $\times$ recall interaction ($F=1.92$).

Figure 25: Power spectra of absolute difference frontal Sigm Zero-Cross collapsed across sex, frequency of recall and task.

Figure 26: Power spectra of absolute difference parietal Alpha First Derivative during the visuo-spatial task for high and low recall females.

Figure 27: Power spectra for absolute difference parietal Alpha First Derivative during the visuo-spatial task for high and low male recallers.

Figure 28: Power spectra of absolute difference parietal Alpha First Derivative during the mathematical task for high and low female recallers.

Figure 29: Power spectra of absolute difference parietal Alpha First Derivative during the mathematical task for high and low male recallers.

df=7,126 $p=.072$).

By comparing Figures 30 and 31 it can be seen that Sigma First Derivative absolute difference measures express an 80 minute cycle during performance on the spatial task but only among male low frequency dream recallers. Female low recallers show a 160 minute rhythm in this measure while high male recallers display a 37 minute Sigma rhythm. High recall females show peak spectral power at 20 minutes with a secondary peak at 37 minutes. During performance on the mathematical task female high recallers express 80 minute Sigma First Derivative cycles while low recall females show no substantial spectral peaks at any periodicity. See Figure 32. From examining Figure 33 it can be seen that high recall males display 160 minute cycles in this Sigma measure with secondary peaks at 53 minutes while low recall males show shorter temporal variation in Sigma during the mathematical task. Repeated measure ANOVA indicated a significant periodicity x task x sex x recall interaction ($F=2.33$ df=7,126 $p=.029$) as well as periodicity x sex x recall and periodicity x task x sex interactions ($F=3.04$ df=7,126 $p=.006$; $F=2.77$ df=7,126 $p=.010$ respectively).

Absolute differences in interhemispheric Beta First Derivative also showed evidence of an 80 minute cycle among high frequency dream recall females and low recall males during performance on the mathematical task as seen in Figures 34 and 35. No substantial spectral peaks were observed for this EEG measure among other groups. Repeated measures ANOVA indicated a significant periodicity x task x

Figure 30: Power spectra of absolute difference parietal Sigma First Derivative during the visuo-spatial task for high and low female recallers.

Figure 31: Power spectra of absolute difference parietal Sigma First Derivative during the visuo-spatial task for high and low male recallers.

Figure 32: Power spectra for absolute difference parietal Sigma First Derivative during the mathematical task for high and low female recallers.

Figure 33: Power spectra of absolute difference parietal Sigma First Derivative during the mathematical task for high and low male recallers.

Figure 34: Power spectra of absolute difference parietal Beta First Derivative during the mathematical task for high and low female recallers.

Figure 35: Power spectra of absolute difference parietal Beta First Derivative during the mathematical task for high and low male recallers.

sex x recall interaction ($F=4.34$ $df=7,126$ $p=.002$).

3.2.3.2 Absolute Differences in Interhemispheric Power

From examining Figures 36 and 37 it can be seen that females show 80 minute cycles in Delta Power during performance on both tasks. Males show 160 min cycles in Delta during the spatial task and 53 minute cycles during mathematical task performance. These results are supported by ANOVA indicating a sex main effect ($F=6.27$ $df=1,18$ $p=.020$) and a marginally significant periodicity x sex interaction ($F=1.96$ $df=7,126$ $p=.070$).

Alpha Power absolute difference measures show a significant periodicity x task x sex x recall interaction ($F=2.07$ $df=7,126$ $p=.049$), a periodicity x task x recall interaction ($F=2.17$ $df=7,126$ $p=.042$) a periodicity x recall interaction ($F=2.18$ $df=7,126$ $p=.042$), a task main effect ($F=71.32$ $df=1,18$ $p=.000$), and a recall main effect ($F=4.91$ $df=1,18$ $p=.042$). These results are illustrated in Figures 38-41. From comparing Figures 38 and 39 respectively, it can be seen that high recall females and males show 40 minute cycles during the spatial task while female and male low recallers show 20 minute cycles. During the mathematical task both high and low male recallers show 80 min rhythms in the absolute difference in interhemispheric Alpha Power as seen in Figure 40. Figure 41 illustrates 40 minute cycles in Alpha Power for both high and low female recallers.

Absolute differences in Beta Power show an 80 minute peak among females and a 160 minute cycle among males during

Figure 36: Power spectra of absolute difference parietal Delta Power during the visuo-spatial task for male and females.

Figure 37: Power spectra of absolute difference parietal Delta Power during the mathematical task for male and females.

Figure 38: Power spectra of absolute difference parietal Alpha Power during the visuo-spatial task for high and low female recallers.

Figure 39: Power spectra of absolute difference parietal Alpha Power during the visuo-spatial task for high and low male recallers.

Figure 40. Power spectra of absolute difference parietal Alpha Power during the mathematical test for high and low female recallers.

