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Ross A Pigeon

PSYCHOPHYSIOLOGY OF COGNITION:
Some EEG Correlates and a New
Descriptive Technique

by

© Ross A. Pigeau

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

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ABSTRACT

The electroencephalogram (EEG) is a record of the ongoing spontaneous electrical activity measured from the cortex. If an assumption is made that a relationship exists between EEG and cognitive behaviour then the nature of that relationship may contain potentially valuable psychophysiological information. Two studies were performed investigating these relationships. They utilized computer quantification procedures carefully developed to ensure maximum description and sensitivity to the EEG signal.

In study #1 a relationship was found between asymmetrical alpha activity and seven cognitive tasks ordered a priori for their presumed hemispheric involvement. More importantly an individual differences factor was found potentially accounting for a large segment of the contradictory findings in the alpha literature. Degree of alpha asymmetry is related to natural overall level of alpha activity in the individual. High and Middle alpha generators display the asymmetry, Low alpha generators do not.

Study #2 replicated the results from study #1 and also established a relationship between theta activity and vigilance. A cumulative addition task varying in difficulty was utilized to influence vigilance levels. As difficulty increases theta increases until the task becomes too difficult, then theta decreases.

A new descriptive technique was developed in order to

study natural frequency clusters in the EEG. A 50 X 50 correlation matrix was calculated for each task where each correlation represents the relationship between FFT power values of two single Hertz frequencies. All possible pairwise correlations are drawn for EEG frequencies from 1 to 50 Hz. Although difficult to grasp conceptually they have shown their potential as a new descriptive tool by showing differences in correlational patterns among tasks and among individuals varying in alpha generation.

ACKNOWLEDGEMENTS

When I first entered graduate school an outgoing Ph.D student once told me: "To get through this ordeal, you've got to work hard and keep your head down. If you look up to see how far you've come, you'll only get depressed. The task seems endless, hopeless and overwhelming". Having successfully completed my Ph.D, I now see that it was sage advice. I would like to add however, that although keeping one's head down and working hard is certainly a necessary condition for successful completion, it is not a sufficient condition. An intellectually stimulating and emotionally supportive environment is vital to endure the 'ordeal'. It is this environment which I would now like to acknowledge and thank. It is a long but distinguished list of individuals to whom I owe my gratitude.

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OVERVIEW

The electroencephalogram (EEG) is a record of complex electrical potentials emanating from and propagating through cortical and subcortical structures. If these potentials are interpreted as signals, then there exists the possibility for information; that is, non-random fluctuations or patterns in the signal. In EEG research it is assumed that some of the information present in the electrical signal reflects moment by moment variations in the dynamic state of the brain. It is further assumed that the moment by moment variations are themselves indicative of variations in underlying mental processes. These interpretations and assumptions provide the theoretical foundation for EEG research.

The overall position in this dissertation is that EEG provides a consistent and reliable measure for investigating the psychophysiology of cognitive processes. This claim is made despite the relatively poor showing of research on EEG and cognition in the literature. For example, Pigeau (1983) reviewed extremely contradictory studies concerning the extent of cerebral lateralization in males versus females while EEG was recorded during the performance of cognitive tasks. Of the twelve studies reviewed, four concluded males were more lateralised than females, four regarded females as more lateralised than males, and four found no differences between the two groups. It is this author's opinion that such inconsistencies are a result of two basic flaws in

experimental methodology. First, dependent variables were used which were not sufficiently sensitive to measure the variances of interest. EEG is a complex event and the manner in which it is analyzed is critical for ensuring maximum sensitivity in the dependent variables. Second, less than optimal independent variables were chosen. This had the effect of minimally differentiating the variance between groups. The first methodological flaw is a measurement problem; the second is a theoretical problem. Chapter 1 is an attempt to study these two problems and suggest possible solutions. Section 1.1 outlines the types of EEG research and the result their assumptions have on strategies for EEG measurement. Based on this discussion a stochastic approach to EEG generation is adopted allowing the use of correlational research models. Also, a comprehensive strategy for EEG measurement will be described which maximizes the amount of information available for any particular segment of EEG derived from a single cortical site. In section 1.2 a review of the major frequency bandwidths conventionally used in EEG research is presented in an attempt to partially resolve the theoretical problem mentioned above. It is assumed that such a review will uncover substantive relationships between EEG and cognitive processes. These relationships can then be the basis for developing sound independent variables. Also, a brief review of EEG asymmetry in the cerebral hemispheres is presented with the same intention of developing a theoretical framework from which to maximize between group dif-

ferences.

Chapter 2 describes a study (study #1) which tests some of the conclusions generated from the introduction. Specifically, a preliminary evaluation of the proposed strategy for EEG description was performed along with an experimental manipulation designed to maximize differential EEG activity in the separate cerebral hemispheres. Variations in cognitive processes as reflected in traditional EEG bandwidths (described in section 1.2) was investigated along with a detailed examination of neutral frequency clusters while subjects are performing individual tasks.

Study #2 (chapter 3) is an extension and replication of the first study. It is intended to further elucidate the relationship between EEG and cognition, as well as refine the proposed EEG description strategy. It is considered that these refined dependent variables, when utilized in conjunction with cognitive tasks chosen on theoretical (introduction) and empirical (study #1) grounds to induce specific EEG changes, yield substantive information concerning the psychophysiology of cognitive processes.

X

CHAPTER 1

EEG MEASUREMENT AND THEORY

This chapter reviews the assumptions of EEG research in order to determine appropriate measurement strategies for yielding reliable and sensitive dependent measures. Also a brief review of the theoretical relationship between conventional EEG bandwidths and cognitive processes is presented for the purpose of guiding future research in this area.

1.1 EEG Measurement

From the time of its first application in recording human cerebral electrical activity, the electroencephalograph has been expected to play a key role in the search for the neurophysiological mechanisms responsible for conscious experience and voluntary action (Low, 1982, p.455)

If two electrodes (with electrolyte) are placed on the scalp of a living animal an electrical potential is detected which, when amplified, yields a signal varying in amplitude (voltage) and frequency (waves per second). This 'electroencephalogram' (EEG) has been the source of experimental research since Berger demonstrated the phenomenon in 1931 (Berger, 1931).

Historically EEG has not lived up to its original expectations (as expressed in the above quotation). Berger's original work identifying major frequency and amplitude characteristics within human EEGs is still quite valid today, despite voluminous attempts in the interim to

refine such descriptions with respect to cognition and overt behaviour. Low (1982) lists 35 psychological constructs which have been correlated with some aspect of EEG. Unfortunately these correlates, on the whole, were not found to be reliable. The situation is not as bleak as it may first appear, however. The unreliability of the correlates in question are more often due to incompatible methodology, equipment specifications and analysis strategies. Issues such as shielding, electrode montage, amplification, filtering, noise source elimination, recording, visual versus computer scoring, and statistical analyses can potentially alter the results. If EEG is carefully and consistently measured then there exist robust EEG correlates of psychological functions. Examples from primarily awake states will be given in section 1.2.

Dependent variables do not exist in a vacuum. They are intimately related to the assumptions underlying the research for which they were developed. In order to create more sensitive dependent variables for EEG research, an exploration of the types of EEG research and their assumptions should be helpful.

1.1.1 Types of EEG Research

[Investigations utilizing EEG have progressed in three ways: 1) studies examining the biological origin of electrical potentials generated by the brain, 2) studies discovering and examining relationships between EEG and mental behaviour, and 3) studies attempting to integrate 1 and 2

(e.g. the bio-electrical origin of mental behaviour). In the present document, emphasis will be placed on the second approach. Admittedly, these approaches are not independent, therefore a discussion of one must incorporate (at least to some degree) a discussion of the other. However, for reasons to be made clear, such a division of investigative approaches is nonetheless valid, at least for heuristic purposes.

Studies examining the biological origin of electrical potentials generated by the brain, rely heavily on models derived from physics, chemistry and biology. Descriptions of membrane potentials, potassium concentrations, ionic current flows, extracellular impedances, wave generation, summation and propagation and much more (see Elul, 1972; Creutzfeldt and Houchin, 1974; Speckmann and Elger, 1982), are essential parameters for scientific experiments in this area. In its purest form such research assumes that a complete physical description of the static and dynamic properties of the brain is essential for understanding EEG. This approach is physiology, or more precisely electrophysiology, rather than psychology.

Another approach in EEG investigations involves attempts to describe mental behaviour using biophysical models. Such studies may assume that particular behaviours associated with specific EEG characteristics are based on known or hypothesized physical interactions within the brain. Precise mathematical models are then built reflecting these interactions. Such integrative EEG research is

certainly valuable. Reducing mental behaviours down to well understood biophysical processes is consistent with contemporary trends in science. However, the brain is such a complex system that research of this kind must inevitably deal with models which, when compared with the brain and its behaviour, are relatively simple. The models are simple because they are limited to particular phenomena (structures and functions) and thus must sacrifice generalizability. For example, Wright and Ihaka (1981) developed a model for lateral hypothalamic regulation of electrocortical activity. To limit the complexity of their model they assumed that 1) the filtering characteristics of the lateral hypothalamus were linear in nature, 2) that these characteristics were time-invariant and 3) that the processes were identical for each hemisphere. Such assumptions, although necessary for investigative reasons, may not be appropriate within the larger context of the brain -- and indeed they are not. The brain exhibits non-linear characteristics (Basar, 1976) and even short segments of EEG are non-stationary (Lopes da Silva, 1982).

The Wright and Ihaka example was meant to criticize neither their model nor the integrative approach, but to illustrate the inherent problems associated with such approaches.

Of the three approaches studies discovering and investigating relationships between EEG and mental behaviour assume that physical descriptions of EEG generation are not

as important as statistical ones. For instance, a statistically powerful dependent measure should be 1) reliable, 2) continuous and 3) show systematic variance. EEG satisfies all of these criteria. It is reliable; alpha wave activity can be consistently generated on multiple occasions in subjects resting with their eyes closed. It is continuous; most contemporary techniques for EEG analysis yield quantitative values possessing properties of ratio scaling. It displays systematic variance; sleep stage scores, as determined by EEG, eye movements and muscle tonus, are periodic fluctuations in the electrophysiological behaviour of sleeping individuals. Furthermore, for analysis purposes, the EEG signal itself is treated statistically, not physically. Lopes da Silva (1982) describes it in this way:

The exact characteristics of EEG signals are, in general terms, unpredictable. This means that we cannot predict precisely the amplitude of an EEG grapho-element or the duration of an EEG wave. Therefore, we say that an EEG signal is a realization of a random or stochastic process... We must note that such a description of an EEG signal as a realization of a random process implies a mathematical but not a biophysical model. (p. 686, original underlining)

Lopes da Silva is quick to point out however, that this does not necessarily imply that the underlying biophysical processes are random in nature, only that "...it may have such a high degree of complexity that only a description in statistical terms is justified (p.686)". The point is that such an assumption allows researchers investigating relationships among EEG, brain structure/function and behaviour to ignore (at least temporarily) the biophysical basis of EEG. Metaphorically it is sufficient, and at times pre-

ferable, to study the electrophysiological forest instead of the neuronal trees.

All EEG analysis strategies assuming stochastic signals are referred to as nonparametric methods (Lopes da Silva, 1982). Such methods include (among others) period analysis, auto- and cross-correlations, fast Fourier transforms and amplitude distributions. They are considered nonparametric because no attempt is made to infer specific models for EEG generation (Lopes da Silva, 1982). Rather, as precise and complete a description as possible of the EEG signal is made for the purpose of using the description in research.

Parametric methods of EEG analysis on the other hand, go beyond descriptive or correlational procedures and attempt to assign relative importance to the generative processes underlying EEG (Lopes da Silva, 1982). This can be performed using analysis techniques already mentioned, or methods like auto-regression, cluster analysis, path analysis and segmentation.

An EEG analysis strategy assuming stochastic signals is chosen in this dissertation. Given this choice, it is necessary to develop EEG quantification methods which maximize the measurement of all potential sources of information in the signal. The measurement approach introduced in the next section is an initial attempt at a comprehensive EEG signal description at a single cortical site.

1.1.2 Measurement Approach

EEG analyses can yield complicated dependent variables, but this is interpreted as an advantage rather than a problem. The brain/mind is a complex system to say the least; it is not unreasonable therefore, to utilize dependent variables reflecting such complexity.

Delta (.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), sigma (13-17 Hz) and beta (17-30 or more Hz) are conventional EEG bandwidths based on years of visual inspection. They have been the mainstay of EEG research. However, attempts have been made to determine if these frequency clusters can be statistically identified. Using factor analytic techniques Dymond, Cogger and Serafetinides (1980) explored this possibility with 92 subjects resting with eyes closed. The EEG was fast Fourier transformed yielding power estimates in 2 Hz increments up to 30 Hz. From the factor loadings of eight factors it seemed that the conventional frequency bands are present in adult awake EEGs. However, Schwibbe, Breull and Becker (1981) have questioned conventional frequency band partitioning citing their own research utilizing factor analytic methods. For instance, "...the general validity of factor analytic parametrization, especially for the alpha range, can be doubted, because for this range, factors can be extracted loaded by faster or less fast frequencies, which depend on the location of the individual peak frequency..."(p.497). The work of Tyson (1982) illustrates such individual peak frequencies. Furthermore there is no reason to believe that such clusters will remain

constant during different cognitive tasks. Dymond, Coger, and Serafetinides' (1980) study explored frequency clustering only in subjects resting with their eyes closed. A strategy will be developed investigating clusters of inter-correlations among frequencies for groups of subjects performing different tasks.

In addition to investigating EEG bandwidths, either conventional bandwidths or new frequency clusters, describing changes in EEG frequencies of unit bandwidth also provides important information. EEG spectrograms, where a segment of EEG is broken down into power values for each single Hz frequency, offers dynamic information, particularly when plotted through time (described later). It is argued that all these methods are valid data reduction techniques for EEG research. Hence, a strategy was developed incorporating all of them. This strategy was initially used to analyse the data from study #1 (chapter 2) and then was refined for study #2 (chapter 3). The strategy involves 1) reducing the EEG signal to traditional quantities, that is, power values within conventional frequency bandwidths, 2) calculating power spectra through time for subjects performing specific tasks, thus isolating dynamic frequency fluctuations, and 3) investigating the correlational clusters among individual single Hz frequencies. A more detailed description of the strategy follows.

1.1.2.1 Traditional Data Reduction

It must be stressed that a stochastic model of EEG

generation is only concerned with the problem of predicting waves at a single point in time, not epochs of EEG covering larger time intervals. For example, although the instantaneous dynamics of EEG generation are not known, (that is EEG cannot be predicted from time t to time $t+1$) the frequency and amplitude characteristics of multiple wave forms may indeed illustrate non-random fluctuations. Conventional EEG frequency bandwidths reflect such non-random fluctuations.

Conventional frequency bandwidths can be measured using any one of a variety of techniques, the three most popular being: 1) fast Fourier transforms (FFTs), 2) filtering, rectification and integration, and 3) period analysis. The first two typically yield a single value representing both amplitude and relative occurrence for a particular frequency during a specified interval of time. These are usually called 'estimates of power' for a frequency bandwidth. The third, period analysis can yield estimates of relative occurrence regardless of amplitude as well as an estimate of power. It will be the method of choice for traditional data reduction in the present dissertation. Period analysis was chosen for two reasons: 1) it yields percent occurrence measures which are independent of amplitude and thus well suited for analyses of faster frequencies with low amplitudes, and 2) since the other two analysis strategies in this dissertation will use FFTs it was considered prudent to consider an alternative form of EEG transformation.

A description of period analysis will be presented

later. It is sufficient at this point to say that period analysis allows the EEG signal to be described in more detail when fairly wide bandwidths are of interest. Therefore, it is ideal for conventional EEG bandwidth investigations.

With most EEG quantification techniques an estimate of the relative amounts of bandwidth activity for both cerebral hemispheres can be calculated using an asymmetry index. A number of indices are used in the literature, but the most common involves subtracting the left hemisphere's EEG activity (for any particular bandwidth) from the right hemisphere and dividing this by the addition of the left hemisphere plus the right (i.e. $L-R/L+R$). An asymmetry index is a valuable tool for studying asymmetrical EEG during cognition (see section 1.2.2)

1.1.2.2 FFT Spectrographs in Time

Conventional frequency bandwidths are observed in most individuals and reflect 'global' systematic variances. Data gathered using this approach usually involves describing and statistically testing changes in delta, theta, alpha, sigma and beta bandwidths. An argument can be made however, for studying the whole frequency spectrum (e.g. 1-51 Hz) for each individual. Schwibbe, Breull and Becker (1981) have argued this for investigators interested in alpha:

A first inspection of the location of peak frequencies of some subjects show a considerable variation... and these locations can even exceed the range of the conventional alpha domain. Therefore in order to parametrize [sic] the variation of this alpha activity one cannot apply the concept of fixed frequency band parti-

tions. Instead the parametrization must be based upon interindividual, flexibly stated frequency groups or ranges... (p.497)

Although studying the whole frequency spectrum is a valuable strategy for identifying individual differences, it is also valuable for isolating group differences. A technique for generating power spectra, that is power values for single Hertz frequencies, is the FFT. FFT analysis separates the EEG waveform into a number of sine and cosine components that are harmonically related, yielding a power measure for each frequency or part frequency. Power is the amount of area squared under the rectified curve. The length of the EEG segment along with the sampling rate determines the spectrum frequency range and its resolution (Cooper, 1976). For the purposes of the present dissertation, a frequency range from 1 to 51 Hz will be used.

A graph of the power spectrum is a visual representation of the power values for each frequency, with power on the ordinate and frequency on the abscissa. For any given task, an individual's EEG for specific epochs can be displayed using this technique. Changes through time in an individual's power spectrum can be illustrated if multiple power spectra from successive epochs are added to a third axis producing a 3-dimensional graph (see figure 1.1). Matejcek (1979) produced a similar EEG 'chronospectrogram' by plotting changes within a specific EEG bandwidth through time. However, 3-dimensional representation provides added descriptive information by allowing the monitoring of peak frequency shifts through time.

Figure 1.1: Example of a 3-D FFT plot. This is from a subject awakened from stage 4 sleep. (asleep at epoch #1, awake at epoch #40)

This individual differences approach is important in its own right, and also yields descriptive potential when taken in combination with the identification of groups of subjects sharing common EEG characteristics and utilizing these characteristics as independent variables. Data which illustrate these individual differences are presented in the next chapter. It was found that subjects can be categorized with respect to level of baseline alpha activity, that is, they may be classified as high or low alpha generators. Furthermore, differences were found between the two groups with respect to alpha hemispheric asymmetry in response to task performance. The work of Mizuki et. al. (1980) suggest that such individual differences may also exist for frontal theta activity (their work will be reviewed in section 1.2).

