FREQUENCY ANALYSIS OF THE HUMAN ELECTROENCEPHALOGRAM DURING THE PERFORMANCE OF A DISCRIMINATION TASK

A Thesis

Presented To

The Faculty of the Department of Psychology

The University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

Jon F. Peters

May, 1970

ACKNOWLEDGMENTS

The author expresses his appreciation:

To, my thesis supervisor, Professor Daniel E. Sheer, for his time, interest, and helpful criticism;

To, Dr. John Siegfried, Dr. Edward Downie, and Dr. Robert Hazelwood, for serving on the Thesis Committee;

To, Mrs. Lillian B. Hix and Mrs. Georgia Laxton for their computer analysis of the data;

To, my wife, Carol, for assistance in several aspects of this study.

FREQUENCY ANALYSIS OF THE HUMAN ELECTROENCEPHALOGRAM DURING THE PERFORMANCE OF A DISCRIMINATION TASK

An Abstract of a Thesis

Presented To

The Faculty of the Department of Psychology

The University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

Jon F. Peters

May, 1970

ABSTRACT

The EEG in five frequency bands was studied in the occipital and frontal areas of two subjects performing a behavioral task.

Each trial of the task was divided into pre-stimulus, stimulus, and post-stimulus periods, with a duration of 10 seconds each. All trials demonstrating activity which was thought to be of muscular origin were discarded. The resulting data showed the following: (1) Activity at 20 Hz was consistently lower during the stimulus period in the occipital electrodes. (2) Activity at 40 and 50 Hz increased in the occipital derivation during the stimulus period in both cases. (3) None of the comparisons showed any significant changes in the F_3-F_z derivations.

Tentative hypotheses were advanced relating the decrease in 20 Hz to behavioral "inhibition" and the increase in 40 and 50 Hz to "facilitation" or possibly "orientation". It was suggested that these data might also be interpreted as electrical corollaries of short term memory processes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEM

The continuous electrical activity of the cortex, which is present even in the apparent absence of any specific peripheral stimulation, has been extensively studied, and this branch of electrophysiology has earned a name of its own: electroencephalography. Recordings of this activity, made through the intact human skull, are referred to as electroencephalograms (EEGs).

The recording of EEGs of man lagged for many years behind their demonstration in animals, partly because in recording through the skull both electrodes lie at a distance from, and on the same side of, the active brain tissue and the potentials are consequently attenuated (Brazier, 1953). An additional factor which has hampered research dealing with the EEG frequencies above approximately 25 Hertz (Hz) in man is muscle artifact (Gibbs & Grass, 1947; Mark, 1947). Finley (1944) pointed out that muscle artifact can be readily mistaken for fast EEG activity, attributable to brain. Thus, one finds three plausible reasons why research on 40 Hz activity in the human EEG as recorded at the scalp has fallen behind its documentation in many subhuman species.

The problem to be investigated stems directly from a pair of studies conducted by Sheer and his colleagues (1966 a, b). In these particular studies, it was reported that the power spectrum of a cat's visual area I showed a significant shift in proportional power from 31.5 Hz to 40 Hz during the S+ period after learning of a visual discrimination task had occurred. Congruent with each response there was also a marked rise in the 31.5-40 Hz bands, with the rise in 40 Hz persisting until the termination of the trial. In a recent review, Sheer (1970) noted that the behavioral data strongly suggest that memory traces involved in short-term storage should take the form of patterned electrical brain activity. In order to further elucidate this relationship, Sheer suggested a research strategy which would commence with attempts to establish correlations between behavior and critical patterns of organized electrical activity.

The purpose of this study, then, is twofold: (1) to demonstrate the presence of 40 Hz activity in the human EEG which can be attributed solely to brain; and (2) to relate this activity to the performance of a discrimination task.

CHAPTER II

REVIEW OF THE LITERATURE

Analysis Methods

With the discarding of the notion that there were two types of waves in the EEG, alpha and beta, and realization that the ongoing EEG was composed of a continuum of frequencies (Gibbs et al., 1935; Travis & Knott, 1936) with a demonstrable relationship between frequency and amplitude (Knott & Travis, 1937), it was but a short step to the introduction of automatic frequency analysis, which would give data relative to two of the three dimensions of the EEG, frequency and voltage. The third parameter, phase, could not be incorporated into the system (Knott, 1953).

The early methods for determining the frequency spectrum of the EEG prior to automization were primarily graphical (Kozhevnikov, 1958; and Engel et al., 1944). Fujimori et al. (1958) analyzed the EEGs of children by this method in an attempt to derive a quantitative expression of slow activity. They concluded that the method was applicable to clinical practice, especially since the results were similar to what was obvious upon visual inspection of the original record. However, a serious drawback to this method is the laboriousness of its application, with analysis of a few seconds of record taking up to a week (W. G. Walter, 1963).

A commonly employed method, visual analysis, is accurate only within the limits of the experience of the observor. For example, it sometimes gives the impression of a transition to an EEG of higher frequency during afferent stimulation. Rusinov (1960) pointed out that this may be due to the suppression of activity at lower frequencies, allowing the faster frequencies to become more clearly evident. He supported his conclusion with data which showed the faster activity to be present prior to the onset of the stimulus.

Before automatic instruments were employed, there were also attempts to compute characteristic features of the EEG curve by Fourier's method of harmonic analysis, which involves the separation of any course in a certain time period into a series of sine waves, the frequency of which is the total multiple of the basic frequency. Each one is then characterized by a certain amplitude and phase relation to the original sine wave (Matoušek, 1967). However, Fourier's method is not in theory directly applicable to the EEG as it assumes that a portion of the signal repeats itself identically in the past and future or is nil outside the recording interval, conditions that rarely occur in physiological signals (Cammarata, 1967). D. O. Walter (1963), in his review of the mathematical relations of this method, pointed out that only certain individual waves are derived from some basic frequency and one can not presume that the whole EEG is derived from one such frequency. It was therefore necessary to generalize Fourier's transform, introducing the concept of statistical variability in the signal (Cammarata, 1967).

Tuned passive filters for detection of individual frequencies of the EEG were first employed by Loomis et al. (1936), to study the differential EEG reactions both within the same subject and across subjects during various behavioral states, including sleep. The integrated output of this tuned circuit expressed the quantity of activity of the brain at a specific frequency which had occurred in the preceding 30 seconds. Drohocki &

Drohocka (1939) and Drohocki (1945) have described a similar method, and employed it for the study of urethane narcosis.

Grass and Gibbs (1938) described the first automatic analyzer which provided a continuous frequency-voltage plot in the EEG frequency range; unfortunately, none but the original experimental model were produced. However, it was used in a number of studies which are discussed in the next chapter.