Figure 41. Power spectra of absolute difference parietal Alpha Power during the mathematical test for high and low male recallers.

performance on the spatial task as seen in Figure 42. Figure 43 illustrates the 80 minute cycle among females during mathematical task performance and the 27 minute rhythm expressed by males. These results were supported by ANOVA indicating a task x sex interaction ($F=6.95$ $df=1,18$ $p=.019$) and a periodicity main effect ($F=3.43$ $df=7,126$ $p=.002$).

None of the remaining absolute difference EEG measures displayed significant 80-120 minute rhythms during task performance.

3.3.1 Ultradian Rhythms in Relative Ratio EEG Measures During Task Performance

3.3.1.1 Frontal EEG Leads:

3.3.1.1.1 Relative Ratio First Derivative Measures

Repeated measures ANOVA indicated a significant task x sex x recall interaction ($F=4.58$ $df=1,18$ $p=.049$), a periodicity main effect ($F=2.75$ $df=7,126$ $p=.012$), a periodicity x sex interaction ($F=2.31$ $df=7,126$ $p=.031$), and a periodicity x task x sex x recall interaction ($F=2.50$ $df=7,126$ $p=.021$) in relative ratios of Beta First Derivative. Closer examination indicated an 80 minute rhythm among low recall females and a 20 minute cycle among high female recallers during the spatial task, as seen in Figure 44. Figure 45 presents the power spectra of relative ratios of Beta Derivative where it can be seen that high recall males show a 160 minute cycle while low recall males express a 32 minute rhythm during spatial task performance. Comparing Figures 46 and 47 it is evident that both male groups and high recall females display 160 min cycles during the

Figure 42: Power spectra of absolute difference parietal Beta Power during the visuo-spatial task for males and females.

Figure 43: Power spectra of absolute difference parietal Beta Power during the mathematical task for males and females.

Figure 44: Power spectra of relative ratio frontal Beta First Derivative during the visuo-spatial task for high and low female recallers.

Figure 45: Power spectra of relative ratio frontal Beta First Derivative during the visuo-spatial task for high and low male recallers.

Figure 46: Power spectra of relative ratio frontal Beta First Derivative during the mathematical task for high and low female recallers.

Figure 47: Power spectra of relative ratio frontal Beta First Derivative during the mathematical task for high and low male recallers.

mathematical task, while low recall females express 80 minute rhythms in this measure.

3.3.2 Parietal Leads:

Repeated measures ANOVA failed to indicate periodicity main effects or interactions in the relative ratios of Zero Cross, First Derivative and Power measures during task performance.

3.4 Ultradian Rhythms in Absolute Differences in Interhemispheric EEG During Sleep

3.4.1 Frontal Leads:

Information from two low recallers, one male and one female, was lost due to loosened electrodes. Therefore all subsequent frontal EEG analyses were based on 22 subjects.

3.4.1.1 Absolute Differences in First Derivative Measures

Beta First Derivative absolute difference measures, illustrated in Figure 48, shows peak spectral power at 80 and 160 minutes collapsed across sex and frequency of dream recall. ANOVA indicated a main effect for periodicity ($F=9.44$ $df=7,126$ $p=.000$) with no interactions.

Repeated measures ANOVA of Sigma First Derivative absolute difference measures resulted in a significant periodicity main effect ($F=5.94$ $df=7,126$ $p=.000$) with no interactions and the means collapsed across groups indicated peak spectral power at 80 minutes, as seen in Figure 49.

3.4.1.2. Absolute Difference Power Measures

Absolute difference in Sigma Power showed an overall 80 minute rhythm supported by ANOVA, indicating a significant periodicity main effect ($F=3.55$ $df=7,126$ $p=.002$) with no

Figure 48: Power spectra of absolute difference frontal Beta First Derivative during sleep.

Figure 49: Power spectra of absolute difference frontal Sigma First Derivative during sleep.

Figure 50: Power spectra of absolute difference frontal Sigma Power during sleep.

interactions, the group means are presented in Figure 50.

3.4.2 Parietal Leads:

3.4.2.1 Absolute Difference Zero Cross Measures

The power spectra for absolute differences in Sigma Zero Cross are presented in Figures 51 and 52 where it can be seen that female high recallers show secondary 80 minute rhythms in this EEG measure. Low recall females show no substantial spectral peaks while male high recallers express a 22 minute cycle and low recall males show 53 minute variations in this Sigma measure. These differences are supported by ANOVA indicating a significant periodicity x sex x recall interaction ($F=2.24$ $df=7,126$ $p=.036$).

3.4.2.2 Absolute Difference First Derivative Measures

Absolute difference measures of Alpha First Derivative showed only a periodicity main effect from ANOVA ($F=3.45$ $df=7,126$ $p=.002$). Figure 53 indicates 160 and 80 minute rhythms in this measure collapsed across sex and frequency of dream recall.