1.1.2.3 Correlational Patterns Among Single Hz Frequencies

Neither of the two previous approaches is new. However, utilizing them in tandem is novel, allowing a more complete description of the relationship between EEG and task performance.

The issue concerning the validity of conventional frequency bandwidths for EEG data reduction was mentioned earlier. It was argued that although factor analytic studies were inconclusive, visual inspection and years of research have substantiated conventional EEG bandwidth division. Nonetheless, the nature of frequency interactions within and between tasks has not been adequately investigated. Perhaps the major reason for this omission is the

lack of an adequate methodology for reducing and simultaneously describing all single Hertz frequency components for specific EEG segments. Inspired by the factor analytic method which is typically employed for such investigations, the present author suggests an alternative data reduction methodology which retains a high level of information yet is not restricted by some assumptions necessary for factor analysis, for example, non-multicollinearity, high N to variable ratio and no communalities exceeding 1.

In study #1 a preliminary factor analysis was performed on the EEG power spectra of a variety of tasks for all subjects. The power spectra were derived using an FFT algorithm which in the present case yielded power values for each of 50 single Hertz frequency bands (i.e. 1-50 Hz, hence 50 variables) for each epoch of EEG. The purpose behind the factor analysis was to extract frequency clusters on orthogonal factors and then determine if the clusters reflected conventional bandwidths. Although factors were extracted upon which frequency clusters were loaded (e.g. 23-50 Hz on the first factor and 9-15 on the second) the legitimacy of employing factor analysis with so few subjects (N=14) is suspect. Its legitimacy is further questioned if task specific factor analyses are performed. However, in the process of executing the factor analysis a correlation matrix of the 50 variables was generated. Preliminary examination of the matrix showed a trend of low correlations among slow EEG frequencies, medium correlations among inter-

mediate frequencies and high correlations among fast frequencies. The trend was quite striking. To take advantage of this information a procedure was developed to represent graphically the 50 by 50 correlation matrices. Briefly, with the aid of an XY plotter, the lower diagonals of the symmetrical matrices were drawn with the magnitude of the correlations represented by circles varying in diameter (see figure 1.2). In study #2 this technique was refined using colours as magnitude estimators. The resulting figures offer a quick and efficient means for visually detecting correlational patterns among all EEG frequencies. It is interesting to note that what is suggested by this form of data analysis is a visual factor analysis. More importantly, it allows direct visual comparisons among matrices from different tasks.

Each point or circle on figure 1.2 represents a single correlation between two single Hertz frequencies. Given that there are 50 frequencies in the power spectra, 2500 correlations are generated. Since the frequencies are being correlated among themselves the matrix is symmetrical. Hence, figure 1.2 displays the lower diagonal with the diagonal line itself signifying 1, where frequencies are correlated with themselves. Figure 1.3 illustrates the nature of the data involved for one correlation between two frequencies, 10 and 20 Hz. For any given subject, each epoch of EEG taken while performing a particular task, was fast Fourier transformed yielding a power spectrum from 1 to 50 Hertz. These power spectra were then summed and averaged

Figure 1.2: Example of a FFT correlation matrix. In this case all of the epochs for all of the tasks for each subject were used ($n=13$). Note: The size of the circles reflect the magnitude of the correlation.

FIGURE 1.3: An example of the data used to generate data point 10,20 in figure 1.2. The power values for 10 and 20 Hz for each subject are correlated.

resulting in one power spectrum for each subject for each task. Figure 1.3 shows that the 10 Hertz power value for each subject is correlated with the 20 Hertz value, thus yielding the 10,20 point in figure 1.2. The important feature of figure 1.2 is not the individual correlations, but the correlational patterns among the frequencies. The patterns provide information about the relationship among the frequencies during specific tasks. Such patterns may be compared for different tasks.

The three approaches described for data transformation and analysis are not mutually exclusive, but neither are they redundant. When taken together they provide a composite description with sufficient overlap among approaches to provide a degree of confidence. Admittedly, interpretive complexity is augmented utilizing this strategy, but the information gains more than offset this drawback.

1.2 EEG Correlates of Cognition

Meaningful analysis of the EEG depends on the assumption that the EEG signals contain information about the functioning of the brain. (Penwick, 1972, p.119)

Conventional EEG bands are widely used in EEG research. However, it is not clear when or where one EEG frequency band should be used as a dependent variable rather than another. This problem is particularly acute in laterality research and has prompted Donchin, Kutas and McCarthy (1977) to suggest strongly that dependent variables in EEG la-

terality research should be based on theoretical considerations. If specific brain functions can be associated with specific EEG frequency bands, then researchers investigating cerebral laterality can choose the bandwidth variable most likely to reflect independent variable manipulations. In other words, a theory concerning the relationship between cognition and EEG, even a preliminary one, is needed in order to increase the possibility for maximizing between group differences. What follows is an attempt to review present knowledge concerning the relationship between each conventional bandwidth and mental behaviour. A similar review and discussion is presented for the relationship between cognitive processes and EEG asymmetry between the cerebral hemispheres.

1.2.1 Cognitive Correlates of Conventional EEG Bandwidths

Delta: In normal adults, delta EEG activity is associated with low levels of central nervous system arousal. It is present during stage 3 and 4 sleep but is usually absent in stages 1,2 and REM as well as in awake individuals. Should delta be present in an alert awake adult individual it is usually indicative of some pathology (Stevens, 1974). Delta is characterized by large amplitude synchronous slow wave activity (> 75 microvolts) lying within the .5 to 4 Hz region. Another manifestation of delta is lower in amplitude with higher frequencies superimposed. This form of delta is often overlooked when visually scoring EEG, yet may also reflect low levels of central

nervous system arousal. In a preliminary study in our laboratory, computer analyzed EEG from a subject aroused from stage 4 sleep does retain relatively high levels of delta for as long as 45 sec. This delta however, has waking EEG characteristics superimposed on the slow wave activity. This result was originally overlooked when visually inspecting the polygraph record, but upon re-examination, was indeed identified (visually). The presence of delta activity in the awake EEG of subjects awakened from stage 4 sleep is consistent with subjective reports of confusion and disorientation. It is interesting to note that neonates often exhibit delta waves with superimposed low voltage mixed frequencies in both REM and awake states following non-REM or quiet sleep episodes (Lombroso, 1982), perhaps suggesting an undeveloped REM state in the former instance and low central nervous arousal in the latter.

The main purpose of the above discussion is to point out that although delta activity is primarily associated with deep sleep, and as such has largely been ignored in awake studies, there are instances when delta is present in awake individuals. The present prospectus is not primarily concerned with changes in delta. It is mentioned briefly only to emphasize its potential in future awake EEG research.

Theta: EEG waves occurring in the 4 to 8 Hz range are classified as theta activity. Theta is abundant and generalized over the cortex in children up to the age of 2,

then gradually diminishes in amplitude and becomes localized in temporal and frontal regions in adults (Knott, 1976; Petersen, Sellden and Eeg-Olofsson, 1975; Lindsley and Wicke, 1974). Theta has been associated with pleasurable emotional responses in children but this correlation has not been found in adults (Niedermeyer, 1982). In an excellent review of theta and psychological phenomena, Schacter (1977) was able to isolate two "grossly different" psychological processes associated with theta activity: 1) active and efficient information processing during problem solving due to the selective and intensive components of attention (e.g. Gale, Christie and Penfold, 1971; Adey, Kado and Walter, 1967; Ishihara and Yoshii, 1973) and 2) apparently the opposite, theta associated with sleep onset (hypnagogic) and low levels of pre-stimulus alertness (e.g. Rechtschaffen and Kales, 1968; Kornfeld and Beatty, 1977; O'Hanlon, Royal and Beatty, 1977).

Evidence for Schacter's conclusion include reports of EEG changes occurring during meditation. Banquet (1973), Elson, Hauri and Cunis (1977), Herbert and Lehman (1977) and Hirai (1978) all reported theta activity associated with meditation. More experienced meditators produce a higher percentage of high voltage (synchronous) theta (Hirai, 1978; Herbert and Lehman, 1977), whereas less experienced meditators display increased alpha amplitudes with intermittent low voltage (desynchronous) theta (Banquet, 1973); Elson, Hauri and Cunis, 1977). Banquet found that click stimula-

tion during deep meditation blocked rhythmic high-amplitude theta for 1 to 3 seconds, while low voltage mixed frequency theta turned into alpha after stimulation. Hirai (1978) reported similar findings and noticed that only very experienced practitioners showed the pure high amplitude theta blocking response to clicking stimulation. Becker and Shapiro (1979) attempted to replicate Hirai's results using 9 Zen meditators, with a median experience of 6 years, and 8 controls. They found no differences in habituation to the clicking response between meditators and controls, although they do mention that "...there is some indication that one or two subjects show a quite different pattern of habituation" (p.149). Unfortunately they do not describe what these different patterns are. Experiments involving click stimulation during meditation are considered important because of their similarity to EEG experiments involving sleep onset. In these experiments, during hypnagogic sleep onset when low voltage theta is present, sensory stimulation induces alpha activity (Morrell, 1966). If alpha activity is induced by stimulation in meditators exhibiting theta, then this is taken as evidence of drowsiness, and not focused attention. This is to be contrasted with theta in alert awake subjects performing problem solving tasks.

In 1972 Ishihara and Yoshii found frontal midline theta activity during continuous arithmetic addition and performance on an intelligence test. In a straightforward and convincing study, Mizuki, Tanaka, Isozaki, Nishijima and Inanaga (1980) showed prominent frontal midline theta during

continuous arithmetic addition and furthermore this theta activity showed a periodicity within the 5 min. of task performance. Frontal midline theta is not present in all individuals. Only 19 of 30 male university students exhibited frontal theta suggesting one or more individual difference variable(s). This is an important finding in that it is congruent with a similar finding in alpha (to be reported in chapter 2). Individual differences in amount of EEG activity has not been adequately investigated in the literature.

Another interesting study by Mizuki, Takii, Nishijima and Inanaga (1983) elucidates the relationship between theta and focused attention in a memory task. Utilizing a paired associate learning test, subjects went through 3 minute each of memorization (MEM), retention (RET) and recall (REC). Frontal midline theta was measured during the 3 minute interval for each condition. The amount of theta activity was greatest during the memorization interval, followed by retention then recall (MEM > RET > REC). A distracting stimulus (white noise) was then introduced into one of the three intervals. When the distraction stimulus was introduced during either memorization or recall the MEM > RET > REC theta ordering was maintained. However, when white noise was introduced during the retention interval the theta order was markedly different: RET > MEM > REC. If it is assumed that focused attention must be increased during the presence of a distracting stimulus the results are consis-

tent. Retention which typically involves rehearsal would require increased attentional efforts when paired with distraction.

Although the term "theta" was originally chosen "...to allude to its presumed thalamic origin (Niedermeyer, 1982, p.83)", the hippocampus has been the site which has attracted most attention for the origin of theta. However, as in Schacter's (1977) review, the ~~present~~ author does not consider it worthwhile to review the hippocampal theta literature because it is extremely difficult to observe in humans. This is due to a tendency for the electrocortical signals to become desynchronized in more developed neocortices (Bennett, 1975). For example, it is relatively easy to record hippocampal theta from rabbits and rats, more difficult in cats where the EEG is balanced between theta and desynchronous activity, and much more difficult in primates where the hippocampal EEG is largely desynchronized (Bennett, 1975). It is perhaps for this reason that the few hippocampal theta studies utilizing human subjects have been inconclusive (e.g. Halgren, Babb and Crandall, 1978a; Halgren, Babb and Crandall, 1978b; Arnolds, Lopes da Silva, Aitink, Kamp and Boeijinga, 1980).

A Synthesis: Posner's (1975) description of attention proposes three 'senses' of the term: (1) the sense of alertness, (2) the sense of selection and (3) the amount of conscious effort invested. These three descriptors account for many of the behaviours observed with theta activity. The sense of alertness is very similar to an orienting

response; the sense of selection implies information processing; and the amount of effort invested is associated with task complexity and difficulty. However, an important variable has not been stressed thus far, a variable which must be considered when any psychological construct is to be associated with EEG. It is the concept of time. EEG is voltage fluctuation through time, and as such, should reflect dynamic, not static, processes. Taking the temporal characteristics of EEG into account, theta may be described as reflecting maintained attention, or attention sustained over time or vigilance. The theta activity associated with the meditation of very experienced Zen practitioners (Hirai, 1978), of astronauts prior to a space launch (Adey, Kado and Walter, 1967) and during problem solving or task performance (Gale, Christie and Penfold, 1971; Mizuki, et. al., 1980), all have in common sustained focused attention.

7 The hypothesis that theta is associated with focal attention maintained through time is consistent with a finding by Mizuki et. al. (1980) of a periodicity in theta activity while performing a continuous task. If focused attention is difficult to sustain, a periodicity in the ability to do so while performing a continuous task is not unexpected. Ultradian rhythms may even be possible. Viewing theta activity as maintained focused attention adds an extra quantitative dimension. It is possible that theta amplitude (i.e. the magnitude of the wave) may reflect degree of focused attention where high amplitude theta

reflects greater focused attention. However, if amplitude is ignored the relative presence or absence of theta activity during a specified interval of EEG may indicate an individual's ability to sustain such levels of focused attention. Period analysis is an ideal method to test this hypothesis. Although it was not tested in study #1 because frontal electrodes were not used, it was investigated for study #2.

Little has been said concerning Schacter's (1977) second psychological process associated with theta; that is, theta's association with sleep onset and low levels of pre-stimulus alertness. Although it was not tested in the present research, this author submits that Schacter's distinction between the two forms of theta is not one of type but of degree. This theta may still be associated with vigilance, but a vigilance occurring at lower levels of arousal directed at spontaneously generated internal phenomenon (e.g. hypnogogic imagery and dreaming).

Alpha: The 8-13 Hz frequency range is called alpha. With an average amplitude between 30 and 90 microvolts, a very synchronous waveform and a preponderance of activity during awake states (Lindsley and Wicke 1974), it is not surprising that alpha was the first dominant frequency observed by Berger (1931) and has subsequently been the focal point for most EEG research, especially with humans.

Alpha is most abundant in occipital-parietal areas of the cortex during relaxed eyes-closed wakefulness and dis-

appears during sleep onset and heightened attention, that is, extremes in arousal. For this reason alpha density has been associated with arousal by an inverted U shaped function (Malmo, 1959; Lindsley, 1960). Challenging this interpretation, Orne and Wilson (1978) reported that heightened arousal, induced by subjects anticipating an electric shock, did not depress alpha density during alpha enhancing biofeedback (Orne and Paskewitz, 1974). Their dependent measures for anxiety and arousal levels included such autonomic nervous system measures as heart rate and number of spontaneous skin conductance responses. Responding to this challenge Hardt and Kamiya (1978) criticised Orne and Paskewitz (1974) for only inferring raised levels of anxiety, not measuring them directly, and using a methodology which selected for low anxiety subjects. Using 8 high and 8 low trait anxiety subjects based on scores derived from the Minnesota Multiphasic Personality Inventory, Hardt and Kamiya found that high-arousal subjects must reduce arousal while low-arousal subjects must become more aroused to increase alpha. Correcting the methodological deficiencies in Orne and Paskewitz's study such as pre-stress alpha biofeedback training, subject anticipation and the lack of stress/non-stress subject comparisons, Frost, Burish and Holmes (1978) found no significant alpha differences between high anxiety induced individuals and normal controls; a result supporting Orne and Paskewitz's conclusions. Unfortunately, Frost, Burish and Holmes' study measured only the presence or absence of alpha exceeding 10

microvolts. Hardt and Kamiya utilized integrated amplitudes. Also, the former asked their subjects to keep their eyes open while the latter had an eyes closed paradigm. The two issues of type of alpha measure and whether the eyes are open or closed are important when comparing results from alpha research. Alpha activity not only occurs less often in eyes-open conditions but the amplitude of the waveform is also much smaller when compared to conditions in which the eyes are closed. Therefore Frost, Burish and Holmes' dependent alpha measure may have been inadequate to detect high anxious versus control differences. Hence, from Hardt and Kamiya's (1978) results, the hypothesis that alpha is related to arousal by an inverted U function is still plausible.

Novikova's (1974) work investigating EEG alpha activity and sensory impairment illustrates the close association between alpha and vision. Using visual EEG inspection he found that congenitally blind subjects showed no evidence of occipital alpha whereas in those subjects where total blindness occurred later in life some levels of alpha activity were retained. This evidence along with findings that alpha disappears or is blocked during eyes open, visual tracking (Peper, 1971) and mental activity (Glass, 1964) has led to an oculomotor-occipital alpha hypothesis (Mulholland, 1972; Mulholland and Peper, 1971). Wertheim (1974) reviewed the evidence for an oculomotor theory and distinguished between the "...oculomotor control system (the efferent

motor system) and the system which samples and interprets sensory information from the field of vision (the afferent sensory system)..." (p.235). Wertheim made this distinction because in the alpha and alpha feedback literature there are reports of eye movements with no concurrent blocking of alpha, for example during mental imagery (Serafinides, 1968) and reading eidetic images with the eyes open (Pollen and Trachtenberg, 1972). For these two modes of perceptual interaction and their reciprocal effect on alpha, Wertheim classified all activities influencing the monitoring of oculomotor activity from visual stimulation (present or anticipated) as 'attentive', and oculomotor monitoring based on internal criteria (independent from external stimulation) as 'intensive'. Hence, attentive (alpha blocking) and intensive (alpha producing) activity are differentiated by the use or non-use of sensory information in oculomotor control.

Recently Wertheim (1981) provided empirical evidence for his theory. He posited that if retinal information is the primary source of feedback for eye movement control (attentive system), then a predictable eye tracking pattern would produce some automation thereby allowing extra-retinal information to be processed (intensive system). Wertheim hypothesized that:

...during ocular pursuit of a target moving in a predictable pattern, the amount of alpha activity observed during periods of on-target eye-tracking should be larger than during periods of error performance. On the other hand, when target movements are unpredictable, retinal feedback is prominent during both on- and off-target performance. Hence, in such a condition little alpha should be observed and only small, if any, differences should appear in the amount of alpha

between periods of on- and off-target tracking performance. (p.433).