Automatic analysis of the EEG is usually performed by electronic harmonic analyzers of various types (W. G. Walter, 1943; Baldock & W. G. Walter, 1946; and Barbour, 1947). Knott et al. (1951) have described an american equivalent to the analyzer developed by W. G. Walter. Hoefer et al. (1949) employed an automatic analyzer of their own design to study the EEGs of normals as well as patients with various neurological defects. It is interesting to note that their analyzer as originally designed covered all frequencies from 1 to 60 Hz. However, upon repeated analysis of different EEGs, nothing significant was found above 30 Hz and thus, the final analysis was limited to activity from 1 to 30 Hz. No activity was seen at all in the filters tuned to frequencies from 18 to 60 Hz when a short alpha burst was analyzed. The band width of the filters employed in the analyzer usually determines whether the process is termed "frequency analysis" (broad band filters) or "spectral analysis" (fine division of frequencies) (Goldstein & Nicotra, 1961; Eidelberg & Cheshire, 1964; and Cohn, 1964).

More recently, Burch, et al. (1964) has abstracted wave shape information from the EEG as an aperiodic function. This method, termed "period analysis", utilizes a digital computer and breaks down the ongoing EEG into major, intermediate, and minor periods which are distributed over three spectrum of "equivalent" frequencies in ten bands per spectrum.

40 Hz in Animals

The occurrence of a pronounced rhythmic electrical bursting in rhinencephalic structures was first discribed by Adrian & Ludwig (1938) in the catfish. Subsequently, a number of investigators have observed and verified the occurrence of this activity in the following organisms: cat (Freeman, 1962; Gault & Leaton, 1963; Hernandez-Peon et al., 1960; Leese, 1960); catfish (Rappoport, 1965); chimpanzee (Adey, 1963); dog (Domino & Ueki, 1960; Sundstein & Sawyer, 1959); frog (Gerard & Young, 1937); hedgehog (Adrian, 1942); monkey (Domino & Ueki, 1960; Hughes & Mazurowski, 1962; MacLean & Delgado, 1953); rabbit (Adrian, 1955); rat (Wooley & Timiras, 1965); toad (Takagi & Shibuya, 1961); and turtle (Boudreau & Freeman, 1962).

The frequency of this activity may differ for various zones in the rhinencephalon--olfactory bulb, prepyriform cortex, and amygdala--and, particularly, for different species; but in most cases it centers at about 40 Hz (Sheer & Grandstaff, 1969). Sheer et al. (1963, 1966 a) and Grandstaff (1965) have shown that airflow through the nasal passage is essential for the appearance of 40 Hz activity in all of these structures under a variety of behavioral conditions. Bilateral removal of the olfactory bulb was seen to abolish this activity, while unilateral nasal occlusion abolished it ipsilaterally with a corresponding increase contralaterally. This work has since been confirmed by Pagano (1966), Pagano & Gault (1964) and Gault & Leaton (1963).

The relationship between olfactory bulb, prepyriform cortex, and amygdala is not invariant with respect to this 40 Hz activity. For example, in the amygdala, it is also related to the novelty and/or "meaningfulness" of the odor associated with the airflow. A necessary condition for the occurrence of 40 Hz activity in the amygdala is orienting behavior characterized by a high level of alertness, EEG arousal patterns at the cortex, and sniffing. In quadruped animals, particularly, olfaction and the associated motor feedback of sniffing are highly adaptive orienting responses for exploratory, food, and sex behavior (Sheer, 1970). These observations on rhinencephalic structures were extended to neocortical areas in a study by Hix (1969) with cats on a successive visual discrimination task. She noted that significant changes in activity at 20 and 40 Hz occurred in visual area I and the motor cortex, but not in auditory area I of one cat tested during the performance of a discrimination task. Specifically, 40 Hz activity was consistently higher during S_D periods with a response than during any other behavior conditions studied. Coincident with this rise in 40 Hz was a systematic drop in activity at 20 Hz in the same cortical areas. Hix advanced the tentative hypothesis that the 40 Hz activity was an electrical correlate of the orienting response and that the 20 Hz activity was an electrical correlate of its inhibition.

40 Hz in Humans

As would be expected, the investigation of 40 Hz activity in subcortical structures in man has not been carried out extensively.

In 1953 Sem-Jacobsen et al. reported activity in the 24-36 Hz range to be present in the human olfactory bulb. This work was later confirmed by Sem-Jacobsen et al. in 1955 and again in 1956(a). In the 1956(a) study, they recorded from the olfactory bulbs of 17 patients (psychotics) who had been implanted for diagnostic purposes. They noted that stimulation of the nasal mucous membrane by various odors was capable of evoking electrical rhythms in the olfactory bulb which varied in frequency from 25 to 38 Hz. Hughes et al. (1970) noted variations in the frequency (<40 to >65 Hz) of the activity of the human olfactory bulb which were specific according to the type of odoriferous stimulus employed and also to a lesser degree the electrode location. They concluded that the perception of an odor depends mainly on the amplitude of the various frequency components.

Gedevani (1969) has described a spontaneous rhythmic activity at 55 Hz (range 50-60 Hz) and a related rhythm of 2-5 Hz in the olfactory bulb of man. He is currently of the opinion that these rhythms seen in the olfactory bulb are an electrical expression of orienting and emotional responses and may be evoked by any external or internal stimuli, as well as by olfactory stimuli. According to Gedevanishvili (1959), Gedevani has also reported sinusoidal bursts of 55 Hz activity to be present in the frontal polar regions of the human brain. This frontal polar activity was hypothesized to be related to either the orienting reflex or the formation of a temporary connection during conditioning.

Brazier (1959) was able to record fast frequency bursts (36 Hz) in the amygdaloid complex of a temporal lobe epileptic that appeared to be accentuated by any unexpected stressful stimulus which also evoked a galvanic skin response. Brazier related this finding to the work of John and Killam (1959) who recorded from the amygdala in the cat during performance of a conditioned avoidance task. They noted prominent bursts of 40 Hz activity occurring in the amygdala during the performance of this task. Adey et al. (1960) have recorded similar bursts from the cat amygdala during approach training. Leese et al. (1955) described rhythmical bursts of activity at 20-30 Hz appearing in the amygdala of three chronic schizophrenics and one subject being treated for intractable pain. They correlated this activity with thoughts either elicited during directed interviews or occurring spontaneously. It was suggested that this type of activity is related to emotionally significant memories.

Chatrian et al. (1958, 1960) recorded from an electrode estimated to be in the anterior calcarine cortex or underlying gray matter. Constant illumination provoked a response in this area characterized by an initial slow potential, followed by a fast discharge of around 50 Hz. This evolved after a variable amount of time into a discharge of 20 to 25 Hz. A similar pattern was seen when the stimulus was terminated.

Perez-Borja et al. (1961 a, b) implanted bilateral electrodes, estimated to be deep in the posterior temporal or parietal lobes, immediately posterior to the pulvinar and anterior to the ventral portion of the calcarine region at about 25 millimeters from the midline. The EEG recorded from these electrodes was a fast focal response (40-45 Hz) which showed nonspecific responsiveness to stimulation in all sensory modalities.