3.4.2.3 Absolute Difference Power Measures

Of the absolute difference power measures from parietal recording sites, Beta, Sigma and Alpha Power displayed 80 minute cycles during sleep. Repeated measures ANOVA of Beta Power indicated a significant main effect for periodicity ($F=2.39$ $df=7,126$ $p=.000$) as illustrated in Figure 54. Eighty minute cycles occur in this EEG measure collapsed across sex and frequency of recall.

Eighty minute rhythms in Sigma Power occur among male

Figure 51: Power spectra of absolute difference parietal Sigma Zero-Cross during sleep for high and low frequency female recallers.

Figure 52: Power spectra of absolute difference parietal Sigma Zero-Cross during sleep for high and low frequency male recallers.

Figure 53: Power spectra of absolute difference parietal Alpha First Derivative during sleep.

Figure 54: Power spectra of absolute difference parietal Beta Power during sleep.

Figure 55. Power spectra of absolute difference parietal Sigma Power during sleep for males and females.

recallers only, as seen in Figure 55. High recall females show 160 minute cycles while low recall females express a 53 minute rhythm in Sigma Power absolute difference EEG. These results are supported by a significant periodicity x sex x recall interaction ($F=3.54$ $df=7,126$ $p=.013$) from ANOVA.

Repeated measures ANOVA of Alpha Power absolute difference measures revealed a significant main effect for periodicity ($F=2.76$ $df=7,126$ $p=.011$) reflected in peak spectral power at 80 minutes as illustrated in Figure 56.

Theta Power absolute difference measures showed a 160 minute rhythm collapsed across groups although a closer examination revealed 80 minute rhythms among males and 160 minute rhythms among female subject as seen in Figure 57. Females also showed secondary peaks in Theta at 80 minutes. ANOVA revealed a significant periodicity main effect with no interactions ($F=2.60$ $df=7,126$ $p=.016$).

3.5 Ultradian Rhythms in Relative Ratios of EEG During Sleep

3.5.1 Frontal Leads:

3.5.1.1 Relative Ratio Power Measures

Relative ratios in Delta Power express an 80 minute cycle among male high recallers only. Low recall males and both female groups show 160 minute cycles as seen by comparing Figures 58 and 59. ANOVA indicated a significant periodicity by sex by recall interaction ($F=4.29$ $df=7, 126$ $p=.000$)

3.5.1.2 Relative Ratio First Derivative Measures

Figure 60 presents the power spectra for Delta First Derivate ratio measures. A 160 minute cycle occurs for low

Figure 56: Power spectra of absolute difference parietal Alpha Power during sleep.

Figure 57: Power spectra of absolute difference parietal Theta Power during sleep for males and females.

Figure 58: Power spectra of relative ratio frontal Delta Power during sleep for high and low frequency male recaller.

Figure 39: Power spectra of relative ratio frontal Delta Power during sleep for high and low frequency female recaller.

Figure 60: Power spectra of relative ratio frontal Delta First Derivative during sleep for high and low frequency recallers.

recallers while high recallers show an 80 minute rhythm in relative ratio Delta First Derivative. However this recall effect did not reach significance, only a main effect for periodicity ($F=3.00$ $df=7, 126$ $p=.006$) was evident from ANOVA.

3.5.2 Parietal Leads:

3.5.2.1 Relative Ratio Zero Cross Measures

Relative ratio Theta Zero Cross showed 80 minute cycles, but only among males. Female low recallers showed 160 minute rhythms while female high recallers displayed 22 minute cycles in this measure. However, ANOVA indicated only a periodicity main effect ($F=2.18$ $df=7, 126$ $p=.041$), as seen in Figure 61.

Repeated measures ANOVA of relative ratio Alpha Zero Cross revealed a periodicity main effect ($F=3.16$ $df=7, 126$ $p=.004$). As seen in Figure 62, means collapsed across sex and frequency recall showed peak spectral power at 80 minutes.

Relative ratio Sigma Zero Cross showed 80 minute cycles among females and among low recall males as seen by comparing Figures 63 and 64. High recall males display 20 minute rhythms in this EEG measures. ANOVA indicated a significant periodicity by sex by recall interaction ($F=2.24$ $df=7, 126$ $p=.036$).

3.5.2.2 Relative Ratio First Derivative Measures

Relative ratios of Alpha First Derivative showed a spectral peak at 80 minutes overall but a closer investigation revealed 80 minute cycles among males and 53 and 160 minute cycles among females as seen in Figure 65. These findings are supported by ANOVA indicating an

Figure 61: Power spectra for relative ratio parietal Theta Zero-Cross during sleep.

Figure 62: Power spectra of relative ratio parietal Alpha Zero-Cross during sleep.

Figure 63: Power spectra of relative ratio Sigma Zero-Cross during sleep for high and low frequency female recallers.

Figure 64: Power spectra of relative ratio parietal Sigma Zero-Cross during sleep for high and low frequency male recallers.