Integrated occipital alpha was recorded from 10 subjects during on- and off-target tracking of a spot of light moving in a continuous circle (predictable pattern) or randomly switching to a congruent circle tangent to the first (unpredictable pattern). Ten predictable and 10 unpredictable 1 minute trials were given interspersed with 20 second rest periods. The results showed that more alpha was recorded during predictable on-target performance, supporting Wertheim's hypothesis.

Although Wertheim's theory was developed to explain the relationship between occipital alpha and the oculomotor system, he did comment that it can perhaps be generalized to include other alpha cortical regions and motor control.

Extending Wertheim's conclusions, Tyson (1982) described an interlocking sensory-motor system, including the oculomotor system, which can be disconnected to allow alpha production. By de-activating either the sensory or motor aspect of the sensory-motor system, the 'attentive' process is disrupted allowing the 'intensive' alpha correlated process to operate. Tyson proposed muscular relaxation strategies to de-activate motor systems and cognitive strategies such as meditation for sensory systems.

Beta: Beta activity (13 or 17 to 30 or more Hz) was the second component of normal EEG reported by Berger

(1931), the first being alpha. Sigma, which was originally defined as activity in the 13 to 17 range, has been included in the beta category because it is not usually present in a synchronized form in awake EEG. As a frequency band, sigma is primarily used in sleep research when spindle activity designates stage 2 sleep.

As summarized by Kuhlo (1976) there seem to be three types of beta rhythms observed in awake normal adults: 1) a central rhythm related to cortical sensory-motor functions, 2) a diffuse rhythm and 3) a posterior beta rhythm which is blocked by visual stimuli and mental activity and is referred to as a "fast alpha variant". Kuhlo went on to say however that "...no convincing evidence has been produced so far suggesting that the presence of any of the above beta rhythms correlates with any psychological variables...(p.46)". It should be pointed out that most of the literature Kuhlo reviewed utilized visual assessment of beta stressing synchronous fast activity, a non-optimal strategy given that the major portion of beta EEG is desynchronous. For example, using period analysis on the EEG of 7 normal subjects sleeping all night, Itil (1970) investigated whether EEG variables recorded during rapid eye movement (REM) could discriminate from drowsiness and awake states. He found that there was significantly more superimposed fast activity during REM compared to relaxed wakefulness as measured by the period analysis first-derivative measure, and postulated:

...that the REM state has a characteristic EEG pattern (slow and very fast waves) and that an increase of superimposed fast activity during REM sleep may be indicative of an increase of mental activity in the form of dreams. (p.207)

Itil went on to say:

...we would further speculate that the recall of dreams depends upon the ratio of fast and slow activity in the EEG during REM periods: the more slow waves in comparison to superimposed fast activity, the less dream recall is possible. (p.207)

The superimposed beta activity referred to by Itil is desynchronous activity. However, beta's desynchronous nature along with its tendency to be superimposed on slower frequencies, forces a new approach to quantification. Visual analysis of delta, alpha and theta activity has yielded reliable results. However, it is inadequate for desynchronous beta activity thus necessitating more sensitive quantitative techniques, such as FFT and period analysis. Before these techniques were widely available beta was often inferred from the reduction in alpha activity. This was usually called 'alpha blocking'. As alpha was reduced during a task, increases in arousal, mental activity and beta rhythms were assumed.

The inverse relationship between alpha and beta has been questioned recently by Spydell, Ford and Sheer (1979). They cite the findings of Doyle, Ornstein and Galin (1974) who found no correlation between alpha and beta power increases or decreases. On theoretical grounds an inverse correlation between alpha and beta should be expected only if percent-time measures are used; that is, where the relative presence or absence of all the frequency bands must sum

to 100. Most alpha researchers however, employ some type of amplitude or power criteria which confound amplitude with percent occurrences. For example, an increase in alpha power from one epoch to another can be due to 1) an amplitude increase of the existing alpha, 2) the same amplitude but an increased amount of alpha occurrences, or 3) both. Evidence illustrating the first case was reported by Pigeau (1980). Using period analysis to quantify the alpha EEG from a study investigating alpha amplitude biofeedback, an increase in alpha power over time was found without a simultaneous increase in either alpha zero-cross or first derivative measures (period analysis will be described in more detail later). Since zero-cross and first derivative measures are percentage measures, alpha power can increase without simultaneous increases in the percentage of time that alpha is present; thus beta events may occur. Hence, since it is possible for beta activity to vary independently of alpha power, beta should not be inferred from the absence of alpha power but measured directly.

Gale with his associates reported a weak quadratic trend in beta power with a task varying spatially complex black and white squares to increase stimulus complexity (Gale, Christie and Penfold, 1971), but observed no beta differences associated with auditory vigilance (Gale, Haslum and Lucas, 1972) or expectancy (Gale, Haslum and Penfold, 1971). Other studies (Walter, Rhodes and Adey, 1967; Kornfeld and Beatty, 1977) also failed to find beta dif-

ferences using beta power estimates.

Watson, Jacobs and Herber (1979) report beta time density correlations with pain threshold, defensiveness, disorientation and susceptibility to boredom. However, a number of methodological difficulties are apparent in this study. First, the authors do not report the electrode placements or the type of recording strategy (mono- or bipolar). Second, fifty-one of the 76 subjects were taking a variety of drugs during the study. Third, although 660 correlation coefficients were calculated only a significance level of .05 was used. Fourth, neither the frequency ranges nor their characteristics were reported.

In brain generated bio-potentials there is presumed to be an inverse relationship between frequency and amplitude: as frequency increases, amplitude decreases. For example, delta waves often reach maxima of 100 microvolts whereas beta activity rarely exceeds 25 microvolts. For this reason computer quantification techniques such as PBTs show beta as a low power event when in fact beta activity is quite prominent. This fact may account for the poor beta results encountered in the literature. The problem is really more one of measurement than theory. For if beta actually is representative of cognitive activity the manner in which it is measured becomes very important. Beta activity can manifest itself in two ways, the first occurring infrequently and the second being quite common: 1) as relatively synchronous activity within certain bandwidths or 2) desynchronous activity across a wider bandwidth. If an EEG analysis such

as FFT is utilized, yielding an estimate of power for each frequency, then it may not be clear whether an increase in beta power is truly indicative of cognitive activity. The reason for this is if cognitive activity desynchronizes the EEG, lower amplitude and power will result because the waveforms cancel each other. Eventhough desynchronous activity means more beta activity, it may be masked in the FFT by the lower amplitude. A measure which detects beta and ignores amplitude is needed along with a power measure. Realizing this problem Sheer (1970, 1974), experimented with the relative presence or absence of high frequency waves (>40 Hz) and found increases in this bandwidth during acquisition of visual discrimination in cats and problem solving in normal children. Also, successful enhancement/suppression biofeedback attempts in this frequency range and in the 21-31 Hz beta range were reported by Bird, Newton, Sheer and Ford (1978) and Beatty (1971). Their results are encouraging for future beta research.

1.2.2 EEG Asymmetry

The theoretical basis for EEG laterality investigations originates in research from a number of disciplines: anatomical studies (Rubens, 1977; Geschwind, 1981), commissurotized, hemispherectomized and lesioned studies (Gazzaniga, 1970; Sperry, 1968, 1970; Smith, 1972; Milner, Branch and Rasmussen, 1964) and behavioural studies (Berlin, 1977; Springer, 1977). Willis, Wheatley and Mitchell (1979) offer a good summary of laterality theory:

It is suggested that, in most people, the left hemisphere treats stimuli serially, operating in a logical, analytic fashion abstracting out relevant details and attaching verbal labels. The right hemisphere processes stimuli many at a time and is primarily a synthesis, more concerned with the overall stimulus configuration, organizing and processing information in wholes or gestalts. (p.473)

In 1977 Donchin, Kutas and McCarthy reviewed the EEG cerebral laterality literature. Pigeau (1983) has reviewed the literature since Donchin, Kutas and McCarthy's paper. What follows is a brief discussion of EEG and cerebral laterality. The reader is referred to the above two documents for a more complete treatment of the topic.

In 1979 Gevins and his colleagues published a series of papers asserting that EEG hemispheric asymmetries during cognitive tasks (specifically chosen to induce such asymmetries) were due to efferent activity, stimulus characteristics and performance related factors, and not due to cognitive differences (Gevins, Zeitlin, Doyle, Yingling, Schaffer, Callaway and Yeager, 1979b; Gevins, Zeitlin, Yingling, Doyle, Dedon, Schaffer, Roumasset and Yeager, 1979c; Gevins, Zeitlin, Doyle, Schaffer and Calloway, 1979a).

Their results challenged a cognitive interpretation of hemispheric EEG asymmetry championed by the research of Galin, Ornstein and their colleagues (Galin, Orstein, Kocel and Merrin, 1971; Galin and Ornstein, 1972; Doyle, Ornstein and Galin, 1974; Galin, Johnstone and Herron, 1978; Ornstein, Johnstone, Herron and Swencionis, 1980; Ornstein, Herron, Johnstone and Swencionis, 1979; Galin, Ornstein,

Herron and Johnstone, 1982). After more than a decade of research, these investigators contend that "cerebral asymmetry in cognitive function is reflected in EEG alpha asymmetry during the performance of cognitive tasks" (Galín, et. al., 1982). In a lengthy footnote defending their research, a footnote of which only a small portion is reproduced here, Galín, et. al. (1982) criticised Gevins' experiments.

There are several possible alternative explanations for Gevins' negative result which are amenable to empirical test. First, the individual trials of the three tasks were presented in a random order and each trial lasted on the average less than 10 sec. Therefore, subjects could not adopt a "set" to do arithmetic or spatial manipulations, i.e., they may have maintained a general readiness and not inhibited the hemisphere less engaged in one or the other task. We have always used tasks involving several minutes of continuous behavior. Second, while Gevins emphasized controlling the active tasks, he nevertheless referred each of them to the totally uncontrolled "baseline" task; gazing passively at a fixation point. Third, Gevins did not do a within-subject analysis of task differences, comparing each subject's arithmetic EEG to thier own spatial rotation EEG. Instead, for each task, he expressed each subject's score, and computed means over the group, and compared the group means. He did not pool all of the 2-3 min of EEG observations on a task for each subject to get the most stable estimates for that subject, but instead used multiple 10- to 15- sec blocks of EEG as separate observations. (p. 43)

Galín also criticised Gevins for an inappropriate choice of reference electrodes.

Galín and his associates are also not without fault, however. Their studies may be criticized for not controlling movement (Galín, Johnstone and Herron, 1978), questionable subject selection criteria (Ornstein, Herron, Johnstone and Swencionis, 1979) and confusing statistical

summary tables (Ornstein, Johnstone, Herron and Swencionis, 1980).

The major conclusion from both the Gevins and Galin groups is that motor involvement should be kept to a minimum in order to reduce movement artifact and allow EEG which is maximally representative of cognitive activity, a conclusion recently verified experimentally by Inouye, Shinosaki and Yagasaki (1982). Although Gevins believes that removing all extra-cognitive factors eliminates EEG asymmetries, Ornstein's results (Ornstein, Herron, Johnstone and Swencionis, 1979) did show EEG asymmetries during tasks requiring very little or no motor responses.

Most EEG laterality studies, including those discussed above, utilize alpha activity as the major dependent variable. If more alpha is present in one cerebral hemisphere than the other it is inferred that the low alpha hemisphere is more cognitively active. This interpretation is based on the assumption that alpha activity represents mental 'idling' and that the inverse, absence of alpha, represents mental activity. The validity of such an assumption may be questioned however, based on the discussion of alpha presented earlier. It does seem that the amount of alpha may indicate the level of sensory-motor de-activation (or Wertheim's intensive activity) but it does not follow that there is a concomitant cessation of mental activity. For example, right hemisphere alpha activity may indicate the level of intensive, gestalt information processing necessary to perform predominantly verbal-analytic tasks. Conversely,

left hemisphere alpha would reflect that intensive portion of spatial-holistic tasks which are serial, verbal and analytic. It is not scientifically rigorous to infer mental activity in one hemisphere from alpha prominence in the opposite hemisphere. Mental activity should be measured directly whether the subject is in an attentive or intensive mode. Perhaps theta and beta bandwidths may provide this dependent measure, although as was mentioned earlier beta alone is not necessarily inversely correlated with alpha.

Spydell, Ford and Sheer (1979) extended their 40 Hz (high beta) EEG investigations to include cerebral lateralization. Their tasks included verbal analogies, verbal mathematics, facial discrimination and figure rotation. Using a R-L/R+L asymmetry ratio, significant differences were obtained between verbal analogies and facial discrimination, and verbal analogies and figure rotation. Verbal analogies resulted in relatively more 40 Hz activity in the left hemisphere than did both figure rotation and facial discrimination. Their experiment is important because it attempts to directly measure hemispheric activation, unlike the alpha studies.

Rugg and Dickens (1982) found exciting evidence for differential hemispheric theta activity. Parietal EEG from subjects performing verbal and visuo-spatial tasks was Fast Fourier analysed to yield power estimates for alpha and theta. Theta showed both a significant main effect for task and a task by hemisphere interaction. Specifically, theta

power increased from the rest condition to the verbal and then the spatial condition. Furthermore, a significant left-right difference was observed for the visuo-spatial task with more theta power in the right hemisphere. Rugg and Dickens suggested that "... the conclusion that the right hemisphere increase in theta in the visuo-spatial task reflects the engagement of specialized mechanisms necessary for visuo-spatial processing should be viewed with caution" (p.206). The present author suggests that the reason for Rugg and Dickens' caution is the lack of hypotheses concerning the functional and structural significance of theta activity. The theta theory outlined in this paper is predictive of Rugg and Dickens' findings especially when the visuo-spatial task proved to be more difficult than the verbal one: "Items in the verbal tasks were performed both more rapidly and more accurately than the visuo-spatial item..." (p.206). It is assumed that difficulty and maintained focused attention are positively correlated, at least until the task becomes too difficult and is abandoned.

Summary

An attempt was made in this chapter to 1) develop a strategy for extracting a maximum amount of information from the EEG signal (assuming a stochastic process), and 2) review EEG correlates to cognition as contained in conventional frequency bandwidths.

In chapter 2 study #1 is presented in which some of the ideas outlined in this chapter were investigated.

CHAPTER 2

EEG and Cognition: Study #1

This experiment was originally designed to study the laterality issue; specifically to resolve the conflict between Gevins and Galin/Ornstein. For example, a source of conflict between these investigators has been the choice of electrode reference. Galin and Ornstein support a bipolar montage with each homologous electrode referenced to a common vertex electrode, whereas Gevins prefers monopolar configurations, with either ipsilateral or linked ear references. The montage utilized in this study was monopolar with linked ear configuration because 1) monopolar differential recordings yield topographically more interpretable signals than bipolar recordings, particularly when asymmetry indices are generated, and 2) it was deemed more conservative to utilize the montage associated with non-significant results (e.g. Gevins et. al., 1979a). Also, in designing the cognitive tasks, emphasis was placed on 1) tasks requiring a response to monitor performance, 2) tasks where such responses elicited minimal or no motor involvement, 3) tasks with small scanning angles or better, tasks with the eyes closed, and 4) tasks requiring sufficient time to induce cognitive 'sets' (Galin, et. al., 1982). These criteria were chosen to compromise the criticisms and cautions voiced by Gevins

and Galin/Ornstein. The chosen tasks were ordered a priori for the relative magnitude of the cognitive processes they are presumed to involve (i.e. verbal-analytic or spatial-holistic).

This data set also allowed evaluation of the analysis strategy outlined in chapter 1. Although the tasks were not specifically chosen to validate such an approach, they do provide adequate and necessary pre-testing.

Based on the discussion in chapter 1 concerning the theoretical relationship between cognition and EEG, the following hypotheses were tested:

1. Since the left and right cerebral hemispheres presumably reflect verbal-analytic and spatial-holistic cognitive processes respectively, the asymmetry index for alpha activity should correlate with an a priori ordering of the tasks. Based on the expected cognitive functions of the two hemispheres this will be manifested as shifting alpha asymmetry from the left to the right hemisphere across the ordered tasks. More alpha activity in one hemisphere will reflect greater intensive verbal-analytic or spatial-holistic cognitive processing.
2. Given that beta activity can vary independently from alpha activity, the asymmetry index for beta activity will not be the inverse of the one for alpha across all tasks.
3. 3-D spectrographs will indentify individual differences based on differences either on single frequencies (or

single bandwidths) or changes in frequencies through time. These individual differences may then be used as independent variables in future research -- e.g. individual differences in producing theta activity as suggested by the work of Mizuki et. al., 1980.

4. Systematic changes in the correlational patterns of single Hertz frequencies will be observed across tasks (more specific hypotheses are not as yet possible given the novelty of the method).

METHOD

Subjects Fourteen volunteers (7 males, 7 females) were chosen as subjects for this experiment. All Ss had some university education and were functionally and familially right handed, as determined by questionnaire. Mean S age was 26.3 yrs. (males = 27.4, females = 25.3).

Apparatus: Two electrodes, P3 and P4 referenced to linked ears, were secured using Grass EC2 electrode paste. The EEG was amplified using Grass EEG pre-amplifiers (Model P511J) with 60 Hz notch filters and was then simultaneously recorded on a Beckman type RM dynograph and an 8 track Vetter Model A FM tape recorder running at 15/16 ips with flutter compensator. A real-time clock activated by the experimenters while the Ss performed the tasks generated an electrical signal lasting 10 seconds. These signals were also recorded on the 8 track tape and demarcated single or successive 10 second EEG segments or 'epochs'. Electrophysiological data reduction was performed using a DEC LSI 11/23 micro-computer with A/D converters, real time clock and mass storage (floppy and hard discs).

All visual tasks and one auditory task were generated by an Apple II+ micro-computer situated outside a shielded and anechoic chamber and were presented both to the experimenters (outside the chamber) and to the S via two 12 inch television monitors and two speakers. All computer programs

were written in Pascal by the experimenters except for the music task which was commercially available (MusiComp by Paul Lotus, Apple Computer Inc., 1980). The remaining auditory tasks were recorded prior to the experiment.

Task Description: The tasks were selected for their presumed ability to induce left or right hemisphere activation. The tasks were then ordered a priori from predominantly right hemisphere tasks requiring 'attentive' spatial-holistic processing to predominantly left hemisphere tasks requiring 'attentive' verbal-analytic processing. Two tasks were performed with the eyes closed: focusing and counting. Of the seven tasks, these two were considered by the experimenters to be most representative of a spatial-holistic task (focusing) and a verbal-analytic task (counting). Both were performed with the eyes closed. The other five tasks were performed with the eyes open and were similarly ordered.