According to Sem-Jacobsen et al. (1956 b) the EEG recorded from the lower part of the occipital lobe of one patient demonstrated the following patterns: activity of 2-8 Hz when the eyes were closed; 4-8 Hz when the eyes were open; and 27-50 Hz when the patient looked at a picture. The activity at 27-50 Hz was elicited only as long as the patient was interested in the picture or object at which he was looking. An increase in frequency from 25 to 50 Hz in the rolandic motor cortex and underlying white matter was noted when the patient passed from a resting state to a more active state.

Bickford et al. (1958) noted a fast response (50-60 Hz) in the right posterior temporal lobe of one patient accompanying a clinical state which they described as a temporal lobe automatism.

Three types of electrical activity have been recorded by Irger et al. (1949) in the human cerebellum. These types were formulated on the basis of the frequency range in which the activity was noted (6-8, 30-50, and 170-220 Hz). In their studies on the electrical activity of the human cerebral cortex, Beritov et al. (1943) also grouped their subjects into three classes, each characterized by a particular band of what they termed beta activity (80, 100-120 and above 120 Hz).

Frequency analysis of the human EEG as recorded at the scalp has not as a rule been extended beyond the 20-30 Hz range (Plutchik, 1966; Peneul et al., 1955; Knott et al., 1959; Kennard & Schwartzmann, 1956; Kennard et al., 1955; Finley, 1943; and Bickford, 1951) with a number of studies oriented to the slower (1-13.5 Hz) end of the frequency spectrum (Yoshii & Hockaday, 1958; Verdeaux et al., 1961; Meister et al., 1959; Matousek, 1968; Friedman & Engel, 1956; and Berkhout & D. O. Walter, 1968). In either case, the majority of the studies are highly clinically oriented, as are those which present data on activity at frequencies around 40 Hz and above.

Those studies presenting data on frequency analysis of the EEG as recorded from the scalp at frequencies around 40 Hz usually do so only as a secondary point of interest, for they do not, as a rule, discuss this activity in any detail. For example, Gibbs and Maltby (1943), in a study on the effects of drugs on the EEG state that, "the frequency curves between 40 and 50 Hz add nothing to the data", and on this basis, excluded it from further discussion. The curves they presented for activity at 40 Hz do not appear to vary greatly from drug to drug. Gibbs et al. (1940) studied the effect of metabolic changes on the frequency spectrum of the EEG. The graphs of their data show activity in the 40 Hz range as recorded monopolarly from the occiput referred to the two ears.

Gibbs (1942) noted an increasing amount of energy in the EEG spectrum above 24 Hz along a gradient from the temporal and frontal areas to the parietal and occipital areas.

In 1950, Gibbs and Lorimer, and Gibbs et al., studied the clinical correlates of what they considered to be a rare EEG pattern consisting of approximately sinusoidal, 30-40 Hz waves occurring in the frontal and to a lesser extent in the parietal and temporal areas. They reported a high correlation between the appearance of this pattern and personality disturbances. In later papers, Gibbs and Gibbs (1962, 1967) further discuss the possible clinical correlates of what they termed exceedingly fast (above 30 Hz) activity. Beta waves at frequencies above 30 Hz were found in 1.15% of the EEGs of a predominantly neuropsychiatric population by Flugel (1969).

Gibbs and Knott (1949) examined the changes with age in the frequency spectrum of the scalp EEG, as recorded from the right occipital area. They noted no systematic increase in voltage with age for activity in the frequency range from 22-60 Hz.

Knott et al. (1942) performed a Fourier transform of the EEG which showed 40 Hz activity to be present in approximately equal amounts during waking and sleep.

Finley (1944) reported EEG activity at around 40 Hz with an amplitude of 50 microvolts which he delineates from muscle artifact on the basis of morphology.

Regan (1968) employed a light sinusoidally modulated at varying frequencies to elicit an evoked potential. Further analysis of this data showed a marked peaking of activity within the 45-55 Hz range. Dewan (1969) recorded from the right occipital area of one subject (S) during photic stimulation at 5 cycles per second. The autospectrum of this activity showed a dominant peak at about 10 Hz, with an additional small peak at 40 Hz. Kaufman and Price (1967) have described a technique with which it is possible to record visually evoked activity from the human scalp with a frequency content of 300-1000 Hz.

Motokizawa and Fujimori (1964) noted that fast activity (13 to 60 Hz) did not increase in association with alpha blocking. However, Grindel (1965) was able to record a simultaneous depression of alpha and beta activity in the occipital areas with the onset of a light stimulus. Activity in the gamma range remained unaltered. Gibbs and Gibbs (1950) reported only a very slight increase in activity at 40 Hz in the occipital area with eye opening. Il'Ianok (1960) employed a modified Walter analyzer to study the occipital EEG. He found a minor drop in the amount of 40 Hz activity present (averaged over 50 seconds) under a steady illumination condition relative to the level seen in total darkness.

According to Jasper (1937), Dietsch (1932) found several frequencies between 17 and 50 Hz when a Fourier analysis was made of some of Berger's alpha and beta waves. Dietsch subdivided these frequencies into categories which he labeled C_1 through C_7. In his classification, C_1 corresponds to those oscillations which Berger termed alpha waves with a duration of 100 milliseconds (msec.) and C_3 to Berger's beta waves (duration 33 msec.). The maximum amplitude of the C_3 components was only 1/30 that obtained by the principal oscillations (Gloor, 1969).

Jasper (1935) recorded from electrodes placed on the forehead and just above the inion. In this derivation, he noted activity varying between 25 and 50 Hz with an amplitude of 15 to 30 microvolts, which he related to the beta rhythm described by Berger. However, in later studies on beta waves, Jasper and Andrews (1936, 1937) occassionally observed frequencies from 35 to 50 Hz, but they could not be definitely shown to be of cortical origin as could the slower beta waves.

Frequencies ranging up to 200 Hz were observed in the EEGs recorded from electrodes placed on the scalp at Fp_1-C_3 and C_3-O_1, in 14 normal Ss by Hall et al. (1967 a, b). Synchronous "spiking" triphasic waves of about 30 msec. total duration with a slight increase in amplitude in the Fp_1-C_3 derivation were also regularly observed. Their rate of occurrence would occassionally be as high as 40 Hz. They concluded that the EEG above 50 Hz contains substantial elements of brain origin.