Figure 65: Power spectra of relative ratio parietal Alpha First Derivative during sleep for males and females.

interaction between periodicity and sex which approached significance ($F=1.83$ $df=7, 126$ $p=.087$) with a periodicity main effect ($F=3.13$ $df=7, 126$ $p=.005$).

None of the remaining relative ratio EEG measures showed significant temporal variation.

3.6 Correlations Between Waking and Sleeping EEG: The BRAC

To assess the hypothesis that rhythms in sleep physiology are continuous throughout wakefulness and controlled by the same oscillatory mechanisms, correlations were computed between the EEG power spectral values at corresponding periodicities from the last two hours of sleep with EEG during task performance. Separate correlations were computed for each group of subjects due to the significant interactions with sex and frequency of dream recall obtained from ANOVA. Correlations were only computed for those EEG measures which displayed significant temporal variation in both sleep and wakefulness. Reviewing the results presented in the preceeding sections of this paper, it is clear that only parietal absolute difference EEG measures are suggestive of an 80 minute BRAC. None of the relative ratio EEG measures showed significant 80 minute cycles in both sleep and wakefulness. Specifically, it is Alpha First Derivative, Alpha Power and Beta Power absolute difference measures which show significant 80 minute rhythms during sleep and during performance on the two tasks. Correlations were computed between the power spectral values at each periodicity to assess whether the spectral profiles were similar in sleep

and in wakefulness. If the same mechanisms govern these ultradian oscillations in EEG, then power spectral values should display a high positive correlation at 80 minutes.

Figures 66 through 69 present the cross-spectral correlations between absolute difference Beta Power during both tasks and during sleep. From examining Figure 67 it can be seen that male low frequency dream recallers show strong negative correlations at 160 and 80 minute periodicities, comparing the EEG power spectra from sleep and during performance on the spatial task. The EEG power spectra during mathematical performance also shows a strong negative correlation with sleep at 80 minutes. These results indicate that rhythms in Beta Power during sleep and wakefulness are strongly out of phase in this group of subjects. Figure 68 presents the cross-spectral correlations in absolute difference Beta Power measures for high recall males. Among these subjects there is a high positive correlation between mathematical power spectra and sleep at 80 minutes. Spatial and sleep power spectra bear only a moderate positive relationship at this frequency. These results suggest that the cortical rhythms associated with mathematical task performance are more closely related to rhythms in EEG activity during sleep than are variations during spatial task performance.

To interpret these correlations and those reported below, it is necessary to re-examine the EEG power spectra presented in the previous sections. Figure 42 illustrates a

Figure 67: Cross-spectral correlations between absolute difference Beta Power during sleep and during the visuo-spatial and mathematical tasks for high male recallers.

Figure 68: Cross-spectra correlations between absolute difference Beta Power during sleep and during the visuo-spatial and mathematical tasks for male low frequency recallers.

160 minute rhythm in absolute values of Beta Power among both male recall groups during the spatial task. EEG during the mathematical task displayed a 27 minute rhythm (See Figure 43). Absolute differences in Beta Power during sleep did show an 80 minute cycle (See Figure 54). These results suggest that the oscillatory mechanisms which govern sleep and waking Beta cycles differ.

Figures 68 and 69 present the cross-spectral correlations between cycles in Beta Power absolute differences in sleep and wakefulness for high and low female dream recallers respectively. Here it can be seen that both groups show negative correlations between waking and sleeping power spectra at 80 minutes. By comparison, Figures 42 and 43 show 80 minute rhythms in Beta Power absolute differences among both groups during performance on both tasks. Group means indicated an 80 minute rhythm during sleep as seen in Figure 54. Since these subjects show 80 minute rhythms in both sleep and wakefulness yet show negative cross-spectral correlations, these results suggest either different oscillatory mechanisms control sleep and waking EEG cycles or the rhythms in Beta Power during sleep and wakefulness are out of phase.

Cross-spectral correlations in Alpha Power, absolute difference measures present a different picture, illustrated in Figures 70 through 73. Correlations between the spatial power spectra and periodicities in sleep for low recall males show a negative correlation, as seen in Figure 70. The power spectra of Alpha Power during the mathematical task bears a

Figure 68: Cross-spectral correlations between absolute difference Beta Power during sleep and during the visuo-spatial and mathematical tasks for low recall females.

Figure 69: Cross-spectral correlations between absolute difference Beta Power during sleep and during the visuo-spatial and mathematical tasks for high recall females.

Figure 70: Cross-spectral correlations between absolute difference Alpha Power during sleep and during the visuo-spatial and mathematical tasks for low recall males.