FOCUSING (FO):

With the S's eyes closed, recorded instructions were given which attempted to elicit a self-directed internal focusing of attention designed to heighten bodily awareness (the instructions for this task were derived from Gendlin, 1978). Part of the instructions asked the S to create a 'handle' reflecting the present state of their internal bodily feelings (see appendix A for a transcript of the instructions). EEG was taken for a total of 5 minutes, after the instruction period. At the end of the task the subject was asked to report

their 'handle' and give a brief summary of their experience of the task. The task was very meditative.

MUSIC (MU):

A commercial program (MusiComp) was used to play various pieces of music electronically. A visual display of the musical notes was also graphically displayed. The S was asked to pay attention to the notes on the monitor and enjoy the music. Three pieces of music were played for a total of approximately 4 minutes during which EEG was recorded. This is the only task not requiring a direct estimate of performance or attention. However, the task was considered novel and pleasant enough to ensure an attentive response for the full 4 minutes.

BLOBS (BL):

With the S's monitor divided into quadrants, four 'blobs' were presented simultaneously for 5 seconds. The 'blobs' consisted of four amorphous contours roughly of the same size and shape, randomly selected from a stimulus pool of 15 blobs. After the stimuli were presented, the S was instructed to remember the shapes of the four blobs for 20 seconds. At the end of the rehearsal period one of the original four blobs appeared in the center of the monitor either in its original orientation rotated 180 degrees (the decision to rotate the blob for any single trial was random). The S's task was to determine in which quadrant the

target had previously appeared. There were 10 trials and the number of correct responses was recorded. EEG was taken during the 20 second rehearsal interval (two 10 second epochs per trial).

MATH (MA):

Four numbers were presented on the monitor for 2 seconds.

e.g. TWO/NINE/FIVE/SEVEN

Afterwards, an arithmetic problem involving simple addition and subtraction was presented.

e.g. $2 + 5 - 6 + 7 = ?$

The S was asked to solve the problem mentally and answer either YES or NO as to whether the answer was one of the original 4 stimulus numbers. For each of 20 trials the program randomly selected new numbers. EEG was sampled and analysed from stimulus onset to just prior response (approximately 10 seconds). The number of correct responses were recorded.

READING FORWARD (RF):

A page of non-fiction, non-technical text selected from Reader's Digest was presented on the monitor. The S was asked to read this text silently for content. When was read, the S was instructed to utter the word 'NEXT', whereupon another page was presented. The task lasted for 2 minutes. The number of lines of text read was recorded and questions were asked concerning content. EEG was recorded in sequential 10 second epoch for the full 2 minutes.

READING BACKWARD (RB):

This task was the same as RF except the (different and still non-technical) text was presented backward. In this case the order of presentation of individual letters was from right to left rather than left to right. The letters themselves were not reversed. Again 2 minutes of EEG were recorded.

COUNTING (CN):

With the S's eyes closed a pre-recorded 2 minute non-fiction, simple, historical passage was played over the speaker. The instructions were to count the number of 'a's and 'the's uttered in the passage after which they were reported and recorded. A second 2 minute passage was then presented with identical instructions. This task is similar to the one utilized by Moore (1979). EEG was recorded during the full 4 minutes of passage presentation.

Procedure: Once the electrodes were secured, the S was seated in a dimly lit anechoic chamber with a TV monitor and speaker facing the S 1 meter away. Two minutes of eyes open and eyes closed resting EEG baselines were recorded before and after the experimental session. The tasks were presented randomly and, where needed, some employed two practice trials to familiarize the S to the task.

Following the experimental session the S was asked to express any feelings or thoughts concerning each of the tasks. Their responses, along with their performance

scores, allowed motivation level and cognitive strategy estimations.

The experimenters controlled all aspects of the experiment from a central work station outside of the anechoic chamber. The 10 second event timer was activated by the experimenters to identify either successive or single 10 second EEG segments or 'epochs'.

EEG Analyses: Before computer quantification the FM recorded EEG was low pass filtered to eliminate all signals above 70 Hz (A.P. Circuit Corp. 24 db/octave). The event signal recorded on the 8 track tape demarcated real-time 10 second epochs of EEG. These epochs of EEG were the sampling 'window' for all computer quantification methods. Based on the polygraph tracings, any 10 second epoch of EEG which showed clear movement artifact was deleted from further analyses. The following EEG analyses were performed on these EEG epochs.

Period Analysis: Period analysis was chosen to evaluate the amplitude and conventional frequency bandwidths for each task because it provides three measures for each bandwidth: two percent-time measure (zero-cross and first-derivative) and one power measure (derived from the zero-cross). Briefly, a zero-cross analysis checks for a change in the sign of the EEG waveform voltage, where such a change is indicative of the voltage passing through zero. A measurement of the elapsed time between two zero-crossing events yields an estimate of the wave's frequency. First-

derivative analysis checks for negative inflections in the EEG voltage; that is, a change from a decreasing voltage signal to an increasing one. The time between two such events provides an estimate of faster frequencies superimposed on the main waveform (see figure 2.1). The power measure is simply the cumulative addition of the absolute voltage values between zero-crossing events. A total power measure was also calculated, giving an estimate of total power across all frequencies. In addition, a hemispheric asymmetry index was calculated for each of the period analysis measures ($\text{Left} - \text{Right} / \text{Left} + \text{Right}$).

For a more complete description of period analysis see Hoffmann, Moffitt, Shearer, Sussman and Wells (1979). They utilized a half-wave period analysis whereas the present study employed a full-wave analysis because alpha activity was of primary interest. To digitize the data for period analysis the raw EEG was sampled at 1000 samples per second by means of the A/D converters. A 7 microvolt threshold criteria was adopted for the first-derivative measure in order to eliminate very low amplitude high frequency activity which is often a consequence of equipment noise.

To summarize, for each electrode there are 13 measures: 3 measures for each of 4 frequency bandwidths (delta .5-4 Hz, theta 4-8 Hz, alpha 8-13 Hz, beta 16-30 Hz), and a total power measure. For the pair of electrodes (P3-P4) 13 asymmetry measures were calculated: one for each of the above measures. Therefore, in total, for any single 10 sec epoch

Figure 2.1: An example of zero-cross and first-derivative events in a voltage signal. From Hoffmann et. al. (1979) p.7

of EEG, there are 39 measures:

2 electrodes x 13 measures + 13 asymmetry measures.

FFTs: The first 4 seconds of each 10 second EEG epoch was sampled and A/D converted at 128 samples per second. At this sampling rate the Nyquist frequency is 64Hz, the highest analysable frequency. The FFT algorithm used was developed by Ahmed and Rao (1975). With 512 data points (4 sec x 128 samples/sec) it yields 256 power values, one for each .25 of a Hertz. Clusters of 4 adjacent power values were summed and averaged resulting in one mean power value for each single Hertz frequency from 1 to 64 Hz. As protection against 60 cycle noise induced from the environment, only frequencies from 1 to 51 Hz were considered in this study.

Only the first 4 seconds of each 10 second EEG epoch were analysed in order to allow sufficient FFT computation time before the next epoch. An FFT power spectrum was thus generated for each epoch of EEG at each scalp electrode site. All individual difference analyses and all correlational frequency patterns utilized this FFT data set.

RESULTS

Conventional EEG Analysis

Given that certain aspects of this study were pilot in nature and hence its purpose more descriptive than inferential, a liberal attitude towards hypothesis testing was taken. This liberalism will be most prominent in an unorthodox strategy for reporting the significance levels of multiple t-tests. The computer statistical package which generated the t-tests (SPSS) also calculated the exact probabilities of the t ratio. Given constant degrees of freedom, the exact probabilities are perfectly correlated with the t ratio, yielding a direct estimate for the strength of the effect. This approach is valid only if the following guidelines are adhered to: 1) the t-tests must share a common theoretical premise (e.g. all eyes open tasks compared with eyes closed tasks), 2) they must have equal degrees of freedom and 3) only t-tests meeting or exceeding a significance level of $P < .05$ are summed and averaged. With these guidelines in mind a quick and elegant way of summarizing the strength of the effect is achieved. [NOTE: The $P < .05$ guideline was violated in one instance for illustrative purposes when discussing the Beta results.]

Alpha:

Alpha activity from each hemisphere's parietal lead was summed and averaged, yielding a single 'cortical' alpha

measure. This was done for the alpha zero-cross, first-derivative and power measures separately. The hemisphere averaged alpha for all epochs of a task for each individual were summed and averaged yielding one value per subject per task (for each of the three period analysis measures).

It was noticed by the experimenters during the experiment that there seemed to be subjects who produced greater amounts of alpha activity than others, particularly when the subjects were resting with their eyes closed (eyes closed baseline). Based on the alpha zero-cross measure the subjects were divided into HIGH or LOW alpha generators by a median split. These two groups were used in most analyses as a post hoc independent variable.

Figure 2.2a is a histogram of alpha zero-cross (summed and averaged across hemisphere) for all subjects for each task. Figures 2.2b and 2.2c show alpha activity for HIGH alpha generators and LOW alpha generators respectively. The first result of note is that alpha activity indeed goes up from eyes-open to eyes-closed resting baseline. The difference between eyes-open and eye-closed is significant both in the pre-experimental condition ($T_{pre} = -5.69$, $df = 13$, $P < .000$) and the post-experimental condition ($T_{post} = -3.95$, $df = 13$, $P < .002$). The effect is of course greater for HIGHS than for LOWs (HIGHS: $T_{pre} = -5.62$, $df = 6$, $P < .001$, $T_{post} = -3.98$, $df = 6$, $P < .007$; LOWs: $T_{pre} = -3.47$, $df = 6$, $P < .013$; $T_{post} = -1.94$, $df = 6$, $P < .101$). As expected FO and CN, two eyes closed tasks, display more alpha than the rest of the tasks in

Figure 2.2: Hemisphere averaged alpha zero-cross for all baselines and tasks for all subjects (A), HIGHS (B) and LOWS (C). (FO-Focusing; MU-Music; BL-Blobs; MA-Math; RF-Reading Forward; RB-Reading Backwards)

which Ss had their eyes open. This difference is greater for HIGH than LOW alpha generators, as expected. Among all the tasks only MU was significantly different from MA and BL significantly different from MA ($T=3.01$, $df=13$, $P<.01$, $T=3.08$, $df=13$, $P<.009$ respectively).

The asymmetry index yielded very interesting results. Figure 2.3a shows the L-R asymmetry ratio for all tasks either baseline adjusted for each subject or non-adjusted. Baseline adjustment was calculated for each subject by subtracting the L-R averaged pre-post eyes open baselines from eyes open tasks and L-R averaged pre-post eyes closed baselines from eyes closed tasks. The adjustment was made to compare Gevins' approach with that of Galin and Ornstein's who do not adjust the data with reference to baseline levels of activity. Gevins argued that asymmetries during task performance should be controlled for by naturally occurring asymmetries in individuals during baseline conditions. However, major differences were not observed between the two approaches. Figures 2.3b and 2.3c show that adjustment versus non-adjustment is not a major concern when calculated for HIGH and LOW alpha generators. Baseline adjustment seems to shift the alpha activity during task performance uniformly to the right hemisphere. The overall shape of the graphs are the same.

Although the asymmetry graph for all subjects (figure 2.3a) definitely shows a left to right trend across the tasks, the linear trend was not significant ($F=3.34$, $df=1,13$, $P<.09$). However, given that the tasks were ordered

Figure 2.3: Left-Right alpha asymmetry measure overall (A),
 HIGHS and LOWs non-adjusted (C), and HIGHS and LOWs
 baseline adjusted (B).

a priori for their presumed influence on alpha asymmetry, this result is encouraging. When the alpha asymmetry data is plotted separately for HIGH and LOW alpha generators an interesting finding is observed: the HIGH subjects show the hypothesized left-right trend better than do the LOW subjects for both adjusted and non-adjusted data (see figures 2.3b and 2.3c). There is a significant linear trend across tasks for HIGHS ($F=6.15$, $df=1,6$, $P<.048$) but not for the LOWs ($F=.12$, $df=1,6$, $P<.74$). The implications of this result will be outlined in the discussion.

Since alpha activity has been so important in the EEG asymmetry literature it was decided to calculate an asymmetry index for alpha utilizing FFT values. Single Hz FFT values within the alpha bandwidth (8-13 Hz) were summed and averaged for each epoch of EEG. There were no significant trends towards the left or right hemispheres across the tasks. High alpha generators were not significantly different from Low alpha generators although the High alpha generators displayed marginally more alpha in the left hemisphere than the LOWs.

Theta:

For the moment, theta results can only be considered to be tentative, since the EEG was not recorded from frontal leads. The major hypotheses generated in the first chapter are topographically related to this area.

Figure 2.4a, 2.4b and 2.4c display the hemisphere averaged theta zero-cross for all tasks and baselines. The

Figure 2.4: Hemisphere averaged theta zero-cross for all baselines and tasks for all subjects (A), HIGHs (B), and LOWs (C). (FO=Focusing; MU=Music; BL= Blobs; MA= Math; RF= Reading Forward; RB=Reading Backwards; CN=Counting)

A

B

C

Figure 2.5: Left-Right theta asymmetry measure overall (A),
HIGHS and LOWS non-adjusted (B), and HIGHS and
LOWS baseline adjusted (C).

shape of the histograms are essentially the inverse of those observed for alpha. The LOW alpha generators show significantly more theta than the HIGHS on PO, BL, and CN tasks, and the Eyes Closed Post baseline (average $P=.025$, $df=12$). Compared with eyes closed baselines, the CN task has significantly more theta ($P<.005$, $df=13$). Interestingly, there are no differences between eyes open and eyes closed baselines, as were found for the alpha activity results.

The theta asymmetry scores were non-significant across task or between HIGH/LOW alpha generators. Figures 2.5a, 2.5b and 2.5c show the trends. Except for PO, the theta asymmetry trend is opposite to that found in the alpha asymmetry results. This results holds for HIGHS only.

Beta:

One HIGH alpha generator was deleted from these analyses due to inordinately high beta activity, probably due to muscle tension. The subject was experiencing a migraine at the time of the experiment (see the FFT spectrum in the next section). The subject was not deleted from the alpha and theta results because these frequencies were not affected; that is, they were representative of the alpha and theta values observed among the HIGHS.

The hemisphere averaged beta (first-derivative) values for the baselines and the tasks are displayed in figure 2.6a. No significant differences were observed between the tasks and the baselines or between the eyes open and eyes closed baselines. However, the mean for the eyes open tasks

Figure 2.6: Hemisphere averaged beta first-derivative for all baselines and tasks for all subjects (A), HIGHS (B) and LOWs (C). (FO=Focusing; MU=Music; BL=Blobs; MA=Math; RF=Reading Forward; RB=Reading Backwards; CN=Counting)

Figure 2.7: Left-Right beta asymmetry measure overall (A) HIGHs and LOWs non-adjusted (B), and HIGHs and LOWs baseline adjusted.

were significantly greater than the mean for the eyes closed tasks (average $P=.0026$, $df=12$). These differences were maintained among the HIGH's (average $P=.014$, $df=5$) but not the LOW's (average $P=.0957$, $df=6$). This is an interesting finding for two reasons: 1) beta increases are not simply due to opening or closing the eyes, there is an important task effect and 2) LOW alpha generators generally maintain the same level of beta activity despite the nature of the task whereas HIGH alpha generators fluctuate.

There were no significant differences utilizing the asymmetry index for beta first-derivative (see figure 2.7). Except for the counting task, which yields more beta activity among the HIGHs in the left hemisphere and LOWs in the right, and the Focusing task where HIGHs and LOWs are the same, the LOWs show consistently less beta activity in the right hemisphere than the HIGHs. Given that these results are non-significant they were described to emphasize that the trend for L-R beta first-derivative is not opposite to that observed for L-R alpha zero-cross. This is support for the beta hypothesis that beta is not the inverse of alpha.

Individual FFT Power Spectra

Individual power spectra were calculated for each epoch during the focusing task. Three dimensional figures were generated for each subject with Power on the Y axis, Frequency in single Hz increments on the X axis and time in epochs on the Z axis. Plotting was performed with hidden surfaces removed. Figure 2.8 is the 3-dimensional power

Figure 2.8: 3-D spectrograph of subject excluded from study because of a migraine headache.

Figure 2.9: 3-D spectrograph for a HIGH alpha generator performing the Focusing task.

Figure 2.10:3-D spectrograph for a LOW alpha generator performing the Focusing task.

spectrum of subject 'C' performing the Focusing task. This subject was dropped because of extreme activity among the higher frequencies due to a migraine. Rather than display the 3-D plots for each subject a representative subject from each alpha generator group is reproduced (figures 2.9 and 2.10). Each subject is plotted twice: once with frequencies ranging from 1 to 51 Hz and once from 51 to 1 Hz. The two plots are necessary in order to show lower power values hidden behind high spectral peaks. The subjects were the middles of their respective groups when rank ordered for alpha activity. Representative differences between HIGHS and LOWs are evident from looking at these figures. As expected, the major differences lie within the 8 to 13 Hz region. However, it seems that HIGH alpha generators also have more power in frequencies greater than 14 Hz in the beta bandwidth. When the power values are summed for frequencies from 14 to 51 Hz the HIGHS have an average total power value of 251.03 whereas the LOWs have one of 235.6. Although the difference is non-significant, it is interesting in light of the fact that LOWs show more beta first-derivative in the focusing task than do the HIGHS. This would mean that although LOWs display more percent beta activity than the HIGHS, beta amplitude for the HIGHS is greater than the LOWs.

Correlational Patterns Among Frequencies

The lower diagonals of the FFT correlation matrices for each of the tasks are shown in figures 2.11 through 2.16.

These correlations were performed on the EEG from the right hemisphere. Only correlations of .5 or greater were drawn (significant at .05 with 13 df). On each page the figures on the left represent frequency correlations within the right hemisphere while those on the right reflect frequency correlations between the left and right hemispheres. The first noticeable cluster is seen in figures 2.11a through 2.11d. These are the eyes closed tasks, Focusing and Counting. The clustering observed when frequencies in the range of 14-19 Hz are correlated with 4-9 Hz frequencies is quite striking, indicating that as FFT power activity in the 4-9 Hz range (roughly theta) increases or decreases, power activity within the 14-19 Hz range (roughly sigma or low beta) similarly increases or decreases. That is, it may be said that during the Focusing and Counting tasks the FFT power values for ranges between 14-19 Hz and 4-9 Hz are in 'phase' or 'coherent' in the frequency domain. This result suggests that a new 'multi-banded' bandwidth may better discriminate between the two eyes closed tasks than a 'unitary' conventional bandwidth. This new 'multi-banded' bandwidth is not present during the pre-experiment eyes closed baseline (figures 2.12c and 2.12d) and only marginally evident during the post-experiment eyes closed baseline (figures 2.13c and 2.13d).