Burch et al. (1967) in their period analysis of the EEG data from the flight of Gemini VII, defined two states of arousal: the T_1 category, interpreted as a state of non-specific neurophysiological arousal as contrasted to the relatively specific visual arousal of the eyes open category. Both arousal states showed an increase in slow components but delta tended to predominate in the T_1 category while slow theta was dominant with the eyes open. In addition, the eyes open state showed twice as much 24 to 35 Hz activity as compared to T_1. This accentuation of the relatively high frequency beta component was thought to characterize the specific visual arousal of the eyes open situation. The predominant 30 to 40 Hz activity in the minor period further defined this specific visual component as being quite well organized and primarily in the fast beta range. Contrasted to the beta component of specific arousal, the T_1 state tended to show increased superimposed activity in the 12 to 18 Hz range which was demonstrated to be a well organized wave shape by the comparatively high 10 to 20 Hz component of the minor period. More recently, Spilker et al. (1969) presented data obtained from Ss trained to control the amplitude of their alpha rhythm. Period analysis of the EEG activity recorded from C_4-O_2 and C_z-A_2 in these Ss showed an increase in the average number of full waves per second in the 33.3-50.0, 50.0-66.7 and 66.7-100.0 Hz frequency bands when the S maintained a low alpha as compared to a high alpha amplitude. However, they are careful to point out that this fast activity above 33.3 Hz may not be of brain origin.

Hans Berger, in his first report on the electroencephalogram of man in 1929 questioned the possibility of detecting mental work as a change in the EEG. His research did not lead to an unequivocal answer, but he was inclined to believe that with strenuous mental work the larger waves of first order with an average duration of 90 msec. are reduced, and the smaller (35 msec.) waves of second order become more numerous. He put forth similar statements in later studies (1930, 1931).

In his fourth report (1932) Berger discusses the appearance of this phenomenon in more detail. It was clearly evident to Berger that the alpha wave became much smaller and in many places was completely missing when one S solved mental arithmetic. In those segments where beta waves alone were present, there was a decrease in potential to 1/5th that of the previously existing voltage. In his twelfth report (1937) Berger presented some contrasting results. He compared the amplitude of beta waves at rest to those of mental work. During mental work, the beta waves with a duration of 11-24 msec. showed not only a four to eightfold increase in amount (sometimes 5 brief beta waves immediately succeeded each other) but they also increased in amplitude. Furthermore, in mental work which continued for a relatively long time, periodic fluctuations became apparent in the EEG with a transient return of the alpha wave (Berger, 1938). He chose to refer to this as the active EEG (Gloor, 1969).

According to Mundy-Castle (1951) there appear to be at least two broad groups of beta activity (maximum 30 Hz), one showing suppression during mental activity and often though not invariably related to alpha frequency, the other apparently augmented by such mental activity. He tentatively hypothesized that beta activity occurring during mental activation represents an accelerated process resultant on scansion of the projection and/or association areas in which patterned neuronal activity is present consequent upon the presentation of stimuli in the form of either visual or mental patterns. He confirmed these findings in 1953 and again in 1957, proposing in the latter paper the terms beta I and beta II for this bifold classification of the beta rhythm.

A significant increase in beta activity (13+ Hz) during verbal learning has been reported by Thompson and Obrist (1963). In a later study (Thompson & Obrist, 1964) they confirmed these original results, and noted that this increase was maximal at a critical time in the learning process; i.e., when syllables were first being anticipated correctly.

Volavka et al. (1967) reported an initial suppression of both beta I and beta II activity with eye opening. A significant increase in these frequencies occurred with the performance of mental arithmetic either with the eyes open or closed.

Sakhialina and Mukhamedova (1958) noted that the initial phase of a form of muscular activity (pedaling a bicycle ergometer) to which the S was not accustomed was accompanied by 30-40 Hz EEG activity. On the first experimental day, these oscillations were recorded from the occipital, parietal, and temporal regions. On subsequent days, they became localized to specific areas in the sensory motor region. Further trials led to a return of the alpha rhythm. They related the appearance of this phenomenon to the gradual consolidation of the sterotype that had been formed, consolidation being apparently associated with concentration and increasingly strict localization of excitation in some limited sections of the cerebral cortex, with some predominance of the inhibition process in all other regions. Similar studies, with confirming results have been carried out by Pavlov and Tochilov (1960), Soloqub (1960), Khavkina (1958), and Shtiurmer (1958). However, Mil'Shtein (1960) was unable to record rapid oscillations of this nature in a similar situation. Thus, the question of contamination by muscle artifact arises. However, Pavlov and Tochilov (1960) by employing strict controls (recording directly from muscle, cooling of muscular tissue, etc.) were able to rule out contamination of this nature, and conclude that this activity was of cerebral origin. Soloqub et al. (1961) noted an increase in activity at 20 Hz during muscular exertion. In an experiment designed to assess the changes in the frequency spectrum of the EEG during activities involving different kinds of auditory, visual, and conceptual functions, Giannitrapani (1969 a) noted the following changes: (1) mental arithmetic showed increased fast activity (21-33 Hz) bilaterally, anterior, more in the prefrontals; (2) listening to noise, an increase in this fast activity bilaterally in prefrontal and temporal areas; (3) listening to music, increase in 33 Hz activity in the left occiput; (4) listening to voice, simulated noise except for a decrease in activity at 33 Hz in the left occiput; and (5) visual examination of a poster and looking through diffusing goggles showed similar changes spread over the entire head.

The literature cited here tends to support the position of rhythmical activity at about 40 Hz being not only recordable at the human scalp and attributable to brain, but also its being related to memory consolidation and/or performance of a mental task. However, it remains for a correlation to be established between behavior and critical patterns of organized EEG activity as suggested by Sheer (1970), which, as stated earlier, is one of the purposes of this study.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Subjects for this study were two paid volunteer undergraduates (Case I and Case II) who were free from any known neurological defects at the time of the recording. These Ss were selected from a larger population on the basis of their ability to relax in the experimental situation thereby drastically reducing the amount of muscle artifact in their EEG records.

Apparatus

The experimental chamber was an electrically shielded, semi-sound-proof room adjoining the recording area. The experimenter was able to view the S via a one way mirror. An intercom system provided verbal communication with the S.

The S was seated in a comfortable reclining chair in front of a table on which the behavioral apparatus (Lehigh Valley human behavior panels) had been placed. The chair and the table were individually positioned for each S to maximize his comfort and to allow to make a response with a minimum of effort.

A combination of Foringer and Lehigh Valley automatic timing equipment was employed to control the inter-trial interval, present the varying groups of stimuli, and record the S's responses.

At the start of each experimental session the following instructions were read to each S:

> Three geometric lighted stimuli will appear on the upper panel and a sound will come from either the right or left speaker in the upper panel. You are to respond by pushing one of the three push panels on the lower panel on which are engraved a triangle, a circle, and a square. When you make a correct response the red light to the right of the response panel will flash. You will receive one dollar for each correct answer.

The thirty trial sequence was repeated until the S responded correctly for 15 consecutive trials. A five minute rest period was allotted between sequences, when more than 30 trials were required for the S to learn the task.

EEG Recordings

The collodion technique was employed to attach Beckman silver silver chlorided electrodes to the S's scalp according to the International 10-20 system. Interelectroded resistances were in all cases under 5,000 ohms. A Microdot mininoise cable linked the electrodes to a Grass electrode box which had been modified to accept twinaxial cable connections. The electrodes were bipolarly connected to the input terminals of eight Grass Model 7P511 EEG amplifiers in a Grass Model 78 polygraph. The frequency response of these amplifiers was down 50% at 10 and 100 Hz.