Figure 71: Cross-spectral correlations between absolute difference Alpha Power during sleep and during the visuo-spatial and mathematical tasks for high male recallers.

strong positive correlation with 160 minute rhythms in sleep. Low male recallers do show an 80 minute cycle in this EEG measure during performance on the mathematical task and 20 and 40 minute rhythms during the spatial task (See Figures 40 and 39 respectively). High recall males show very strong evidence of an 80 minute BRAC in this EEG measure as seen in Figure 71, displaying high positive correlations between sleep EEG cycles and EEG power spectra on both tasks. These subjects showed 40 minute Alpha Power absolute difference cycles during spatial task performance and 80 min rhythms during the mathematical task as seen in Figures 38 and 40, and an 80 minute rhythm during sleep (See Figure 56). High recall females show highest cross-spectral correlations between EEG mathematical power spectra and sleep cycles at 80 minutes, as can be seen by examining Figure 72. Low recall females also show high cross-spectral correlations at 80 minutes and also at other ultradian frequencies (See Figure 73). During spatial task performance high females show 40 minute cycles and low recall females display 36 minute rhythms in Alpha Power absolute difference measures as seen in Figures 38 and 41 respectively. During mathematical task performance both female groups show 40 minute cycles in this EEG measure (See Figure 41). During sleep, both groups show 80 minute ultradian variation. The reader is referred to Figure 56.

One remaining absolute difference EEG measure displayed significant 80 minute rhythms in both sleep and wakefulness:

Figure 72. Cross-spectral correlations between absolute difference Alpha Power during sleep and during the visuo-spatial and mathematical tasks for high recall females.

Figure 73. Cross-spectral correlations between absolute difference Alpha Power during sleep and during the visuo-spatial and mathematical tasks for low recall females.

Alpha First Derivative. From examining Figures 74 and 75, it can be seen that neither male recall group showed strong cross-spectral correlations between sleep and waking EEG cycles, nor did they show 80 minute rhythms in Alpha First Derivative absolute difference during the tasks (See Figures 27 and 29). Secondary 80 minute cycles were observed for this EEG measure during sleep as seen in Figure 53. High recall females show strong evidence of an 80 minute BRAC between sleep EEG and cycles in EEG during performance on the spatial task (See Figure 76). These subjects also show 80 min rhythms in EEG during task performance but only during the mathematical task as seen in Figures 28. Low recall females show moderate negative cross-spectral correlations between sleep cycles and EEG rhythms during performance on both tasks, illustrated in Figure 77. These subjects did not show 80 minute rhythms in Alpha First Derivative during task performance. (See Figures 26 and 28).

To provide the reader with information concerning spectral peaks among individual subjects in sleep and wakefulness, Table 9 presents this data. Here it can be seen that group trends are representative of individual subjects' data. From examining this table it can be seen that high recall males and females show stronger evidence of 80 minute cycles in both sleep and wakefulness. High recall females show the strongest evidence of the continuity of ultradian variations, as indicated by the cross-spectral correlations discussed in the previous section. The consistency of group trends also enhances the subjective reliability of the

Figure 74: Cross-spectral correlations between absolute difference Alpha First Derivative during sleep and during the visuo-spatial and mathematical tasks for high males.

Figure 75: Cross-spectral correlations between absolute difference Alpha First Derivative during sleep and during the visuo-spatial and mathematical tasks for low males.

Figure 76: Cross-spectral correlations between absolute difference Alpha First Derivative during sleep and during the visuo-spatial and mathematical tasks for high recall females.

Figure 77: Cross-spectral correlations between absolute difference Alpha First Derivative during sleep and during visuo-spatial and mathematical tasks for low recall females.

Table 9: The periodicity of peak spectral power for individual subjects on night and day EEG measures used to assess the BRAC hypothesis.

Periodicity of Peak Spectral Power
in minutes

Recall	Sex	Code	Alpha First Derivative			Alpha Power			Beta Power		
			Night	Math	Spatial	Night	Math	Spatial	Night	Math	Spatial
HIGH	M	OBRAC	80	80	53	80	80	80	80	80	80
		KBRAC	160	80	160	80	53	80	53	80	40
		DBRAC	160	160	53	53	80	53	53	40	160
		CFRAC	160	160	160	160	80	80	160	160	80
HIGH	F	ABRAC	80	80	80	20	80	160	22	80	40
		SBRAC	80	160	80	80	80	80	80	80	160
		UBRAC	80	80	80	40	80	53	40	40	36
		JBRAC	160	80	53	37	40	80	80	80	80
LOW	M	FDRAC	80	80	80	160	37	40	80	80	80
		EBRAC	37	40	80	80	80	37	80	22	80
		RBRAC	80	80	80	80	37	40	40	40	80
		OBRAC	37	160	160	53	80	160	80	80	40
LOW	F	IBRAC	80	160	22	160	80	80	160	160	53
		WBRAC	160	80	40	22	160	80	37	160	160
		NBRAC	80	53	160	53	40	160	40	80	160
		BBRAC	40	80	160	80	40	22	40	36	40
LOW	F	LEBRAC	80	40	160	160	80	40	160	80	160
		TBRAC	80	53	80	80	40	80	40	80	22
		VBRAC	160	80	22	20	160	80	37	40	22
		MBRAC	80	80	80	20	80	40	80	160	37
LOW	F	PBRAC	160	22	80	80	37	80	80	22	80
		GBRAC	40	160	53	160	40	40	160	22	22

correlations discussed above.