The second noticeable correlational cluster is an expanding 'unitary' cluster. Some tasks exhibit a strong 30-50 Hz unitary cluster (i.e. 30-50 Hz correlated with 30-50

Figure 2.11

Figure 2.12

Figure 2.13

Figure 2.14

Figure 2.15

Figure 2.16

Hz), while others exhibit a larger 20-50 Hz unitary cluster. It is suggested that perhaps the smaller cluster is associated with simpler tasks whereas the larger cluster with more complex tasks. Figures 2.15a through 2.15d illustrate the differences between Reading Forward and Reading Backward within and between hemispheres. The correlational matrix for the Reading Forward task is much less saturated in the 20-30 Hz range than is the matrix for Reading Backwards, a much more difficult task. Within this frequency range Reading Forward is similar to Music (figures 2.16a and 2.16b) and Eyes Open Post baseline (figure 2.13a). Reading Backwards on the other hand is more similar to Blobs (figures 2.14a and 2.14b) and Math (figures 2.14c and 2.14d). Blobs and Math were more difficult tasks than Music and Eyes Open Post baseline.

The third correlational pattern in this data set seems to reflect hemispheric power synchrony during formal cognitive engagement. The left-right hemisphere correlations for Eyes Closed Pre- baseline (figure 2.12d), Eyes Open Post baseline (figure 2.13c) and Eyes Closed Post baseline (figure 2.13d) all show less saturation among the higher frequencies than do all of the other (formal) tasks. This suggests that the cerebral hemispheres are less synchronized with respect to power within higher frequencies when the subject is not formally engaged in a task. More specifically, when subjects are left on their own (relaxing), more individual cognitive variation occurs thus reducing the correlations. When forced to perform the same tasks

however, individual variation between hemisphere is reduced
thus increasing the correlations.

DISCUSSION

The results obtained from this study demonstrate that the analysis strategy proposed in chapter 1 does yield interesting and consistent findings. However, the potential gains from this approach have only been minimally realized in this experiment. Suggestions for refinement and extension will be made as the results are discussed.

The major finding within the alpha bandwidth is the differentiation between HIGH and LOW alpha generators. HIGH alpha generators displayed the hypothesized relationship between tasks and alpha asymmetry whereas the LOW alpha generators did not. This finding has important implications for subject selection criteria, and may have contributed to the conflict between Gevins and Galin-Ornstein. If Gevins had a sample of individuals who were predominantly low alpha generators his results are not unexpected. Galin and Ornstein on the other hand may have utilized high alpha individuals. Admittedly such an explanation is weak given that no evidence exists supporting it, but at least on one occasion Ornstein, Herron, Johnstone and Swencionis (1979) chose their subjects on their ability to display EEG asymmetry during a screening session. Those subjects displaying "negligible or reversed specialization (p.399)" were excluded from the experiment. Given that LOWs were less lateralized with respect to alpha than HIGHS in this pilot study, it is possible that Ornstein et. al. (1979) were also inadvertently selecting high alpha generators. Another

possible reason for Gevins' negative results is his use of FFTs partialled into conventional frequency bandwidths. The results from the present study found that hemispheric alpha activity utilizing FFT derived data did not show the left to right hemisphere trend observed with the L-R alpha zero-cross measure. It seems that percent alpha is more important than power for detecting asymmetries in alpha.

The fact that the tasks were chosen a priori for their presumed ability to induce relative amounts of verbal-analytic or spatial-holistic cognitive processes is strong support for the validity of the results. To this author's knowledge this is the first demonstration for an ordering of tasks according to propensity to induce hemispheric asymmetry.

The theta results are also promising insofar as this frequency may reflect cognitive activity. The fact that more theta was observed during Counting than the Eyes Closed Baselines suggests that the 'sustained attention' or 'vigilance' hypothesis developed in chapter 1 is valid. Unfortunately there were no differences among tasks, perhaps due to the posterior electrode site. There were, however, differences between HIGH and LOW alpha generators among some of the tasks. Whether this is indicative of a strong alpha effect carrying over into the theta bandwidth or a distinctive theta effect can not be determined at this time. A frontal electrode placement would best resolve this issue.

Simply opening or closing the eyes did not significan-

tly change beta activity during baseline conditions, but differences were observed between eyes open and eyes closed during task performance. LOWs maintained a high but less differentiated beta level across tasks whereas the HIGHs had comparable beta levels only during eyes open tasks. The eyes closed tasks (Focusing and Counting) were significantly reduced in beta among the high alpha generators. The lack of beta differentiation among the eyes open tasks may be more a function of the tasks chosen than the measure. A task varying in difficulty level may be better suited to elicit changes both in the theta and beta bandwidths. This strategy may also induce a systematic asymmetry in the L-R beta measure.

The lack of an inverse relationship in the asymmetry scores between alpha and beta across tasks, suggests that alpha does not simply represent mental 'idling' (Galin and Ornstein, 1972). Indeed, the non-adjusted beta asymmetry figures show more beta in the right hemisphere. It seems that the right hemisphere is more active electrophysiologically than the left, at least for the percentage measures.

The FFT spectrographs drawn for each subject support the high versus low alpha split selected on the basis of alpha zero-cross values. Unfortunately the Focusing task was not adequate to illustrate changes in time. A task is needed which varies on some dimension through time. Also, although not calculated for this study, spectrographs can be collapsed across groups to yield mean spectrographs through time (e.g. one for HIGHs and one for LOWs). The advantage

of full frequency spectrographs, as opposed to single bandwidth graphs through time, is the ability to detect frequency shifts, a neglected area of investigation. This technique will be used in the dissertation where a task specifically designed to change some variable through time will be performed.

The three interesting results arising from the FFT correlation matrices justify its use as an analytical technique. The concept of 'multi-banded' bandwidths versus 'unitary' bandwidths has not been investigated in the literature. Unitary bandwidths have been the mainstay of EEG research, and involve either arbitrarily described or empirically derived clusters of adjacent EEG frequencies. Multi-banded bandwidths are two or more highly correlated unitary bandwidths. The advantage of a multi-banded concept is, potentially, greater discriminative power. Averaging across wider bandwidths, if they are correlated, has the effect of statistically stabilizing the measure. Systematic variance should increase and error variance decrease because dependent variables are combined which supposedly are sensitive to a common process. This is a rationale for performing factor analysis as well.

Expanding unitary clusters are an interesting phenomenon. They reflect changes in frequency rather than power. More specifically, they reflect an increasing number of frequencies becoming synchronized with respect to power. Presently, what this means is largely speculation. It was

suggested that the expanding cluster is associated with task difficulty. This association may be part of a larger process involving an optimal arousal/difficulty continuum, one very similar to those developed by Wundt, Hebb, McClelland and Berlyne (Zuckerman, 1979). An inverted U shaped function is hypothesized where the ordinate represents correlational saturation predominantly in the higher frequencies and the abscissa represents task difficulty (see figure 2.17). Correlational saturation refers to the expanding unitary cluster among the high frequencies observed in the results. Low correlational saturation reflects a narrow unitary cluster (e.g. 30-50 Hz); high correlational saturation reflects a wide unitary cluster (e.g. 20-50 Hz). An index reflecting degree of saturation can be calculated a number of ways: for example 1) simple addition of the individual correlations making up whole unitary clusters, or 2) addition of correlations not common to two overlapping unitary clusters.

Figure 2.17: Proposed relationship between task difficulty and correlational saturation.

To explain the manner in which task difficulty can affect FFT frequency correlations the notion of entrainment is introduced.

Each point in the diagonal matrix represents the correlation between two FFT frequencies for all subjects. A low correlation or a cluster of low correlations means that random individual differences exist in the FFTs. This should occur in resting baseline matrices where the mentation of individual subjects is free to vary. However, during formal task performance requiring similar cognitive processes and effort from all subjects, the EEG should become entrained; that is, generate similar FFT spectra, particularly among the higher frequencies. As the tasks become more difficult or demanding entrainment of individual FFT spectra increases, thus increasing the correlations. But, as task difficulty continues to increase, individual differences in coping strategies and effort will dominate, resulting in lower entrainment and hence lower correlations. To test this hypothesis a task controlling a 'difficulty' continuum is needed.

The concept of entrainment is also useful in discussing the third correlational pattern result: higher hemispheric correlational saturation during task performance compared with baselines. Low saturation during baseline conditions is probably due to randomly varying hemispheric activation (within subject) associated with spontaneous mentation. The tasks however, seem to entrain the hemispheres to produce

2

similar FFT spectra within subject, at least among the higher frequencies. It is important to stress that this result does not argue against the validity of hemispheric laterality. High correlational saturation refers only to the relationship between left and right hemisphere power measures for specific frequencies. Information concerning the magnitude of the difference between power measures is ignored, thus power asymmetries can exist in the presence of high correlational saturation. This does not reduce the importance of the inter-hemispheric correlations. There does seem to be entrainment of hemispheric EEG induced by task performance. It is possible that this interhemispheric entrainment is influenced by the same optimal arousal/difficulty continuum hypothesized for correlational saturation within a single hemisphere; that is, there exists an optimal difficulty level where hemispheric entrainment is maximized. Difficulty levels above or below this optimum will reduce entrainment and hence correlational saturation. Again, a task controlling some kind of 'difficulty' continuum would address this issue.

In conclusion, it is this author's opinion that the EEG analysis strategy proposed in the introduction offers the experimenter a wide range of descriptive tools to elucidate the substantive nature of EEG and its relationship to cognition.

CHAPTER 3

EEG and Cognition: Study #2

This study was designed for three purposes: 1) to replicate the findings in study #1 with a larger sample size and different tasks, 2) to contribute further substantive EEG information concerning individual differences and hemispheric asymmetries, and 3) to refine and extend the analysis strategy for EEG quantification already reviewed and pre-tested.

The discovery in study #1 of an alpha generator factor and its influence on hemispheric asymmetry may account for a significant portion of the conflicting results observed in the EEG asymmetry literature (Pigeau, 1983). It is necessary therefore, to investigate EEG hemispheric asymmetry and task performance for individuals generating varying amounts of alpha activity. Elucidating the nature of such relationships may provide experimental avenues for future research yielding less conflicting outcomes.

Given the existence of an alpha generator factor, it is possible that similar individual differences exist in other frequency bandwidths. Of interest in the present study is a theta generator factor. It was proposed, in the introduction (Chapter 1), that theta activity reflects sustained focused attention or vigilance. Should this relationship be demonstrated experimentally it may be hypothesized that

individuals manifesting large amounts of theta activity may exhibit a greater capacity for engaging in vigilance.

Since both alpha and theta individual differences are investigated using the same subjects in this study, non-orthogonality exists between these two independent variables. Hence, the data were analyzed as though they were two separate experiments; that is, interactions between the alpha and theta factors will not be considered. Although information concerning the amount of subject overlap between the two non-orthogonal factors will be summarized, it will be performed for descriptive purposes only.

In study #1, an a priori 'shotgun' approach was used for task selection. The tasks were chosen and ordered for their presumed ability to induce left or right hemisphere activation. Two of the tasks, Focusing and Counting, were re-used for the present study because they induced an overall maximum asymmetry within the alpha range, particularly among high alpha generators. The tasks were presented in their original form as well as in a variant form designed to test specific hypotheses. The Focusing task has been described previously as an attempt to elicit a self-directed internal focusing of attention designed to heighten bodily awareness. Admittedly, the task is less structured compared to the other tasks (see the instructions in Appendix A), but it is believed that the very nature of its unstructuredness has contributed to its success as a visuo-spatial (holistic) task. A structured task implies a task with unambiguous instructions sequentially ordered in time. For example, the

Math task used in study #1 forced subjects first to memorize four numbers quickly, second to perform three arithmetic calculations, third to determine if the arithmetic solution matched any of the original four numbers, and fourth to provide a correct response (the goal). Not only is the task itself serial, analytical and linear, but the structure of the task is serial, analytical and linear. That is, both the cognitive nature of the task and the overall framework by which the task can be performed correctly involve serial, analytical and linear processing strategies. Such tasks are optimal if the objective is to induce serial, verbal-analytical processes. However, these may be inappropriate to visuo-spatial task objectives. Most visuo-spatial tasks in the research literature are very structured (e.g. Gevins et al., 1979a; Galin et al., 1978). Thus, even though a task is geared toward eliciting visuo-spatial cognitive strategies, the structure of task presentation may nonetheless induce some linear analytic strategies. Hence, the original Focusing task was found to be the best visuo-spatial task precisely because it was less structured. To test this possibility the Focusing task was modified to incorporate a sequentially ordered and less ambiguous set of instructions requesting temporally spaced responses. Although the overall nature of the task will be similar (from a visual-spatial perspective), the instructions will seem more linear, specific and less ambiguous to the subject.

The counting task was also modified. During study #1

subjects may have adopted an auditory 'matching' strategy for word detection instead of cognitive identification. To force a cognitive approach to the task and also to introduce a higher order cognitive component (identification rather than simple recognition), a second version of the task required the detection of proper nouns. A semantic evaluation for identification is needed to identify proper nouns; simple auditory matching cannot be utilized.

It will be recalled that an adequate test of the theta hypothesis and the entrainment hypothesis for correlational saturation was not included in study #1. A positive correlation was posited between amount of theta activity and level of vigilance. A similar correlation was posited between correlational saturation of the EEG frequency spectrum and subject entrainment during task performance. To test these possibilities a new task was designed; a task establishing a difficulty continuum by presenting varying difficulty levels of continuous addition. To the degree that vigilance and entrainment are related to difficulty level, theta activity and correlational saturation should increase, at least until the task becomes too difficult. Frontal electrodes were included in this study to test these hypotheses.

A major finding from study #1 was the successful establishment of an asymmetry continuum generated from an a priori ordering of the tasks. A similar ordering is also performed in this study.

Specific hypotheses.

Given the theoretical discussion presented in the first chapter, the results generated from study #1 and the changes introduced for the present study, a number of hypotheses can be outlined. Due to the scope of the study and the new analysis strategies, the hypotheses are both specific and general.

Alpha

- 1) The overall relative left-right alpha asymmetry should be replicated with the Focusing and Counting tasks (that is, collapsed across the versions of each task). There should be relatively more alpha in the right hemisphere for Counting than for Focusing.
- 2) This asymmetry trend should be prominent for the high alpha generators and absent for low alpha generators.
- 3) The a priori ordering of the tasks from most left to most right hemisphere activation is:

Unstructured Focusing
Structured Focusing
Counting articles
Counting proper nouns

'Activation' in this case means 'alpha activation', not the more conventional notion of cortical activation utilized in the literature.

- 4) The addition task which has six levels of difficulty will show an alpha asymmetry index similar to that produced during the Counting task (when collapsed across difficulty level).

Theta.

- 1) Since all the tasks involve some degree of vigilance there may be no difference among them in frontal theta. The only potential for difference may lie between Focusing and the other two tasks.
- 2) In the addition task, frontal theta should increase as difficulty increases, reach an optimal level, and then decrease as the task becomes too difficult (an inverted U shaped function).
- 3) The nature of frontal theta asymmetry is not known. However it is hypothesized that, for the increasing difficulty levels of the addition task, an inverted U shaped function will also be reflected in the asymmetry measure.
- 4) Theoretically, there is no reason for the differences in theta mentioned above to vary for high or low theta generators. It is the theta trend across difficulty level which is important, not absolute amount of theta. However, if amount of theta activity reflects level of vigilance, then individuals manifesting large amounts of theta activity may possess a greater capacity for engaging in vigilance. These individuals may therefore have higher performance scores in the addition task.

Beta.

- 1) If beta is a direct measure of hemispheric activation then it should display an asymmetry relationship which

is the inverse of alpha. Otherwise, alpha does not represent mental 'idling'.

3-D Spectrographs.

In study #1 the spectrographs were of individuals performing the Focusing task through time. In this study, group spectrographs are plotted.

- 1) There will be visually identifiable changes in the topography of the FFT 'planes' as difficulty level increases in the Addition tasks. The nature of these peaks is largely speculative. For example, the theta and alpha peaks may vary inversely.
- 2) The spectrographs for the Focusing task will be different from those for the Counting task. The Counting task should have more theta.

Correlational Patterns.

- 1) The expanding unitary cluster from 20 to 30 Hz will vary as a function of task difficulty. As difficulty increases, correlational saturation in the 20 to 30 Hz range will also increase.
- 2) The pattern of correlational clusters will vary as a function of alpha generation; that is, high alpha generators will show a different correlational pattern than low alpha generators. The difference will probably manifest itself around the alpha and beta unitary clusters.

METHOD

Subjects:

Seventy subjects were tested; however, due to equipment malfunction, the data for 16 subjects were omitted. Of the remaining 54 subjects, 21 were males with a mean age of 22.8 years, and 33 were females with a mean age of 23.6 years. The subjects were either paid volunteers or introductory Psychology students given course credit for participation. All subjects were functionally and familially right-handed, as determined by questionnaire. One subject's data were deleted from the study when it was discovered that she fell asleep during the Focusing task.

Apparatus:

The EEG acquisition and quantification equipment were the same as that used in study #1, with the exception of two more electrodes at sites F3 and F4 referenced to linked ears. The 8 track Vetter Model A FM Tape recorder ran at 3 3/4 ips with flutter compensator. As in study #1 an event marker activated by the experimenter demarcated single or successive 10 second EEG segments or 'epochs'. EEG data reduction was performed using a dual channel band pass filter (A.P. Circuit Corp.) and a DEC LSI 11/23 micro-computer with A/D converters, real time clock and mass storage (floppy and hard discs). The EEG amplifiers were

counterbalanced across hemisphere for the frontal and parietal sites to eliminate differences as a result of amplifier inequalities. All experimental tasks were recorded on tape.