The amplified cortical signals were stored on magnetic tape via an Ampex SP300 tape recorder, permitting off-line computer analysis of the records. A specially constructed hybrid analog computer (Benignus, 1967) was employed to perform the frequency analysis of the EEGs.

Program number 1 was employed for this study. This program will write out two channels of moving window normalized band power functions for any brain areas selected. Five band powers are computed with 23%

(1/3 octave) band-pass filters with center frequencies at 20, 25, 31.5, 40, and 50 Hz. The upper and lower half power points for the broad band filter was 55 and 18 Hz, respectively. The low pass filters employed for moving window integration have adjustable time constants from .1 seconds through 1.5 seconds. The dividers make continuous divisions, giving the mean normalized band power at any given point in time. The output equation for one channel is $\frac{\int X^2 40}{\int X^2 BP}$ in which X^2_{40} is the square of the voltage from the 40 cycle filter and X^2_{BP} is the square of the voltage from the broad band filter. The resulting output is displayed as a histogram on a Brush pen recorder.

CHAPTER IV

RESULTS

The data to be presented here are based on only those trials which were judged to be devoid of muscle artifact upon examination of the original ink written record. The criterion used to discard trials was the presence of any activity which on the basis of its morphology was felt to be of muscular origin (Finley, 1944). If such activity was discernible anywhere within the 10 second pre-stimulus (PRE), stimulus (STIM) or post-stimulus (POST) periods, regardless of its duration, that trial for that electrode pair was discarded.

A Friedman two-way analysis of variance by ranks (Siegel, 1956) was obtained on the data, to indicate the overall level of significance attained across conditions. Table 1 gives the values for this statistic for both cases. Only those frequency bands and electrode combinations which achieved overall significance in both cases as noted in Table 1 were subjected to further analysis. A modification of the Friedman statistic (Miller, 1966) was employed to test for specific differences between conditions. Values obtained by this method are shown in Tables 2 and 3.

20 Hz Activity

A significant ($p < .05$) systematic decrease in 20 Hz activity occurred during the STIM as compared to the PRE and POST periods in the occipital electrode combinations for both cases. This systematic decrement is clearly seen in Figure 1. A significant decrease in power in the F_3-F_z

TABLE 1

SIGNIFICANCE LEVELS FOR EACH FREQUENCY BAND ACROSS THE THREE CONDITIONS (PRE-STIMULUS PERIOD, STIMULUS PERIOD, POST-STIMULUS PERIOD) AT EACH ELECTRODE PLACEMENT

Case I

O_2-O_z			F_3-F_z		
Freq.	X^2r	P	Freq.	X^2r	P
20	24.2788	$<.001$ *	20	1.7872	$>.05$
25	2.0878	$>.05$	25	.2880	$>.05$
31.5	27.5938	$<.001$	31.5	2.8512	$>.05$
40	23.4312	$<.001$ *	40	.8752	$>.05$
50	24.0110	$<.001$ *	50	.6624	$>.05$

Case II

O_1-O_z			F_3-F_z		
Freq.	X^2r	P	Freq.	X^2r	P
20	15.600	$<.001$ *	20	8.0024	$<.05$
25	6.0384	$<.05$	25	2.8630	$>.05$
31.5	4.8752	$>.05$	31.5	5.1114	$>.05$
40	21.3744	$<.001$ *	40	3.4342	$>.05$
50	15.5008	$<.001$ *	50	3.4342	$>.05$

* The electrode placements and frequency bands, significant in both cases.

TABLE 2

MEAN RANK DIFFERENCES BETWEEN CONDITIONS FOR CASE I

O_2-O_z Derivation

FREQ.	PRE-STIM	PRE-POST	STIM-POST
20	1.3293 *	.4620	.8663
40	1.2513 *	.2503	1.0010
50	1.2898 *	.3273	.9625

F_3-F_z Derivation

FREQ.	PRE-STIM	PRE-POST	STIM-POST
20	.2812	.4687	.1875
40	.0625	.3125	.2500
50	.1875	.2812	.0937

* $p < .05$

** $p < .01$

*** $p < .001$

TABLE 3

MEAN RANK DIFFERENCES BETWEEN CONDITIONS FOR CASE II

O_1-O_z Derivation

FREQ.	PRE-STIM	PRE-POST	STIM-POST
20	1.0000 *	.3437	1.3437 ***
40	1.3125 ***	.1875	1.5000 ***
50	.8750 *	.5000	1.3750 ***