To summarize, high frequency dream recallers and in particular, females, show stronger evidence of a BRAC than do low frequency dream recallers. High recall males and females show an 80 minute BRAC in absolute difference Alpha Power. High recall females also show an 80 minute BRAC in absolute difference Alpha First Derivative measures. Absolute difference Beta Power shows moderate to strong negative correlations between sleep and wakefulness. If the same oscillatory mechanism or mechanisms control rhythms in Beta Power in sleep and wakefulness it appears that there is a substantial phase lag during the transition from sleep to wakefulness. It is also possible that rhythms in this EEG frequency band are controlled by different mechanisms.

DISCUSSION

The central purpose of this study was to investigate 80 minute basic rest-activity cycles in interhemispheric EEG and to determine individual differences in EEG rhythms. Hypothesis 1, that rhythms in waking EEG were strongly related to rhythms in EEG activity during sleep was supported for absolute difference measures of interhemispheric Alpha Power and Alpha First Derivative. Hypothesis 2, that Delta, Theta and Total Power, Beta and Delta First Derivative and Sigma and Delta Zero-Cross absolute difference measures would display strongest evidence of a BRAC was not confirmed. Only Alpha Power, Beta Power and Alpha First Derivative showed predominant 80 minute rhythms in both sleep and wakefulness, the criterion used to select EEG measures to assess the BRAC. Variations in EEG activity in either sleep or wakefulness, but not both, suggest that oscillations in cortical activity are not maintained in the transition from sleep to wakefulness. This study also demonstrated individual differences in expressions of the BRAC which relate to the concept of waking/sleep state transitions.

High frequency dream recallers showed stronger positive correlations between waking and sleeping EEG cycles than did low frequency recallers, examining Alpha Power absolute difference EEG measures. Strong negative correlations may indicate that rhythms in interhemispheric EEG activity are controlled by separate oscillatory mechanisms in sleep and in wakefulness or that interhemispheric rhythms are controlled

by the same mechanisms but are out of phase in sleep and wakefulness. An extreme but plausible view is that low frequency dream recallers may not be able to maintain the integrity of rhythmic cortical processes in the transition from sleep to wakefulness. This view however, requires a closer examination, as the relation between waking and sleeping EEG cycles appears to be moderated by frequency of dream recall and sex.

In Alpha First Derivative absolute difference measures, high recall females show a stronger BRAC at 80 minutes than low recall females and both male groups. These results suggest that high recall females maintain the integrity of cortical oscillations in the transition from sleep to wakefulness greater degree than all other groups. That is, the periodicity and phase relationship appear to be maintained in the transition from sleep to wakefulness. The fact that only three EEG measures, all absolute differences, demonstrated 80 minute rhythms in both sleep and wakefulness suggests that BRAC oscillatory mechanisms influence only a few EEG frequency bands. It is interesting to note that beta and alpha measures, those that showed evidence of a BRAC in this study are the frequency bands of focus in research on the functional correlates of EEG activity as discussed in Chapter 1 of this paper. Recently Ray and Cole (1985) have suggested that Alpha activity reflects the attentional demands of a task while Beta activity relates more to the emotional and information processing components of cognitive tasks. If it is assumed that EEG activity reflects underlying

cognitive processes, then the correlations between waking and sleeping Beta and Alpha cycles may reflect the continuity or similarity of cognitive processes in sleep and wakefulness. Study 3 also provided evidence of differences in the periodicity of interhemispheric EEG activity within both sleep and wakefulness among male and female recall groups.

Of the absolute difference EEG measures from frontal recording sites, Alpha Power and Alpha Zero Cross showed 80 minute rhythms among both female groups during the spatial task and the mathematical task respectively. During spatial task performance low recall males showed an 80 minute rhythm in Alpha Power and Alpha Zero Cross among both male recall groups. In parietal absolute difference measures all subjects showed an 80 minute rhythm in Delta First Derivative during the mathematical task. In addition, high recall females showed an 80 minute rhythm in Alpha First Derivative and Beta First Derivative during the spatial task and mathematical tasks respectively. Low recall males also showed an 80 minute Beta First Derivative rhythm during the mathematical task. Both female recall groups showed 80 minute rhythms in Delta Power and Beta Power during both tasks. Males showed an 80 minute Alpha Power cycle during the mathematical task. In Sigma First Derivative absolute differences only low recall males showed an 80 minute rhythm during spatial task performance.

Of the relative ratio EEG measures only frontal Beta First Derivative showed 80 minute rhythms and only among low

recall females during the spatial task.