Task Description:

There were three tasks: Focusing, Counting and Addition, each having two versions. The Addition task contained six levels of difficulty. On the surface the Addition task is very straightforward involving simple sequential addition. The subject, with his eyes closed, was asked to add in his head, numbers presented auditorially over a 10 second period. Each number presented was to be added to the previous total. Eight numbers were presented per trial, one number every 1.25 seconds, for a total of 24 trials. Difficulty level was manipulated by controlling the magnitude of the numbers to be added. Numbers used for each difficulty level were:

Easy	Level 1: 1,2
	Level 2: 2,3,4,5,6
	Level 3: 4,5,6,7,8
	Level 4: 6,7,8,9,12
	Level 5: 8,9,12,13,14
Difficult	Level 6: 12,13,14,15,16

Each trial involved a random presentation (with replacement) of the set of numbers at a single difficulty level. There were two identical versions of the Addition task for each subject, each with 12 trials (2 trials at each difficulty level), making Addition temporally equivalent to Focusing and Counting (each of which also had two versions, see below). The presentation order for any single session of the

Addition task was pseudo-random, that is, difficulty level was presented randomly within blocks of 6 trials. At the end of each trial the subject was asked the total. They were also asked two questions: On a scale from 1 to 6 where 1 is very sure and 6 is not sure, rate how sure you are of your answer, and 2) On a scale from 1 to 6 where 1 is easy and 6 is difficult how easy or difficult did you find this trial? The EEG was recorded only during the 10 second period the trial was in progress, not during the subject's response.

The instructions for both versions of the Focusing task are reproduced in appendix A. Both versions were constructed such that 5 forty-five second periods of EEG activity were recorded. During each 45 sec period the subject attempted to perform the task silently as per the instructions. At the end of the Unstructured Focusing task the subject was asked the "handle or image" they had during the task. They were also asked their general impressions of the task. For the Structured Focusing task a response concerning the failure or success of performing the instructions was required after each 45 second period.

The Counting Articles task ("a", "the") was performed in exactly the same manner as in study #1. Counting Proper Nouns was similar except the instructions directed the subject to count the number of proper nouns uttered. To make this task easier the Ss were instructed to count proper nouns such as "Jacques Cartier" or "United States of America" as 1 instead of 2 and 3 respectively. For each Counting task there were 2 two minute trials. The subjects

were asked to count silently. EEG was recorded in successive 10 second epochs throughout each 2 minute presentation.

All tasks were performed with the eyes closed in a totally dark experimental chamber.

Procedure: Before the subjects were prepared for the experiment they were asked to complete an informal questionnaire (see appendix B). The questions were designed to sample characteristics of the subjects which may discriminate among either the alpha or theta generation groups. The EEG electrodes were secured using headbands at the P3, P4 and F3, F4 cortical sites referenced to linked ears. EOG, references and ground were secured using tape. The S was briefed on all tasks during this period.

Each S was seated in an electrically shielded anechoic chamber with his head positioned in a chin-rest/head-restraint device to reduce involuntary head movements. Instructions and tasks were presented through a speaker situated 1 meter in front of the S. Four EEG baselines were recorded before the tasks: 5 ten second epochs each for resting with eyes open-lights on, eyes open-lights off, eyes closed-lights on and eyes closed-lights off. The order of presentation was counterbalanced. During the experiment the lights were off and the subject was requested to close his eyes. All task's were performed in darkness, with the eyes shut.

The tasks were presented in counterbalanced order with the proviso that no task's two versions were presented

successively. The experimental session lasted approximately 40 minutes.

EEG Analysis: EEG quantification and analysis were identical to study #1 with the following exceptions. First, for period analysis the EEG for the parietal leads was bandpass filtered to allow activity between 1.8 and 40 Hz; the frontal leads were filtered between 4 and 70 Hz. The filtering characteristics were different for the frontal leads in order to eliminate eye movement artifact and allow higher beta frequencies often manifesting at this site. However, with such a filtering strategy parietal-frontal comparisons for beta activity cannot be made. The filters were counter-balanced across hemisphere in order to eliminate asymmetry differences due to filter inequalities. Second, FFTs were performed on the first 8 seconds of each 10 second epoch. This is in contrast to the 4 second sample used in study #1 and allowed a more representative FFT spectrogram (that is, comparable to the EEG sampled using period analysis). However, given the much larger subject sample size in this study, computer resources and time constraints, the FFT quantification of only a single cortical site was performed, left frontal (F3). All 3-D spectrographs and correlational matrices were performed on the FFTs from this site.

RESULTS

Alpha and Theta Generators:

The alpha zero-cross values at the parietal sites of each hemisphere during the eyes closed (dark) baseline were summed and averaged yielding a mean parietal alpha zero-cross measure for each subject. The subjects were then rank ordered from highest to lowest on this measure. The ordered subjects were divided evenly into high, middle and low alpha generators, 18 subjects per group. The high alpha group ended up with 17 subjects since the subject who fell asleep was a high alpha generator. All analyses utilizing alpha generation as an independent variable were performed with these three groups.

The theta generator factor was similarly constructed. All subjects were re-ordered and re-divided based on mean theta zero-cross values from the average of the frontal leads during the resting baseline with eyes closed (dark). Three groups were constructed: high theta generators, middle theta generators and low theta generators. Each group contained 18 subjects except for the high theta group which contained 17.

The two factors, levels of alpha generation and theta generation, are not orthogonal since the same subjects make up both factors. Hence, they were treated independently for hypothesis testing. Descriptive statistics were performed however, in order to summarize the relationship between the

two factors. Table 3.1 illustrates the distribution of subjects for both factors.

		Theta generators			
		HIGH	MIDDLE	LOW	
Alpha Generators	HIGH	:	:	:	:
		:	:	:	:
		:	:	:	:
	MIDDLE	:	:	:	:
		:	:	:	:
		:	:	:	:
	LOW	:	:	:	:
		:	:	:	:
		:	:	:	:

Table 3.1 Distribution of subjects on both factors.

Table 3.1 illustrates that high alpha generators are made up mostly of low and middle theta generators; middle alpha generators are made up mostly of high and low theta generators; low alpha generators are made up of high and middle theta generators. The only apparent trend is that similar groups in each factor share few subjects; rather, they seem to be comprised of an equal number from the other two groups.

Table 3.2 and 3.3 display the distribution of sex and mean age for each factor. Separate ANOVA's were performed for each factor with age as the dependent variable. There was no significant difference among the mean ages for the alpha groups. The theta groups were significantly different however ($F = 3.92$, $df=2,50$, $P < .026$). It appears that there is a negative linear relationship between amount of theta

		SEX	AGE
Alpha Generators	HIGH	Males = 8	X = 23.2 yrs.
		Females = 9	
	MIDDLE	Males = 7	X = 22.7 yrs.
		Females = 11	
	LOW	Males = 6	X = 23.9 yrs.
		Females = 12	

Table 3.2: Distribution of sex and mean age across the alpha groups.

		SEX	AGE
Theta Generators	HIGH	Males = 8	X = 20.53 yrs.
		Females = 9	
	MIDDLE	Males = 6	X = 22.72 yrs.
		Females = 12	
	LOW	Males = 7	X = 26.39 yrs.
		Females = 11	

Table 3.3: Distribution of sex and mean age across the theta groups.

produced and the age of the subjects. High theta generators are younger than middle theta generators who, in turn, are younger than low theta generators. Separate 3 (alpha or theta groups) by 2 (male, female) chi-square tests proved to be non-significant.

EEG Results:

Most of the ANOVAs performed on the data were mixed designs or split-plot factorials. There was usually at least one independent variable involving repeated measures (e.g. task type). The statistical package 'BMDP2V' with tests for orthogonal trends was used almost exclusively.

Given the large number of dependent variables and hence the extremely large number of possible statistical tests, only tests involving (directly or indirectly) the main hypotheses were performed. Data 'snooping' was kept to a minimum.

All EEG results utilizing traditional bandwidths (alpha, theta and beta) were statistically analyzed using the period analysis variables. Three-dimensional spectrographs and correlational matrices utilized FFTs.

Alpha:

The first major hypothesis to be tested was the replication of an alpha asymmetry for the Focusing and Counting tasks. A 3 between (alpha groups) by 2 within (Focusing-Counting) by 2 within (version 1 - version 2) mixed design

ANOVA, was performed on the asymmetry measure for alpha zero-cross at the parietal locations.

There was a main effect for task ($F=13.46, df=1, 50, P < .0006$) and more importantly there was a significant interaction between type of task and type of alpha generator ($F=3.83, df=2, 50, P < .028$). The interaction is illustrated in figure 3.1. This interaction supports the hypothesis that Counting produces more relative right hemisphere alpha than Focusing and replicates study #1. Low alpha generators do not show the alpha asymmetry; high and middle alpha generators do. To test the hypothesis that the tasks can be ordered a priori for their presumed ability to induce left or right hemisphere activation a 3 (alpha groups) by 4 (Unstructured Focusing, Structured Focusing, Counting Articles, Counting Nouns) ANOVA with tests for trends was performed. There was a significant linear interaction between alpha generators and this ordering of the tasks ($F=7.48, df=2, 50, P < .0014$). Figure 3.2 demonstrates the relationship. Separate trend analyses for each group on all tasks yield a significant linear trend for high alpha generators ($F=8.78, df=1, 16, P < .0092$), a significant linear trend for middle alpha generators ($F=11.76, df=1, 17, P < .0032$) and non-significant trends for low alpha generators. The left-right alpha power measure produced similar significant results (see figure 3.3, linear interaction $F=3.25, df=2, 50, P < .047$). This alpha asymmetry effect for the Focusing and Counting tasks is specific to the parietal site. Similar analyses for asymmetrical alpha zero-cross and power activi-

Figure 3.1: L-R alpha zero-cross values from the parietal location for the Focusing (FO) tasks and the Counting (CN) tasks, at each level of the alpha generation factor.

Figure 3.2: L-R alpha zero-cross parietal for the tasks offered for hemisphericity for each level of the alpha generation factor. (UFO= Unstructured focusing; SFO= Structured Focusing; COA= Counting Articles; CON= Counting Proper Nouns)

Figure 3.3: L-R alpha power parietal for the tasks ordered for hemisphericity at each level of the alpha generation factor.
 (UFO= Unstructured Focusing; SFO= Structured Focusing; COA= Counting Articles; CON= Counting Proper Nouns)

ty at the frontal site showed no significant results.

The average alpha zero-cross values (i.e., averaged across hemisphere) at the parietal site for the baseline conditions are plotted in figure 3.4A. There was a significant Dark-Light by Eyes Open-Closed interaction ($F=28.02$, $df=1,50$, $P < .000$). Interestingly, this interaction was also significant at the frontal site (figure 3.4B; $F=22.51$, $df=1,50$, $P < .000$). The average alpha zero-cross values for Eyes Closed baseline (dark), Focusing (both versions), Counting (both versions) and Addition (all levels) are depicted in figure 3.5. There is a significant decreasing linear trend from the baseline condition to the Addition task ($F=47.95$, $df=1,50$, $P < .0000$). There was also a significant interaction between task and alpha generators ($F=5.06$, $df=6,150$, $P < .0001$) showing the expected pattern: low alpha generators show no decreasing trends, middle alpha generators show a marked decreasing trend and high alpha generators show a prominent decreasing trend.

Over the 6 difficulty levels in the addition task there were no significant main effects or interactions with alpha generators on the left-right alpha zero-cross measure at the parietal location. There were no significant differences at the frontal site either.

The hypothesis that the Addition task's alpha asymmetry index would be similar to Counting (both versions) is partially supported. The asymmetry indices for alpha zero-cross at the parietal site were summed and averaged across

Figure 3.4: Hemispherically averaged alpha zero-cross (A) and power (B) for baseline conditions.

Figure 3.5: Hemispherically averaged alpha zero-cross collapsed across all subjects for all the tasks.

(ECD= Eyes Closed Dark; FO= Focusing;
CN= Counting; ADD= Addition)

levels of the Addition task. This yielded a single mean asymmetry index for the Addition task for each subject. Figure 3.6 illustrates the position Addition occupies with respect to the Focusing and Counting tasks. Addition does produce an alpha asymmetry value more similar to Counting than Focusing, as hypothesized. However, it must be stressed that the interaction with groups is not significant. There is a linear main effect for tasks collapsed across alpha groups ($F=24.1$, $df=1,50$, $P < .000$) supporting the hypothesis, but the inconsistent asymmetry results for low alpha generators (see figure 3.6) essentially eliminated any interaction. This suggests that although low alpha generators do not show the asymmetry trend that the high and middle alpha generators do for Focusing and Counting, they do show comparable alpha asymmetry values for the Addition task.

There were no significant differences among the theta generator groups for any of the above analyses on alpha activity.

Theta:

The theta hypotheses primarily address variations in the Addition task. To test whether theta is related to difficulty level by an inverted U shaped function, theta zero-cross and theta power were averaged across hemispheres for each subject for all levels of the Addition task. In Figures 3.7A and 3.7B the results are plotted for theta zero-cross and theta power respectively. From trend

Figure 3.6: L-R alpha zero-cross parietal interaction between alpha groups and tasks including Addition. (FO= Focusing; CN= Counting; ADD= Addition)

Figure 3.7: Hemispherically averaged theta zero-cross (A) and power (frontal site) at each level of the Addition task.

analyses of 3 (generator type) x 6 (addition levels) mixed ANOVAs significant quadratic main effects for difficulty level were found both for theta zero-cross ($F=4.57$, $df=1,50$, $P < .037$) and theta power ($F=4.96$, $df=1,50$, $P < .031$). There was no interaction between high, middle or low theta generators and difficulty level for either the zero-cross or power measure. This suggests that dividing subjects on the basis of the amount of theta zero-cross produced during eyes-closed baseline (dark condition) does not differentiate the degree to which theta changes across additional level. High, middle and low alpha generators on the other hand do show a significant linear interaction with addition level for theta power ($F=3.15$, $df=2,50$, $P < .052$). The interaction is graphed in figure 3.8. All three groups show a quadratic trend (second degree polynomial), but the low and high alpha generators also show increasing linear trends. The middle alpha generator group seems to respond differentially from the other two groups. This uniqueness surfaces again in the behavioral and correlation matrices results.

The asymmetry index for frontal theta power yielded a significant linear interaction between addition level and alpha generators ($F=3.29$, $df=2,50$, $P < .045$) and a significant cubic interaction between Addition and theta generators ($F=4.62$, $df=2,50$, $P < .015$). Figure 3.9 shows the former, figure 3.10 the latter. The linear interaction in figure 3.9 between Addition level and alpha generators is particularly interesting. Both the low and middle alpha generators show increasing trends towards greater relative theta acti-

Figure 3.8: Hemispherically averaged theta power interaction between alpha groups and levels of the Addition task.

Figure 3.9: L-R theta power frontal interaction between the alpha groups and difficulty level of the Addition task.

Figure 3.10: L-R theta power frontal interaction between the theta groups and difficulty level of the Addition task.

vity in the left hemisphere as Addition level increases. High alpha generators show an opposite trend. A trend towards the left hemisphere with increasing difficulty level is consistent with cerebral laterality theory (Willis et al., 1979); since Addition is considered a left hemisphere task. The apparent extreme asymmetry differences between high, middle and low alpha generators is enticing but non-significant. The same can be said for the high, middle and low theta generators in figure 3.10.

The above theta trends were observed only at the frontal site. All similar analyses performed at the parietal location were non-significant.

At this point it is appropriate to include two behavioural results. Both the theta hypotheses generated in the introduction and the analyses designed to test these hypotheses assume that the Addition task indeed increases in difficulty. To empirically validate this assumption, it will be recalled that the subjects were asked to rate for difficulty each trial of the Addition task. Difficulty was assessed on a scale from 1 to 6 where 1 is "easy" and 6 was "difficult". Figure 3.11 illustrates, for each experimentally designed level of difficulty, the distribution of the subjects' estimate of difficulty. It can be seen that as actual difficulty level increases the subjects' estimate of difficulty also increases. The correlation between the two is $r = .755$. A second way to test the validity of the Addition task was to calculate a performance ratio from the

Figure 3.11: Percent frequency histograms of subject estimated difficulty level of the Addition task with actual difficulty level. Continued on next page.

Figure 3.11 continued.

Figure 3.12: Percent-correct performance on all levels of the Addition task

subject's response total for each trial. The subject's answer for the trial was divided by the correct answer and then multiplied by 100, yielding percent correct estimate for each level of difficulty. The results are illustrated in figure 3.12. There is a clear and significant ($F=73.34$, $df=1,50$, $P < .0000$) decreasing linear trend from level 1 (easiest) to level 6 (most difficult). As difficulty increases the subjects' percent correct score decreases, as it should if the Addition task is indeed varying degree of difficulty.

It was reported that high, middle or low theta generators did not show different theta trends across the difficulty levels of the Addition task. Also, they did not show significant differences on the percent-correct measure. These results do not support the hypothesis that high theta generators should perform better than lows on the Addition task. However, this may not be the most judicial test of the hypothesis given that the groups were selected from the amount of theta generated during a baseline condition, not during the Addition task itself. To examine this hypothesis more directly, the subjects were rank ordered on the basis of their overall performance score (percent-correct measure) for the Addition task. The top, middle and bottom thirds were made into groups: high-correct performers, middle-correct performers and low-correct performers. Separate mixed ANOVAs (3 groups $\times$ 6 levels of difficulty) were performed on frontal theta power and theta zero-cross. Significant interactions were found for both measures: a linear

Figure 3.13: Hemispherically averaged theta power frontal interaction between the percent-correct groups and difficulty level on the Addition task.

Figure 3.14: Hemispherically averaged theta zero-cross frontal interaction between the percent-correct groups and difficulty level on the Addition task.

Figure 3.15: Hemispherically averaged theta power frontal for each task. (ECD= Eyes Closed Dark; PO= Focusing; CN= Counting; ADD= Addition)

interaction for theta power ($F=3.55$, $df=2,50$, $P < .036$) and a quadratic interaction for theta zero-cross ($F=4.18$, $df=2,50$, $P < .021$). Figures 3.13 and 3.14 illustrate the interactions. High and middle-correct performers maintain a higher level of theta activity than do low-correct performers. These results do support the hypothesis that a relationship exists between amount of theta activity and task performance.

A significant decreasing linear trend was observed in frontal theta power for Counting Articles, Counting Nouns and Addition (collapsed across all levels). The respective means were: COA=180.1, CON=174.5 and ADD=168.5 ($F=5.46$, $df=1,50$, $P < .024$). The relevancy of this finding will be raised in the discussion.

The final theta hypothesis concerns a prediction that Counting will produce more frontal theta activity than Focusing. A significant main effect between the two is observed ($F=29.19$, $df=1,50$, $P < .000$), supporting the hypothesis (see figure 3.15). There were no main effects or interactions with either alpha or theta generator types.