F_3-F_z Derivation

FREQ.	PRE-STIM	PRE-POST	STIM-POST
20	.4284	.6426	1.0710 *
40	.3570	.3570	.7140
50	.3570	.7140	.3570

* $p < .05$
** $p < .01$
***$p < .001$

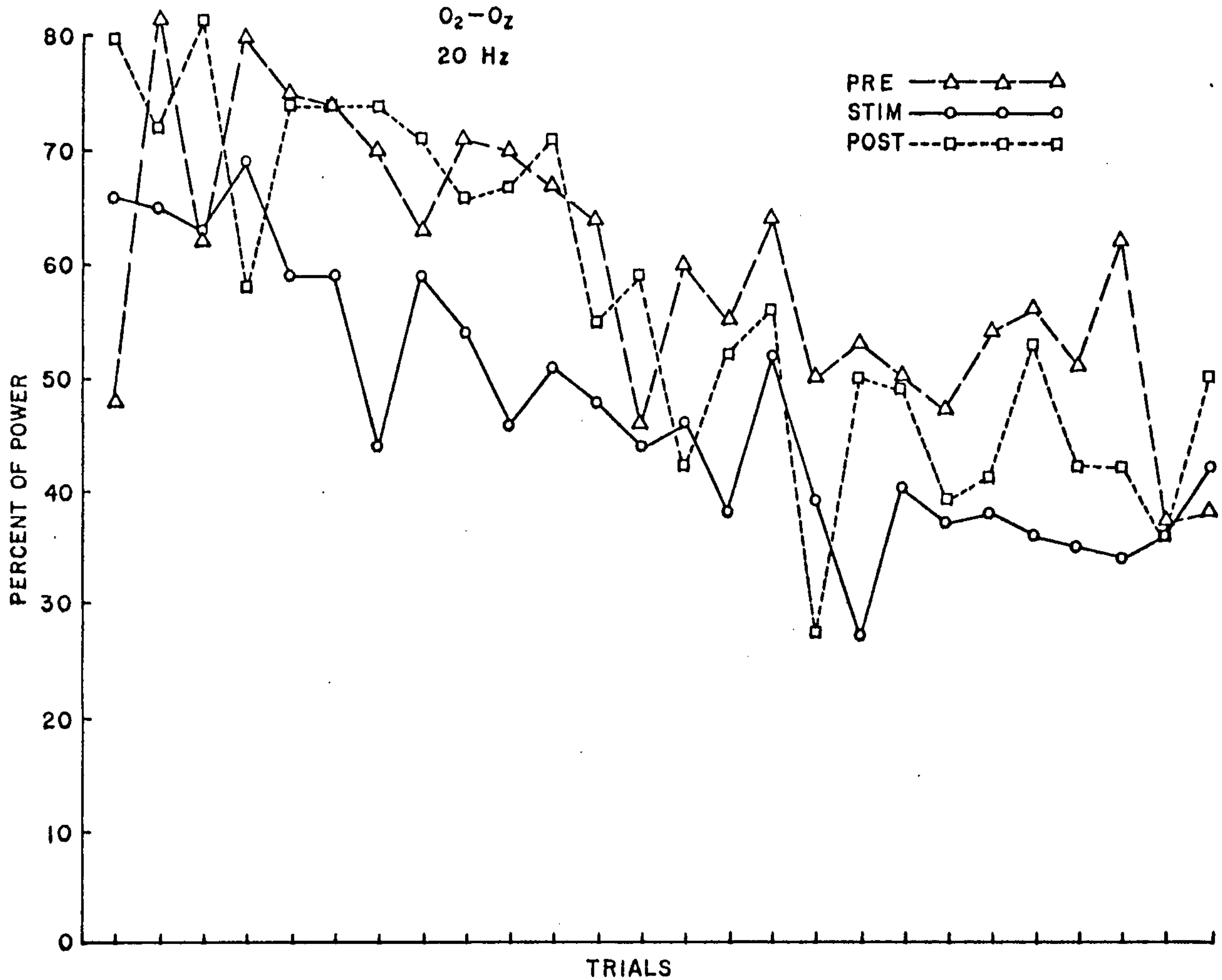

FIGURE I

PER CENT POWER IN THE 20Hz FREQUENCY BAND AT THE O_2-O_z PLACEMENT DURING THE THREE CONDITIONS ACROSS THE TWENTY-SIX TRIALS combination during the STIM is present only for Case II as seen in Table 3.

25 Hz Activity

The Friedman rank statistic indicated a significant overall change in the activity in this band width occurred at the O_1-O_z derivation in Case II. However, the comparison carried out with the Miller statistic showed no significant differences between the three conditions. No other statistical differences were noted in the band.

31.5 Hz Activity

Significant changes in this frequency band as reflected in the Friedman statistic occurred only in the occipital derivations for Case I.

40 Hz Activity

Tables 2 and 3 show a significant increase in the percent power of 40 Hz activity during the STIM for both cases occurring in the occipital electrodes. None of the comparisons showed any significant changes occurring in the activity at this frequency in the frontal electrode combinations. Figure 2 depicts this difference in percent power for the O_2-O_z electrode combination in Case I.

50 Hz Activity

Activity in this band width, paralleled the changes seen in the 40 Hz band for each case and each electrode combination.

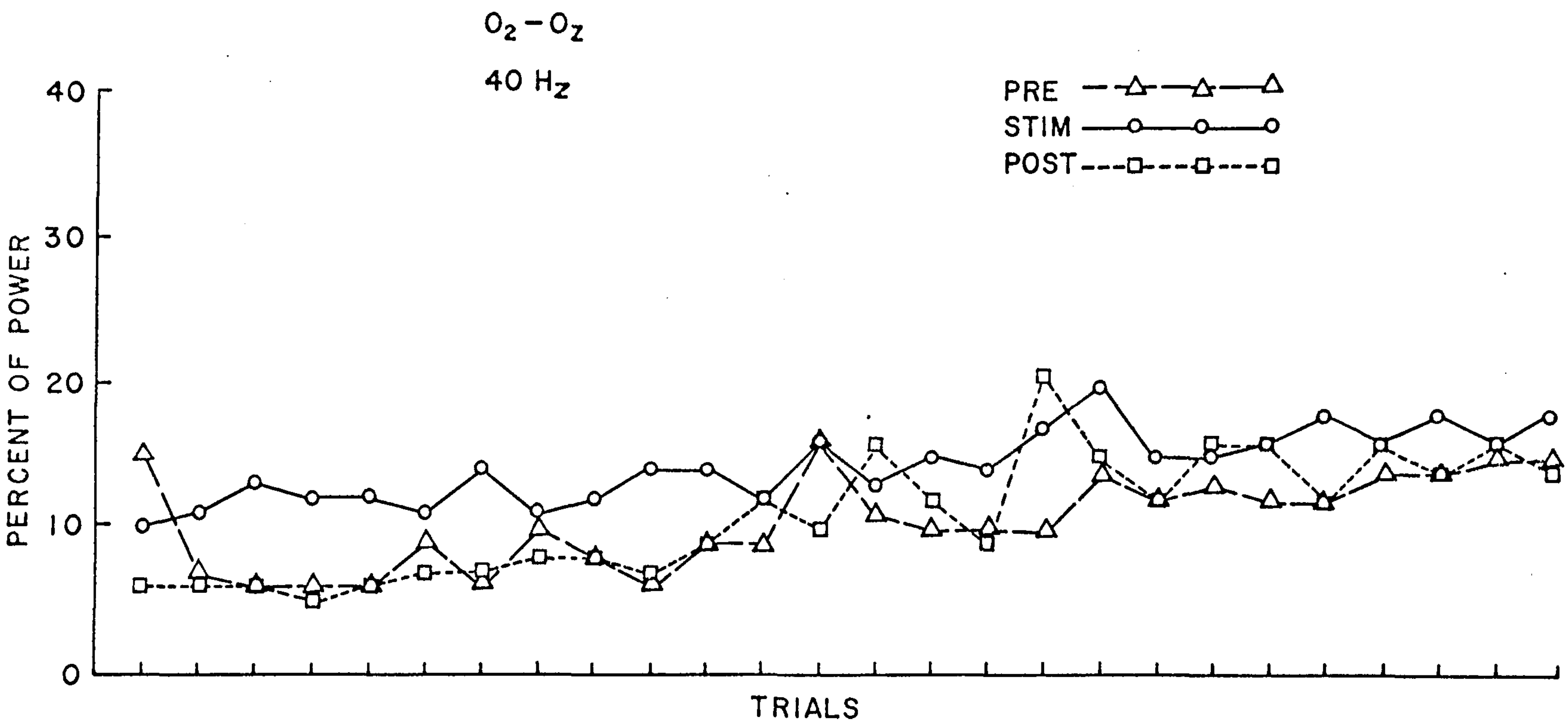

FIGURE 2
PER CENT POWER IN THE 40Hz FREQUENCY BAND AT THE O_2-O_Z PLACEMENT DURING THE THREE CONDITIONS ACROSS THE TWENTY-SIX TRIALS

CHAPTER V

DISCUSSION

The rigid criterion employed for the discarding of trials coupled with the data presented, offer considerable support for one purpose of this study stated previously as "to demonstrate the presence of 40 Hz activity in the human EEG which can be attributed solely to brain". That this finding is in good agreement with the literature cited earlier, concerning EEG activity at around 40 Hz as recorded from the scalp, further substantiates the conclusion that with the proper controls one can reliably record activity in this frequency range which is attributable to brain. However, in lieu of the large number of trials which had to be discarded (as many as 44 trials for one case) due to the presence of muscle artifact, it takes on additional significance. Indeed, it points directly to the possibility of erroneous data being reported in studies of this nature, unless the data are first carefully screened for the presence of artifact of this nature.