During sleep high male recallers showed an 80 minute absolute difference Delta First Derivative and a Beta First Derivative rhythm from frontal recording sites. Low recall females also showed an 80 minute rhythm in Beta First Derivative. Both female recall groups showed an 80 minute rhythm in Sigma Power and females as well as low male recallers showed an 80 minute Sigma First Derivative absolute difference rhythm. Eighty minute rhythms were also obtained from parietal absolute difference measures. All subjects showed 80 minute Beta Power, Alpha Power and Alpha First Derivative cycles. Both male recall groups showed an 80 minute Sigma Power rhythm and female low recallers showed an 80 minute Sigma Zero Cross cycle.

Of the relative ratio measures from frontal sites, Delta First Derivative showed an 80 minute rhythms among high recallers and Delta Power showed an 80 minute rhythm among high frequency male recallers. Parietal Sigma Zero Cross relative ratios displayed an 80 minute rhythm among females and low male recallers. Sigma First Derivative showed an 80 minute rhythm among high female recallers while analysis of Alpha First Derivative relative ratios revealed an 80 minute rhythm among both male recall groups.

In support of Studies 1 and 2, ultradian rhythms were observed among more absolute difference EEG measures than the relative ratios of EEG activity. These results do not support the view that periods of greater right hemisphere activity are followed by increased activity in the left hemisphere or

that oscillations in cerebral "dominance" characterize sleep and wakefulness. Rather these results suggest that it is the degree of absolute difference between the two hemispheres which oscillates with an 80-120 minute period. Thus periods of small interhemispheric differences followed by periods of larger differences characterize ultradian rhythms in EEG in both sleep and wakefulness. A possible interpretation of this measure is that small absolute differences between the two hemispheres reflect a period of hemispheric balance, where similar amounts of activity within an EEG frequency band occur in both hemispheres at the same time. Large differences between the two hemispheres may be conceived of as imbalance or asymmetry. Thus the 80-120 minute rhythms in absolute difference EEG measures obtained in all three studies reported in this paper, may be viewed as an oscillation in hemispheric balance-imbalance.

Recently Manseau and Broughton (1984) demonstrated bilaterally synchronous Theta rhythms during wakefulness from frontal recording sites, indicating that 80-120 minute EEG cycles in the right and left hemispheres were in phase. These findings are consistent with the hypothesis presented above. Although Studies 1 & 3 did not provide evidence of 80-120 minute Theta rhythms in either frontal or parietal absolute difference or relative ratios of interhemispheric activity, significant 80 minute rhythms were obtained in other EEG frequency bands. It should also be noted that Manseau and Broughton (1984) did not require subjects to perform tasks

beyond completing questionnaires after EEG recording sessions.

Several researchers have suggested that both EEG (Okawa et al, 1984) and performance (Kripke et al, 1983) may be influenced by environmental factors and task demands. Kripke et al (1983) have suggested that the social cues available in a group testing situation such as Klein and Armitage (1979) may bias results by entraining subjects' rhythms. Although the present study tested subjects individually, it is possible that the ten minute testing periods influenced performance cycles. If this contention is correct, then environmental factors may affect high and low recallers differentially, a possibility that will be discussed in greater detail below.

Perhaps a more serious problem in Studies 1 and 3 is the short sampling interval during task performance. Recently, Broughton, Stampi, Romano, Cirignotta, Baruzzi and Lugaresi (1985) have suggested that a sampling period of at least five cycles is necessary to produce reliable spectral estimates. Study 1 of this paper assessed ultradian rhythms for four hours producing a maximum of four 80 minute rhythms while Study 3 allowed an observation of only one cycle, testing subjects for two hours in wakefulness. However, significant periodicity x sex x recall interactions were obtained, suggesting that the length of the sampling period required to detect reliable periodicities may differ among groups. Furthermore significant 80 minute rhythms during sleep which are positively correlated with daytime variation in EEG

suggest that these periodicities are not produced by the testing conditions and that the testing interval was adequate for an evaluation of the relationship between waking and sleeping EEG cycles. In support of the cross-spectral correlations, 80-120 minute peaks in balance EEG measures were more prevalent among individual high recall subjects than other group members. These individual differences further enhance the conclusions drawn in this paper, that balance EEG measures more adequately describe ultradian variation in EEG activity than do models of uni-hemispheric predominance.

It should be noted that the ideal situation is to monitor and analyze EEG activity and performance throughout twenty-four hour periods, although this is a labor intensive effort that generally requires a "trade-off" between the number of subjects and the sampling period. Future research may provide evidence of the adequacy of the sampling period in Study 3, as a means for assessing the BRAC.

Although there are some methodological difficulties with the studies presented here, the results generate a number of questions, among them, why should high frequency dream recallers, especially females, show stronger evidence of ultradian variation in sleep and wakefulness, suggesting that these rhythms are more strongly entrained?