Beta

As hypothesized, asymmetrical beta activity does not vary inversely from asymmetrical alpha activity across the Focusing and Counting tasks. There were no significant trends or interactions using the left-right beta first-derivative measure. It is interesting to note that of the

few significant analyses (only 3) utilizing beta first-derivative, they all involve either main effects or interactions with theta generators. All three significant analyses were also from frontal locations. The trend is towards greater beta activity among middle and low theta generators. All alpha generator analyses were non-significant. Figure 3.16 displays the significant linear interaction between theta generators and Additional level on frontal beta first-derivative averaged across both hemispheres ($F=4.38$, $df=2,50$, $P < .018$). High and low theta generators seem to show an increasing linear trend whereas middle theta generators show no such trend (there is perhaps a slight quadratic trend). The absolute values for high, middle and low theta generators in figure 3.16 is representative of the main effect for theta generators during baseline, Focusing and Counting conditions as well; that is, beta activity is greatest in the frontal site for low theta generators and least for high theta generators (for baseline: $F=8.76$, $df=2,50$, $P < .001$; for Focusing and Counting: $F=6.69$, $df=2,50$, $P < .003$). Figures 3.17 and 3.18 show the trend in beta across tasks for the frontal and parietal sites. Both yield significant quadratic trends (Frontal: $F=53.14$, $df=1,50$, $P < .0000$; Parietal: $F=28.8$, $df=1,50$, $P < .0000$). There were no interactions with type of theta generators. Beta activity generally increases at both sites from baseline to Addition.

It was mentioned that due to the lack of a significant main effect for Focusing versus Counting on the left-right

Figure 3.16: Hemispherically averaged beta first-derivative frontal interaction between theta groups and difficulty level on the Addition task

Figured 3.17: Hemispherically averaged Beta first-derivative frontal for all tasks. (ECD= Eyes Closed Dark; FO= Focusing; CN= Countng; ADD= Addition)

Figure 3.18: Hemispherically averaged beta first-derivative parietal for all tasks. (ECD= Eyes Closed Dark; FO= Focusing; CN= Counting; ADD= Addition)

beta first-derivative measure, it was concluded that beta activity is not simply the inverse of alpha (where a significant main effect exists). Another way of investigating the possibility of this relationship is to correlate left-right beta first-derivative with left-right alpha zero-cross or left-right alpha power within each task. Such correlations would reflect the degree to which beta and alpha vary hemispherically during a single task. Table 3.4 displays these correlations for the alpha generators. The first result of note is that for all subjects there are significant inverse correlations between beta first-derivative, alpha zero-cross and alpha power. These correlations become smaller however, from the baseline condition to the Addition tasks. Generally, middle alpha generators have higher correlations than either high or low alpha generators, particularly for alpha power/beta first-derivative correlations. Low alpha generators have consistently lower correlations than either the middle or high alpha generators. Also, many of the correlations for low alpha generators are positive, in direct contrast to high and middle alpha subjects. Another interesting observation from this table is the apparent quadratic trend for all groups from the first difficulty level in the Addition task to the sixth. These quadratic trends mirror the U shaped functions hypothesized for this task. It seems that although beta and alpha asymmetries may be related in some instances the relationship is affected by at least two factors: 1) type of alpha genera-

L-R Beta First-Derivative with L-R Alpha Zero-cross					L-R Beta First-Derivative with L-R Alpha Power				
Alpha Generators					Alpha Generators				
TASKS	All Subj N=53	HIGH N=17	MIDDLE N=18	LOW N=18	TASKS	All Subj N=53	HIGH N=17	MIDDLE N=18	LOW N=18
ECD	-.445	-.649	-.471	-.174	ECD	-.376	-.489	-.500	.310
UFO	-.482	-.600	-.690	.096	UFO	-.448	-.557	-.812	.365
SFO	-.526	-.663	-.672	-.014	SFO	-.392	-.583	-.697	.481
COA	-.432	-.501	-.583	-.072	COA	-.296	-.519	-.577	.519
CON	-.412	-.556	-.648	.183	CON	-.273	-.490	-.652	.575
AD1	-.356	-.422	-.399	-.262	AD1	-.277	-.392	-.467	.076
AD2	-.354	-.396	-.399	-.144	AD2	-.126	-.183	-.351	.367
AD3	-.057	-.320	-.031	.286	AD3	-.133	-.449	-.175	.528
AD4	-.272	-.343	-.287	-.187	AD4	-.093	-.121	-.341	.333
AD5	-.337	-.369	-.195	-.467	AD5	-.176	-.314	-.182	-.039
AD6	-.339	-.523	-.310	-.286	AD6	-.198	-.318	-.324	.089
Crit. r					Crit. r				
at .01	.354	.575	.561	.561	at .01	.354	.575	.561	.561
at .05	.273	.435	.444	.444	at .05	.273	.435	.444	.444

Table 3.4: Correlations between L-R beta first-derivative with L-R alpha zero-cross and L-R alpha power for each task (parietal site only). Also, correlations are broken down for alpha generators. (ECD= Eyes Closed Dark baseline, UFO= Unstructured Focusing; SFO= Structured Focusing; COA= Counting Articles, CON= Counting Nouns; AD= Addition)

tor and 2) the level of difficulty of the task.

3-D Spectrographs:

Three dimensional spectrographs were generated for overall, high, middle and low alpha generators only. Theta generators were not included due to the magnitude of the quantitative procedure involved in generating such graphs. Obvious and expected differences between the groups are evident in figure 3.19. High alpha generators display more alpha during the Eyes Closed baseline (dark) than either middle or low alpha generators. Figure 3.20 shows the progression of alpha production among high alpha generators across the baseline conditions: 1) eyes open in the light, 2) eyes open in the dark, 3) eyes closed in the light and 4) eyes closed in the dark. Figure 3.21 illustrates the differences between Unstructured Focusing and Counting Proper Nouns; increases in the alpha peaks during the Focusing task are noticeable. There were no other striking differences using this technique.

Correlational Patterns:

The intercorrelation matrices for single Hertz frequencies for each task are presented in Colour Plates 3.1 through 3.15. Changes have been made to the matrices for cosmetic and interpretational purposes. In study #1 the matrices were plotted in black and white with circles varying in diameter to reflect the size of the correlation. This procedure required a "cutoff criterion" to increase contrast by plotting only those correlations exceeding a

Figure 3.19: 3-D spectrographs of High, Middle and Low alpha generators performing Eyes Closed Dark baseline.

Figure 3-20: 3-D spectrographs of High alpha generators during the four baseline conditions.

Figure 3.21: 3-D spectrographs for High alpha generators during Unstructured Focusing and Counting Proper Nouns.

specified magnitude (e.g., $r > .5$). Unfortunately the choice of a proper cutoff criterion is largely arbitrary (although an attempt was made to justify the criterion using critical values, such a strategy is nominal). Important information may be lost with too conservative a criterion; on the other hand no criterion reduces contrast. To correct this problem colour coding of the magnitudes for each correlation was performed. Each correlational point is represented by a square whoses colour provides maximum contrast with the colours of adjacent correlations. The colour scheme also reflects the colour spectrum. It is

$r = .84$ to $.99$	--> Red
$r = .70$ to $.84$	--> Orange
$r = .56$ to $.70$	--> Yellow
$r = .42$ to $.56$	--> Green
$r = .28$ to $.42$	--> Blue
$r = .14$ to $.28$	--> Purple
$r = \text{less than } .14$	--> Black

Colour coding allows complete representation of the matrices yet does not sacrifice information yields resulting from poor contrast. For each task four matrices were calculated and presented: one for all subjects ($N=53$), and one each for high ($N=17$), middle ($N=18$), and low ($N=18$) alpha generators.

The first difference to note is the low or zero correlations for middle alpha generators. A large number of correlations between the range of 0 to 25 Hz are low when compared to either the low or high alpha generators. This trend of low correlational saturation is consistent across tasks. On the whole, low alpha generators show the highest,

Colour Plate 3.1: Correlational Matrices collapsed across all tasks.

Colour Plate 3.2: Correlational Matrices for the Eyes Open
Light baseline condition.

Colour Plate 3.3: Correlational Matrices for the Eyes Open
Dark baseline condition.

Colour Plate 3.4: Correlational Matrices for the Eyes Closed
Light baseline condition.

Colour Plate 3.5: Correlational Matrices for the Eyes Closed
Dark baseline condition

Colour Plate 3.6: Correlational Matrices for Unstructured Focusing.

Colour Plate 3.7: Correlational Matrices for Structured Focusing

Colour Plate 3.8: Correlational Matrices for Counting Articles. .

Colour Plate 3.9: Correlational Matrices for Counting Proper Nouns.

Colour Plate 3.10: Correlational Matrices for Addition level 1.

Colour Plate 3.11: Correlational Matrices for Addition level 2.

Colour Plate 3.12: Correlational Matrices for Addition level 3.

Colour Plate 3.13: Correlational Matrices for Addition level 4.

Colour Plate 3.14: Correlational Matrices for Addition level 5.

Colour Plate 3.15: Correlational Matrices for Addition level 6.

high generators the next highest and lows the least amount of correlational saturation.

Unitary bandwidths (clusters of adjacent frequencies) are observed in many of the matrices. They are manifested as triangles (usually coloured red) situated along the hypotenuse of each matrix. Examples of unitary bandwidths can be seen in Colour Plate 3.1 for the middle alpha generators. Here a cluster of adjacent frequencies occurs between 30 and 40 Hz. Another is evident between 40 and 50 Hz. This suggests that the power spectral values for the EEG frequencies in these two clusters vary together for middle alpha generators across all tasks. These should be contrasted with low alpha generators where a single large unitary bandwidth is evident. High alpha generators have a unitary bandwidth between 34 and 50 Hz. More interesting however is a characteristic low correlation strip at 32-33 Hz. It is evident throughout most tasks whereas low and middle alpha generators do not demonstrate it.

High and middle alpha generators show consistent unitary bandwidths across tasks. Low alpha generators show more variance in correlational saturation across tasks than the other two groups. They display large differences between tasks (e.g. between Focusing and Counting, see Colour Plates 3.5 to 3.8). However, the differences are consistent within task. Structured and Unstructured Focusing show very similar correlation matrices; so do Counting Articles and Counting Nouns.

Behavioural Measures:

Many of the analyses for the behavioural data were non-significant. Chi-squares between alpha (or theta) generators with each of the rated items in the questionnaire were non-significant. Between group ANOVAs on numbers of hours of sleep and time for sleep onset were also non-significant.

Two statistically significant behavioural results were reported earlier. Subjects were able to subjectively discriminate difficulty level. Also their performance degraded as difficulty increased. These results established a valid difficulty continuum, from which EEG analyses could be compared.

An intriguing interaction was found from a 3×2 ANOVA on the performance scores derived from Counting Articles and Counting Proper Nouns. The interaction is depicted in figure 3.22. High alpha generators produce the highest percent-correct scores for Counting Articles; next highest are low alpha generators, then middle alpha generators. Interestingly the order reverses for percent correct scores from Counting Proper Nouns; high alpha generators do poorest whereas middle generators do best. The ordinal place remains the same for low alpha generators.

A 3 way interaction was found among alpha groups, Addition levels and trials for percent-correct scores ($F=2.61$, $df=30,750$, $P < .0000$). The interaction is graphed in figures 3.23A, 3.23B and 3.23C. Middle alpha generators display the most variance across Addition level and trials compared to high and low alpha generators.

Figured 3.22: Percent-correct performance score for the different alpha groups on Counting Articles and Counting Proper Nouns.

Figure 3.23A: Percent-correct performance scores for High alpha generators for each trial of each level of the Addition task.

Figure 3.23B: Percent-correct performance scores for Middle alpha generators on each trial of each level of the Addition task.

Figure 3.23C: Percent-correct performance score for Low alpha generators on each trial of each level of the Addition task.

DISCUSSION

Study #1 has been replicated. Counting proper nouns or articles produced more relative alpha activity in the right hemisphere than did either Structured or Unstructured Focusing. The effect was present for middle and high alpha generators only, again in agreement with Study #1. The tasks were correctly ordered a priori for their presumed hemispheric influence, particularly for middle alpha generators. Such evidence supports a cognitive interpretation of alpha asymmetries since movement and behavioural responses were not involved during EEG analyses (Galin et al., 1982). This EEG effect for cognition is robust, having been replicated with a larger sample size and different tasks. Simply changing the structure of the Focusing task influenced hemispheric alpha in the hypothesized direction; that is, towards the right, as represented by the mean. Also, adding the additional verbal-analytic component to the Counting task, by identifying proper nouns rather than simple articles, produced the hypothesized shift (to the right) in alpha asymmetry, again as represented by the mean.

In study #1 a dichotomous classification for alpha production was used because of small sample size. The trichotomous grouping strategy utilized in study #2 allowed a more thorough investigation of this subject factor. Between group differences for type of alpha generator will be discussed throughout this section. Although high alpha genera-

tors do show the predicted asymmetry and the low alpha generators do not, the linear trend for middle alpha generators is stronger than for the highs. This result is inconsistent with a hypothesized linear relationship between type of alpha generator and EEG asymmetry. However, the difference is not large enough to suggest a ceiling and floor effect. Even if it were, it is not clear how a ceiling or floor effect could be an artifact of either the analysis technique or the algorithm used to calculate the asymmetry ratio.

The asymmetry findings for alpha are topographically related to the parietal leads. No statistically significant results for alpha asymmetry were found at the frontal site. This is not surprising given that alpha occurs predominantly in the posterior regions of the cortex (Lindsley and Wicke, 1974). However, identical significant differences were obtained at both the frontal and parietal locations for hemispherically averaged alpha with respect to baseline conditions. Increases in alpha zero-cross from Eyes Open to Eyes Closed baselines were obtained in both Lights-on and Lights-off conditions. With the eyes open less alpha was produced when the light were on than when they were off. On the other hand, with the eyes closed no differences between lighting conditions were found (see figures 3.4A and 3.4B). These results are important for two reasons. First, the frontal and parietal sites yielded identical results for averaged alpha (although at lower values for the frontal location). This suggests an alpha spreading effect from the

parietal to the frontal regions either laterally across the cortex or from a common subcortical origin (e.g. Thalamus). An attenuated alpha signal reaching the frontal cortex might explain the lack of asymmetry findings at this site.

Second, if alpha activity is indicative of 'intensive' cognitive processes (Wertheim, 1974) then shutting the eyes may represent a conditioned response for intensive cognitive activity. Intensive processing can be achieved by breaking the sensory-motor loop (Tyson, 1982), either by reducing sensory input or reducing motor responses. Closing the eyes definitely reduces visual sensation, allowing intensive cognitive processes. However, more alpha was produced with the eyes shut but the lights on than with the eyes open and the lights off; this, despite the fact that more visual sensation filters through closed eye lids when the lights are on than when the eyes are open in total darkness. It is suggested that simply closing the eyes elicits a conditioned response to adopt an intensive cognitive style. Partial support for this theory can be found from the results displayed in figure 3.5. A decreasing alpha trend exists from Eyes Closed baseline to Addition. The lights are off and the eyes shut for all tasks. Each task from baseline to Addition puts greater demands for sensory-motor involvement. Although Focusing can be construed as encouraging deactivation of the sensory-motor loop, subjects were not able to 'experience' the task. They were constantly concerned and puzzled with the purpose of the task, what they had to do.

The word 'do' is important in this context. It implies sensory-motor activation. Hence this 'doing' decreased alpha activity from baseline values. Counting and Addition definitely do require sensory-motor involvement: stimuli is attended to and responses are required. A decrement in alpha was therefore expected.

As hypothesized theta activity showed the most consistent trends at the frontal location (Schacter, 1977). A statistically significant, inverted curvilinear relationship exists between theta and difficulty level as manipulated in the Addition task. As difficulty level increases theta increases until the task became too difficult, then theta correspondingly decreased. Task difficulty is interpreted in the present case as increased levels of vigilance, but the Addition task also involves varying levels of cognitive processing. For example, with larger numbers, short-term memory must play a prominent role to perform the task correctly. Also, the 'rate' of information processing must increase for larger numbers since stimulus presentation rate remains constant across difficulty levels. Therefore cognitive processing and vigilance covary in the Addition task. However, the Counting Articles task can be conceived as a vigilance task, at least compared to Addition. It required the detection of two target words, 'a' and 'the', in prose. The subjects needed to sustain their attention for a two minute period in order to correctly perform the task. The Counting Nouns task is identical except for the extra cognitive component. The addition of this component in fact made

the task easier as the percent-correct results attest (Counting Articles produced more errors than Counting Nouns). It is not unreasonable to suggest therefore that less vigilance was required during Counting Nouns than during Counting Articles. If frontal theta activity reflects level of sustained focused attention then a decrease in theta should occur from Counting Articles to Counting Nouns to Addition. This trend was indeed found and supports a 'vigilance' interpretation of theta activity.

Such evidence offers support for observed differences in theta activity between subjects performing well versus subjects performing poorly in the Addition task. It will be recalled that the original hypothesis called for a distinction between high, middle and low theta generators on performance scores for the Addition task. The groups were divided on the basis of a subject's rank order of frontal theta zero-cross during the eyes closed baseline (dark condition). This is a non-optimal strategy for investigating the relationship between theta and performance measures. When the subjects were divided on the basis of their performance on the Addition task, high percent-correct subjects showed a linear increase in theta activity from level 1 to level 6. Low and middle percent-correct subjects showed the inverted U shaped function (see figure 3.13). This result is interesting because most errors occurred at levels 4, 5 and 6. Individuals who performed better overall on the addition task would need to do better at the higher diffi-

culty levels, and hence maintain higher levels of theta. Those individuals who did not perform as well showed decreases in theta activity in levels 4 to 6. In light of the above discussion, high percent-correct individuals perhaps maintained their vigilance levels allowing information processing to occur for more difficult Addition trials.

Significant increases in frontal theta power from Eyes Closed baseline and Focusing to Counting and Addition suggests that vigilance was less involved during Focusing. A possible explanation is that Focusing was not performed successfully by the subjects. Compared to Counting or Addition, the Focusing task was much less familiar to our subjects as a 'task'. Reports from individuals performing the Focusing task included comments such as "I didn't really know what I was supposed to do", "Vague" and "That was strange but fun". Perhaps experienced meditators could maintain the proper vigilance necessary to perform the task and thus show higher level of theta activity (e.g. Hirai, 1978 where experienced meditators produced large amounts of theta), but of the 53 university students used as subjects in the present study only 12 (22.6%) reported trying meditation; and of these 12 subjects none were experienced meditators.