The apparent inverse relationship between activity at 20 Hz and that at 40 Hz parallels that reported previously by Sheer (1970) and Hix (1969) in feline studies.

Sheer (1970) and Hix (1969) noted that this relationship varied between the S_D and S_Δ conditions of a visual discrimination task and related it to behavioral "facilitation" (40 Hz) and "inhibition" (20 Hz). The experimental paradigm employed here, by loose analogy contains an S_Δ (or "inhibitory") period, in the form of the PRE and POST conditions. Thus, one could conceive of the increase in 20 Hz activity during the PRE and POST periods to a level above that seen in the STIM period as an electrical expression of "inhibition". The possibility that this reduction in activity at 20 Hz during STIM is a parallel to the decrease in beta I activity which occurs during mental activity, as described by Mundy-Castle (1951, 1953, 1957), should also be considered. However, Motokizawa & Fujimori's (1964) finding that fast activity (13 to 60 Hz) did not increase with alpha blocking, would tend to rule against this decrement in 20 Hz being harmonically related to alpha blocking. Also, Mundy-Castle stated that this beta I decrement was not invariably related to alpha frequency.

The possibility of a computational error (i.e., since the program involves the computation of per cent power, if one frequency increases another must decrease) accounting for this apparent relationship can be ruled out on the grounds that the relationship is not perfect (14 of 40 trials did not show this relationship in the occipital derivations) and the remaining frequency bands were not similarly affected.

The prominent localization of the significant changes to the occipital electrodes as compared to the F_3-F_z combination raises the question of the data being contaminated by a visual evoked potential. This is especially true, since the visual evoked response is known to contain high frequency components (Regan, 1968). However, preliminary analysis of the data employing a Fabri-Tek 1070 signal averager synched to the stimulus onset revealed no discernible evoked response to the visual stimuli. Rather, a more plausible explanation might lie in the anatomical relationship between the electrode's position and the underlying neural structures. The O_1-O_z and O_2-O_z combinations would lie over the occipital cortex whereas F_3-F_z would lie more over the precentral or premotor areas (behind the frontal association areas). Thus, the 0_1-0_z and 0_2-0_z pairs would lie in direct relationship to cortical areas significantly involved in the S's performance of the task (whereas the F_3-F_z pair would not), and would thereby be prone to demonstrate changes in the EEG frequency spectrum coincident with task performance. Such a hypothesis is not entirely without precedent. In 1966, Giannitrapani studied the changes in average EEG frequency (5 second epoch) during resting and thinking. He noted a significant overall increase in average frequency from 32.8 to 38.9 Hz in the thinking as compared to the resting state. There was also a significant electrode placement effect, with the increase in mean frequency being maximal in the frontal areas and minimal at the occiput. The increase at the frontal derivations was significantly greater than that occurring at any other combination. He concluded that these differential findings were the result of differential involvement of the areas studied and an indication of their functional role for the conditions studied. He reported similar findings in 1969 (b). That the maximal frequency changes occurred in the frontal areas (Giannitrapani, 1966) as opposed to the occiput appears contradictory to the findings of this study. However, the task employed was markedly different in the two situations. Giannitrapani (1966) employed a mental multiplication task which he considers to be "verbal" (Giannitrapani, 1969 b) whereas a predominantly visual task was employed here. In a study employing two conditions of strong, complex, visual stimulation (i.e., silent and oral reading), Knott (1938) noted a definite shift in the frequency spectrum of the occipital EEG to faster frequencies as compared to a relaxed eyes closed control condition. He associated this shift to faster frequencies with the occurrence of more complex functional structuring of the cortex under the reading conditions. A figure presented in a similar paper by Grass & Gibbs (1938) shows an increase in activity at 40 Hz with a corresponding decrement in activity at 20 Hz occurring in the left occipital area of one S during reading as compared to a resting eyes closed condition. This data, closely parallels the findings of this study.

That high frequency activity is elicited in the occipital areas by visual stimulation (Chatrian et al., 1958, 1960 and Perez-Borja et al., 1961 a, b) which may be recorded at the scalp (Regan, 1968 and Dewan, 1969) coupled with the dominant role vision plays in this task, would offer further support for the apparent occipital focus of the noted frequency changes.

The apparent drop in 40 Hz activity during the STIM period, to PRE and POST levels seen in the last 13 trials of Figure 1 could possibly be related to the finding by Sem-Jacobsen et al. (1961 a, b) that the focal fast response in the lower occipital lobe disappeared when the patient lost interest in the picture or object he was examining. It is entirely possible that the S had lost interest in those last 13 trials, since he was unable to solve the problem (nor could any other S) even on his second attempt. However, an analysis of the last 13 trials for both frequencies with Miller's statistic, reveals that the percent power at 40 Hz increased above PRE levels during the STIM period. Therefore, a slight increase in power during the POST periods would appear to account for the graphically apparent drop in per cent power during the STIM. A comparison of PRE and POST levels for these last 13 trials shows an increment (not statistically significant) in the per cent power during POST as compared to PRE levels. It is interesting to note that there is a corresponding decrement in the per cent power at 20 Hz during these 13 trials. Such a carry over of these faster frequencies into the POST, with a corresponding drop in 20 Hz activity, may be a reflection of extended "orientation" by the S to the situation, as a result of his inability to solve the task at hand .

The increase in proportional power in both the 40 and 50 Hz bands may not be due to a total increase in power of all frequencies above about 35 Hz. Rather, it may be related to an increase in some intermediate (between 40-50 Hz) value which would be included in both bands by the computer (due to filter overlap), and thereby show up as an increase in both bands. A finer grained analysis would be necessary to delineate this possibility.

The discarding of large numbers of trials from each of the cases precludes any statements about the possible relationship of the changes in the EEG frequency spectrum and the actual learning of the discrimination task at this time. However, since none of the PRE-POST comparisons performed achieved significance, one may conclude that the appearance of these electrical patterns is indeed related to the Ss performance of the task. Preliminary analysis of the data from a similar project presently being conducted in this laboratory shows a marked increment in 40 Hz activity occurring in the left occipital area which is response contingent.