It has been demonstrated that frequency of dream recall relates to field independent - field dependent modes of cognitive style, such that individuals who are field

independent report higher dream recall while low frequency recallers tend to be more field dependent (Skeldrake & Cormack, 1974). It has also been shown that individuals with a rich daydream and fantasy world tend to be field independent in cognitive style, with superior visuo-spatial and mental rotation skills (Goodenough, 1980; Singer and Antrobus, 1972). Problem solving during dreaming has been said to be more creative and less constrained than problem solving in wakefulness (Armitage, 1983; Faraday, 1973, 1974; Garfield, 1974). Thus individuals who are high frequency dream recallers may have a more creative approach to problem solving in wakefulness. The frequency of dream recall measure employed in the present studies may reflect a more flexible cognitive style.

The underlying assumption in the search for 80-120 minute variations in cognitive processes has been the existence of a waking analogue to dreaming (Kripke, 1982). If these cognitive processes are under rhythmic control, then high frequency recallers would be expected to show clearer evidence of a BRAC as obtained in Study 3 of this paper. One possible interpretation is that high frequency dream recallers are more flexible cognitively and physiologically than low recallers. That is, high recallers are less affected by the task demands, extended performance and the general experimental environment than are low recallers such that no disruption in underlying biological rhythms occurs when high recallers enter the experimental situation. An alternative possibility is that low frequency dream recallers respond to

the experimental situation more quickly than high recallers, altering the periodicity of biological processes. Although both of these views are plausible the data from the studies reported here favor the former interpretation. Study 3 indicated strong positive correlations between waking and sleeping EEG cycles among high recallers and especially in high recall females. These results were taken as evidence for the integrity of oscillatory processes in the transition from sleep to wakefulness. Both Studies 2 and 3 indicated 80 minute rhythms in balance EEG measures during sleep among high recallers who were either not required to perform a task or prior to task performance. Thus 80-120 minute rhythms in interhemispheric EEG during sleep are not a result of task performance demands. However the effect of sleeping in the laboratory on ultradian rhythms cannot be assessed. Although "first night" effects attributable to the novelty of sleeping in laboratory have been demonstrated (Antrobus, Fein, Jordan, Ellman and Arkin, 1978), there is no theoretical reason to assume that the oscillatory mechanisms which govern a BRAC in EEG activity would be disrupted by sleeping in the laboratory. In Study 2, high frequency dream recallers also showed 80 minute rhythms in balance EEG measures on a second night in the laboratory, arguing against the "first night" hypothesis. Thus the argument developed here favors the view that the organization of rhythmic cortical activity differs among high and low dream recallers and interacts with sex.

The question remains, why should females show clearer

evidence of a BRAC than males? Extending the discussion of frequency of dream recall above, females and in particular high frequency females may be more flexible cognitively and physiologically as suggested by the stronger positive correlations between waking and sleeping EEG cycles. Or perhaps the social and cultural factors which influence the acquisition of field independence - field dependence (Goodenough, 1980) differentially affect the entrainment or ontogenetic development of ultradian rhythms in cognitive and electrophysiological processes among the sexes. Differences in ultradian rhythms among male and female dream recallers need to be confirmed by additional research before plausible explanations can be offered. Nonetheless, the results from these studies suggest that frequency of dream recall and sex moderate the expression of ultradian rhythms in both sleep and wakefulness.

Summary and Conclusions

In Study 1 it was found that females showed 80-120 minute variations in balance EEG measures during extended task performance. Males showed 80-120 minute cycles in relative ratio EEG measures.

Study 2 indicated that ultradian variation in EEG activity during sleep is best described as an 80-120 cycle in hemispheric balance EEG measures, attenuated among high frequency dream recallers. Few significant ultradian variations were obtained in relative ratio EEG measures.

Study 3 showed that both sex and frequency of dream recall moderate the expression of 80-120 minute cycles in EEG

during sleep and during wakefulness. In addition it was determined that hemispheric balance in Alpha First Derivative, Beta Power and Alpha Power showed ultradian variation in both sleep and wakefulness. Correlations between the power spectra of these EEG measures indicated strong continuity of rhythmic EEG activity in the transition from sleep to wakefulness. These data were taken as evidence for Kleitman's BRAC hypothesis that 80-120 minute cycles in physiological processes are governed by similar oscillatory mechanisms across sleep and wakefulness.

Future research should explore the relationship between interhemispheric EEG cycles and the phases of REM and NREM sleep to assess more fully the relationship between hemispheric balance and the onset of sleep stages. Future endeavors may also demonstrate the reliability of ultradian variation in EEG activity in Alpha and Beta EEG balance measures.

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Appendix 1: Frequency of Dream recall Questionnaire

Typically, how often do you remember your dreams upon awakening in the morning? (check one)

- ☐ Rarely-once a month or less
- ☐ Infrequently-one to four times a month
- ☐ Sometimes-one to two times per week
- ☐ Often-two to five times per week
- ☐ Usually-every morning with rare exception

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