An interesting result with respect to 'vigilance' and frontal theta activity is the asymmetry finding for the Addition task. Low and middle alpha generators showed significant linear or quadratic trends toward the left hemisphere as difficulty level increased. Addition involves

verbal-analytic information processing and is presumed to activate the left hemisphere. Differential hemispheric theta activity may reflect the level of vigilance needed in that hemisphere to correctly perform the task. It is not apparent how differential vigilance levels can exist in each hemisphere. Vigilance, as sustained focused attention, is usually interpreted as a general higher order arousal function; one which expresses an overall cognitive readiness to perform or maintain information processing. For any single individual, vigilance is usually discussed in the singular. Multiple 'vigilances', existing simultaneously are not addressed in the cognitive literature. The asymmetry result for theta forces either a redefinition of vigilance or a theory positing that theta may reflect more than vigilance, perhaps degree of information processing. These may be important avenues for future research.

In light of a 'vigilance' theory for theta activity, the result that high theta generators are younger than low generators is relevant. The subjects were selected from their rank ordered theta activity during Eyes Closed (dark) baseline. Younger subjects may have experienced more excitement upon entering the experimental situation and hence may have exercised vigilance and orienting behaviour. Older subjects perhaps adopted a laissez faire attitude resulting in lower theta activity. Although speculative, this explanation is consistent.

The theta results were observed at the frontal sites

only. This is consistent with the work of Mizuki et al (1980) and Mizuki et al (1983) who specifically study 'frontal midline theta'.

Beta activity yielded few significant results. As hypothesized the asymmetry ratio for beta activity did not vary inversely with the asymmetry ratio for alpha, across task (Spydell et al., 1979). Within task however, the correlations between alpha and beta asymmetry show a trend. High inverse correlations exist between alpha and beta asymmetry for the baseline and Focusing tasks, but the correlations become smaller with Counting and Addition. Studies #1 and 2 have demonstrated that alpha asymmetry is a stable measure (relative to beta asymmetry) showing consistent trends across tasks. This suggests that the low correlations between asymmetrical alpha and beta within Counting and Addition originate in the beta measure. This means either that the variance within beta becomes more random when performing the Counting and Addition tasks or it reflects some, as yet, unknown process (perhaps semantic processing). The extreme increase in beta activity (hemispherically averaged) for the Addition task compared to all others (see figures 3.17 and 3.18) may represent increased information processing. Of these tasks Addition does maximally tax the information processing capacity of subjects.

The 3-D spectrographs yielded expected results. They validated expected differences between high, middle and low alpha generators; they also validated the expected alpha

production differences for Eyes Open and Eyes Closed baselines. Gradual changes in frequency peaks through time were not observed for any of the tasks. This testifies to the constancy of spectral peaks through time, at least when averaged across subjects. Evidence for changing alpha peaks in individuals has been reported by Tyson (1982), but averaging across subjects seems to eliminate this phenomenon.

The potential of 3-D spectrographs as descriptive tools for EEG analysis has not been realized in this study. A more detailed investigation is needed in future research. For the present circumstances however, 3-D spectrographs offer an important visual bridge between raw EEG and the correlational matrices for single Hertz frequencies.

As is so often the case in EEG research, data are generated which cannot all be investigated. The problem was partly solved for period analysis measures by restricting statistical analyses to a priori hypotheses; post hoc analyses were limited. In the case of correlational matrices few hypotheses were generated because the technique is novel. Hence, all of the matrices were presented in this study to allow the reader his own interpretations. Discussion will be limited to overall similarities and differences. First, the uniqueness of middle alpha generators is evident. They have lower correlations between low frequency power values (1-22 Hz), as derived from FFTs, and high frequency power values (24-50 Hz). Low and high

alpha generators show more saturation (higher correlations) in this part of the matrices. One reason for low correlations is higher variance among the power values for those frequencies. The concept of entrainment, introduced in study #1, becomes relevant in this context. Less saturated matrices, as are found among middle alpha generators, reflect less entrainment when compared to the other alpha groups. That is, the tasks are less successful in 'entraining' similar PFT spectra among individuals, suggesting that the middle alpha generators are less homogeneous as a group with respect to PFT spectra (for those frequencies with low correlations). Given this interpretation, their performance scores should reflect such variances. Their scores for the different trials of the Addition task (see figures 3.23A, 3.23B and 3.23C) display much more variability across trials and Addition levels than either high or low alpha generators.

Second, consistent correlational patterns differentiated task type among low alpha generators. They demonstrated high overall saturation during both versions of the Focusing task, dense saturation among high frequencies only for both versions of the Counting task and diffuse saturation levels for the Addition task (all levels). The other alpha groups were relatively constant across tasks with respect to frequency clusters. This greater correlational variance across tasks for low alpha generators suggests that they are not good candidates for standard EEG quantification procedures utilizing conventional frequency bandwidths. EEG

analysis strategies (e.g. Galin et al., 1982) involving predetermined bandwidths assume that these bandwidths are valid and stable across tasks. They must reflect systematic variances for power and percent occurrence within that bandwidth only. If variance is due to fluctuating frequency clusters, error is introduced to the measure. This may be the reason low alpha generators do not show the hypothesized alpha asymmetries with left or right hemisphere involvement. Their alpha variance may be more due to a shifting frequency cluster rather than systematic variance within cluster.

Third, the expanding or contracting unitary bandwidth (20-30Hz) hypothesized to reflect difficulty level is not clearly demonstrated. It seems to be slightly present for low alpha generators but the trend is not strong. Two possible explanations for these results are: 1) the relationship may occur at posterior leads only (see study #1), and 2) the colour mapped procedure devised for this study may be inappropriate to make such fine discriminations. A proposed strategy to solve this problem involves using the actual correlations within each matrix as data for a repeated measures ANOVA. The correlations must first be transformed in order to approximate a normal distribution (Howell, 1982). Systematic differences in the mean magnitude of the correlations would reveal expanding or contracting clusters (within specific frequency bandwidths).

Fourth, multi-banded bandwidths were not as prevalent in this study as they were in study #1. The frontal loca-

tion may be the primary reason for this deficiency since the matrices generated for study #1 were from the parietals. The predominant multi-banded bandwidth in study #1 involved 4 to 9 with 14 to 19 Hertz frequencies. It can only be marginally seen in Colour Plate 3.1 for all tasks. The high alpha generators do show a fairly consistent multi-banded bandwidth in the ranges of 14 to 17 and 30 to 45 Hertz. It is observed during Eyes Closed (light) baseline, Unstructured and Structured Focusing, Counting Articles, and Addition levels 2, 5 and 6. An interpretation would be premature at this point.

Summary

Study #2 replicated the alpha asymmetry findings of study #1 with different subjects and three different tasks. The 'intentional' theory of cognitive processing and its presumed relationship with increased levels of alpha activity is partially supported by baseline alpha levels. Theta activity at the frontal leads reflects sustained focused attention or vigilance as manipulated by the various tasks. Results from correlational matrices suggest that low alpha generators fluctuate across frequency clusters whereas high and middle generators fluctuate within frequency clusters.

CONCLUSION

Although complex and many faceted, brain electrical activity is consistent if properly measured. In this author's opinion the Gevins-Galin/Ornstein conflict is resolved. Cognitive processes can be reflected in EEG activity if the proper quantitative and methodological procedures are employed and if movement is minimized. Very fine discriminations were possible within both alpha and theta bandwidths.

To assume that all EEG-cognition relationships can be reflected in traditional EEG research emphasizing fluctuations within bandwidths is simplistic. It has been demonstrated that this conventional avenue is important and fruitful, but it is also evident that it has limitations. Although it could be argued that the last thing electrophysiological research needs is yet another data transformation technique, single Hertz correlational matrices of EEG spectra is an important new way of describing EEG data. It allows a sensitive monitoring of fluctuating frequency clusters across tasks, subjects or time. Traditional methods of EEG investigation concentrate on changes within unitary frequency bandwidths, making the assumption that these bandwidths are stable with respect to frequency. This assumption may be incorrect in some cases, as study #2 has shown. Low alpha generators demonstrate much greater variance among correlational clusters than either high or middle

alpha generators; very likely accounting for their non-significant asymmetry results. The question "why do low alpha generators not show the same asymmetry results as do high and middle alpha generators?" now becomes "why do low alpha generators manifest less stable frequency clusters?". A possible explanation could be the greater amount of desynchronous activity generated by low alpha generators. Large amounts of desynchronous activity produce 'flatter' FFT power spectra; that is, low power values across most frequencies. There is the risk of system noise (eg. equipment, environment) influencing the power values at these low levels, hence correlations may be less consistent across task. This explanation does not account for the similar correlation matrices of two versions of the same task (eg. structured and unstructured focusing). If noise were the problem all correlational matrices for low alpha generators should vary in a random fashion. Future research is needed to investigate both the properties of FFT correlational matrices and the issue of low alpha generators.

There has been a trend in the neurological and psychological sciences to attribute anatomical, neurophysiological and behavioural differences to the left and right cerebral hemispheres. Indeed a major portion of this author's work has supported such interpretations. Statistically strong, consistent and meaningful EEG differences were isolated hemispherically. However, an alternative thrust for future EEG research is to determine electrophysiological similarities or communalities between the two hemispheres during

cognition and information processing. Restricting EEG investigations to hemispheric differences ignores half of the phenomenon. A potentially powerful tool for elucidating hemispheric communalities are FFT correlation matrices across hemispheres. Most of the matrices generated in the present document involved correlating FFT spectra from single sites with themselves. Correlating hemispherically homologous FFT spectra allows a unique opportunity to describe interhemispheric correlational patterns among EEG frequencies. These patterns express common frequency clusters, either unitary or multi-banded. Examples of such a technique are presented in study #1.

An 'idling' hypothesis for alpha activity is not warranted. The correlations between left-right alpha and left-right beta were large and negative for Eyes Closed baseline (in the dark) and the Focusing task but steadily decreased from Counting to Addition. Since linear trends across tasks were significant for left-right alpha activity, the ratio of hemispheric alpha is stable and consistent. This suggests that the non-covarying variances in the low correlations originate from left-right beta. If beta represents cortical activation then it should covary across all tasks, assuming the 'idling' hypothesis for alpha. Given that beta does not covary with alpha across all tasks one of two conclusions is possible: 1) beta does not represent cortical activation but some other frequency does; or 2) alpha does not represent cortical idling. No other frequen-

cies showed statistically significant asymmetry trends across tasks at the parietal sites. The second conclusion is therefore endorsed in this document. Alpha is indicative of some cognitive process of its own. Wertheim's (1974) theory of 'intensive' versus 'attentive' modes of cognitive processing (with elaborations from Tyson, 1982) and its relationship to alpha activity explains the baseline alpha results from study #2. Although it remains unclear whether 'intensive' cognitive modes can operate in each cerebral hemisphere, because studies #1 and 2 did not directly address this issue, it is considered a viable theory.

The conclusion that EEG can reflect vigilance level is supported strongly by the frontal theta results of study #2. Increased theta activity is associated with increasing levels of cognitive difficulty. Also, subjects who performed poorly in the Addition task did not show the characteristic increase in theta activity across difficulty levels. It is unlikely that these important results are due to artifact, especially eye movements. The EEG was filtered, those epochs showing extreme eye movements were deleted and theta effects were observed asymmetrically.

The two propositions that alpha reflects an 'active' cognitive process rather than mental 'idling' and theta represents vigilant behaviour opens up fertile fields of investigation. For instance, EEG allows electrophysiological monitoring with relatively little discomfort to the individual. Relationships between EEG and cognition discovered during awake states can be applied to sleep where direct

manipulation of cognitive processes is not possible. Theta activity has been associated with vigilant behaviour. If subject's were awakened when their frontal theta activity exceeded some individually assessed threshold (perhaps 1 standard deviation away from an individual's mean theta activity) and asked to report their sleep mentation, that mentation may involve cognitive processes similar to those uncovered during awake experiments. The work of Ogilvie, Hunt, Tyson, Lucescu and Jenkins (1982) utilized a similar methodology for investigating the relationship between alpha activity and lucid dreaming. The evidence that alpha differences predominate at parietal locations whereas theta manifests systematic differences at frontal regions, adds a topographical element to cognition and EEG. Frontal alpha and parietal theta may reflect markedly different processes. Lastly, subject factors such as level of alpha or theta generation introduces a neglected dimension of EEG research. A very informal and unsuccessful attempt was made in study #2 to investigate behavioural correlates of (alpha and theta) group membership. Given the validity of alpha and theta individual differences a concerted effort should be made to discover behavioural and personality correlates.

Studies #1 and 2 support the bandwidth specific theories for alpha and theta activity outlined in chapter 1. They also suggest potential areas in which the theories can be expanded or changed. It has been mentioned that level of information processing may be related to theta activity.

Theta may also reflect maintenance of 'state', where 'state' in this case refers to the physiological and psychological 'set' an individual must adopt to perform a specific task. It may be less confusing to substitute the word 'micro-state' for state in order to distinguish its more common 'macro-state' usage, such as normal waking consciousness, sleep, drug induced altered states and comas. Level of vigilance may assist to maintain these micro-states. Theta activity therefore may reflect continuity of micro-states. Dividing subjects on the basis of their alpha levels during Eyes Closed baselines (dark) produced significant differences among the groups on alpha asymmetry measures across tasks. However, the alpha groups were not significantly different on any of the performance measures, suggesting that alpha may reflect an overall cognitive 'style' the subject brings to the task rather than the efficiency of task performance. Lastly, beta activity may be associated with global information processing.

Overall, the results from study #1 and 2 point to an optimistic attitude toward conventional EEG research, despite the cautions of many authors (eg. Low, 1980; Donchin, Kutas and McCarthy, 1977; Gevins et al, 1979a; Paskewitz, 1977; and to some extent Pigeau, 1983).

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APPENDIX A

Focusing Task Instructions

Unstructured Part

1. If the instructions for this task seem vague, don't worry about it. From time to time I'll give you further instructions. There will be periods when I won't be saying anything and you'll be carrying out the instructions. Alright..., Relax and your eyes closed. Take a few deep breaths... When you are ready just sense into your body and ask yourself, "How am I inside right now?" and don't answer. Make a space for whatever comes up. Listen to your body. Don't put words on it... Just put all your attention on what is going on inside your body and see how it is.

>>> 45 seconds of quiet <<<

2. Perhaps you are listening to several parts of your body. Choose the main one and go with it. Focus all your attention on that one feeling or sensation. You don't do anything except let it come up and be with it.

>>> 45 seconds of quiet <<<

3. If this sensation changes or moves, let it do that. Whatever it does, follow the feeling and pay attention to it.

>>> 45 seconds of quiet <<<

4. Now take what is fresh or new in the feel of it now, and as you feel it, try to find a word or two, or a picture which captures what your present feeling is all about. The word or picture is a handle on your experience and doesn't have to make sense to anyone but you.

>>> 45 seconds of quiet <<<

5. Now match the handle to the feeling and see if the word or picture is just right in capturing your feelings. Change the image to match the feeling till they are a good fit.

>>> 45 seconds of quiet <<<

6. When you are ready, you may open your eyes.

Structured Part

1. For this task you'll be asked to direct your attention inward, to specific parts of your body. At each step I will direct you to which body part you should attend. There will be periods when I won't be saying anything and you'll be carrying out the instructions. At the end of these periods I'll ask how successful you were in attending to that body part. Try not to let your mind wander. Try to 'experience' that body part. Remember, the purpose of this task is to focus on specific parts of your body and then tell me how successful you were, after I ask you. Alright... Relax and keep your eyes closed. Take a few deep breaths... When you are ready, just sense into your body and locate both your ankles. Focus all of your attention on your ankles. Ask yourself "How do they feel?" but don't answer. Just sense them.

>>> 45 seconds of quiet <<<

2. On a scale from 1 to 5 where 1 is 'not successful' and 5 is 'very successful', rate your ability to focus on your ankles. (RESPONSE)... Now focus all of your attention on both your knees.. Locate one feeling or sensation in them and go with it.

>>> 45 seconds of quiet <<<

3. On a scale from 1 to 5 where 1 is 'not successful' and 5 is very successful, rate your ability to focus on your knees. (RESPONSE)... Now go from your knees to your stomach. Again locate one feeling or sensation. If this sensation changes or moves, let it do that. Whatever it does, follow the feeling and pay attention

to your stomach.

>>> 45 seconds of quiet <<<

4. On a scale from 1 to 5 where 1 is 'not successful' and 5 is very successful, rate your ability to focus on your stomach. (RESPONSE)... Now, focus your attention on your heart. Take what is fresh or new in the way your heart feels now, and focus on it.

>>> 45 seconds of quiet <<<

5. On a scale from 1 to 5 where 1 is 'not successful' and 5 is very successful, rate your ability to focus on your heart. (RESPONSE)... From your heart, switch your attention to the inside of your head. Try to visualize and feel the inside of your head.

>>> 45 seconds of quiet <<<

6. On a scale from 1 to 5 where 1 is 'not successful' and 5 is very successful, rate your ability to focus on your heart. (RESPONSE).

Appendix B

QUESTIONNAIRE

NAME: _____ Age: _____ Sex: _____

1. Typically, how often do you remember your dream(s) upon awakening in the morning? (check one)

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

2. Approximately how many hours do you sleep at night? _____
 If you nap, how much time do you nap during the day? _____

3. Estimate how long it usually takes for you to fall asleep after you turn out the lights and settle down? _____ minutes

4. Do you consider sleeping as a waste of time or do you think sleeping is important? (check one)

_____ sleeping is a waste of time.
 _____ sleeping is important.

5. Have you ever realized you were dreaming while you were still asleep and dreaming?

_____ always
 _____ often
 _____ sometimes
 _____ rarely
 _____ never

6. Have you ever tried meditation? (check one)

_____ yes if yes what kind? _____
 _____ no

7. On the average how long can you study before your attention wanders? (For example, looking out the window or making a cup of coffee or daydreaming.) (check one)

_____ for hours at a time
 _____ for one hour
 _____ for half an hour
 _____ for fifteen minutes
 _____ for ten minutes
 _____ for five minutes
 _____ for one minute

8. Answer Yes or No to the following questions.

_____ Do you paint pictures? (Using oils, pastels, etc)
 _____ Do you sculp? (Wood, form clay, soapstone, etc)
 _____ Do you play a musical instrument?
 _____ Do you sing entire songs?
 _____ Do you write fiction or poetry?
 _____ Do you act in theater productions?

9. How often do you have headaches? (check one)

_____ always
 _____ often
 _____ sometimes
 _____ rarely
 _____ never

10. If you were asked to close your eyes and imagine a beautiful sunset would you: (check one)

_____ see a picture inside your head?
 _____ not see a picture but be able to describe the experience anyway?
 _____ not see a picture and unable to describe the experience?

11. Have you ever had a nightmare and stopped it by willing yourself awake (as opposed to just waking up naturally)?

_____ Yes
 _____ No

3 3

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END

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FIN