The presence of a marked increase in 40 and 50 Hz and corresponding drop in 20 Hz activity from the first trial on in both cases, and the carry over of these patterns into the POST period in the last 13 trials for Case I, would favor an "orienting" interpretation of the results. However, it should be stressed that the data appear to be indicative of possible correlations between behavior and specific EEG patterns as suggested by Sheer (1970). This is especially true, in light of the parallel findings by Grass & Gibbs (1938) obtained under reading conditions. Further support for this point might be garnished from the studies by Thompson & Obrist (1963, 1964) which show a significant increase in beta activity occurring at a critical time in the learning process.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The EEG in five frequency bands was studied in the occipital and frontal areas of two subjects performing a behavioral task.

Each trial of the task was divided into pre-stimulus, stimulus, and post-stimulus periods, with a duration of 10 seconds each. All trials demonstrating activity which was thought to be of muscular origin were discarded. The resulting data showed the following: (1) Activity at 20 Hz was consistently lower during the stimulus period in the occipital electrodes. (2) Activity at 40 and 50 Hz increased in the occipital derivation during the stimulus period in both cases. (3) None of the comparisons showed any significant changes in the F_3-F_z derivations.

Tentative hypotheses were advanced relating the decrease in 20 Hz to behavioral "inhibition" and the increase in 40 and 50 Hz to "facilitation" or possibly "orientation". It was suggested that these data might also be interpreted as electrical corollaries of short term memory processes.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adey, W. R. Potential for telemetry in the recording of brain waves from animals and men exposed to the stresses of space flight. In L. E. Slater (Ed.), Bio-Telemetry. New York: Pergamon Press, 1963. Pp. 289-302.

Adey, W. R., Dunlop, C. W., & Hendrix, C. E. Hippocampal slow waves. Archives of Neurology, 1960, 3, 74-90.

Adrian, E. D. Olfactory reactions in the brain of the hedgehog. Journal of Physiology (London), 1942, 100, 459-473.

Adrian, E. D. Electrical oscillations in the olfactory organ. Journal of Physiology (London), 1955, 128, 21.

Adrian, E. D., & Ludwig, C. Nervous discharges from the olfactory organs of fish. Journal of Physiology (London), 1938, 94, 441-460.

Baldock, G., & Walter, W. G. A new electronic analyzer. Electronics and Engineering, 1946, 18, 339-344.

Barbour, I. An automatic low frequency analyzer. Review of Scientific Instruments, 1947, 18, 516-522.

Benignus, V. A. A hybrid system for computer analysis of EEG data. Unpublished doctoral dissertation, University of Houston, 1967.

Berger, H. Über das elektrenkephalagramm des menschen. Archiv für psychiatrie und Nervenkrankheiten, 1929, 87, 527-570.

Berger, H. Über das elektrenkephalogramm des menschen. Journal für Psychologie und Neurologie, 1930, 40, 160-179.

Berger, H. Über das elektrenkephalogramm des menschen. Dritte Mitteilung. Archive für Psychiatrie und Nervenkrankheiten, 1931, 94, 16-60.

Berger, H. Über das elektrenkephalogramm des menschen. Vierte Mitteilung. Archiv für Psychiatrie und Nervenkrankheiten, 1932, 97, 6-26.

Berger, H. Über das elektrenkephalogramm des menschen. Zwölfte Mitteilung. Archiv für Psychiatrie und Nervenkrankheiten, 1937, 106, 165-187.

Berger, H. Über das elektrenkephalogramm des menschen. Vierzehnte Mitteilüng Archiv für Psychiatrie und Nervenkrankheiten, 1938, 108, 407-431.

Beritov, I., Bakuradze, A., & Dzidzishvill, N. Encephalographic studies of the brain in cases of concussion. Beritashvill Institute Physiology, 1943, 5, 473-491.

Berkhout, J., & Walter, D. O. Temporal stability and individual differences in the human EEG: an analysis of variance of spectral values. IEEE Transactions on Biomedical Engineering, 1968, 15, 165-168.

Bickford, R. G. Use of frequency discrimination in the automatic electroencephalographic control of anesthesia (servo-anesthesia). Electroencephalography and Clinical Neurophysiology, 1951, 3, 83-86.

Bickford, R. G., Chatrian, G. E., & Uihlein, A. Deep focal fast discharge associated with a temporal lobe automatism. Electroencephalography and Clinical Neurophysiology, 1958, 10, 185.

Boudreau, J. F., & Freeman, W. J. Olfactory bulb responses in the turtle. Nature, 1962, 193, 782-783.

Brazier, M. A. B. The electrical activity of the nervous system. New York: MacMillan Company, 1953. P. 183.

Brazier, M. A. B. In Killam, K. F. & Killam, E. K. Central action of chloropromazine and reserpine. H. Abramson (ed.), Neuropharmacology. New York: Josiah Macy, Jr. Foundation, 1959. Pp. 163-164.

Burch, N. R., Dossett, R. G., Vonderman, A. L., & Lester, B. K. Period analysis of the electroencephalogram from the orbital flight of Gemini VII. Final Report. National Aeronautics and Space Administration. Washington, D. C., 1967.

Burch, N. R., Nettleton, Jr., W. J., Sweeney, J., & Edwards, Jr., R. J. Period analysis of the electroencephalogram on a general-purpose digital computer. Annals of the New York Academy of Sciences, 1964, 115, 827-843.

Cammarata, S. Mathematical methods and electronic computers in the study of physiological electrical signals. Electroencephalography and Clinical Neurophysiology, 1967, Suppl. 26, 9-11.

Chatrian, E., Bickford, R. G., & Uihlein, A. A depth electrographic study of the human occipital response to steady illumination. Electroencephalography and Clinical Neurophysiology, 1958, 10, 362.

Chatrian, G. E., Bickford, R. G., & Uihlein, A. Depth electrographic study of a fast rhythm evoked from the human calcarine region by steady illumination. Electroencephalography and Clinical Neurophysiology, 1960, 12, 167-176.

Cohn, R. An electronically derived distribution of the human EEG. Electroencephalography and Clinical Neurophysiology, 1964, 17, 454.

Dewan, E. M. Nonlinear cross-spectral analysis and pattern recognition: Application to brain waves. Physical and Mathematical Science Research Papers, 1969, 367, 12-16.

Dietsch, G. Fourier-analyse von elektrencephalogrammen des menschen. Pflügers Archiv für die Gesamte Physiologie, 1932, 230, 106-112.

Domino, E. F., & Ueki, S. An analysis of the electrical burst phenomence in some rhinencephalic structures of the dog and monkey. Electroencephalography and Clinical Neurophysiology, 1960, 12, 635-648.

Drohocki, Z., & Drohocka, J. L'électrospectrogramme du cerveau. Comptes Rendus société de Biologie, 1939, 130, 95-98.

Drohocki, Z. Electrospectrographie qualitative et quantitative du cerveau. Schweizer Archiv für Neurologie, Neurochirurgia and Psychiatrie, 1945, 55, 85-128.

Eidelberg, E., & Cheshire, F. C. A Technique for spectral analysis of EEG. Electroencephalography and Clinical Neurophysiology, 1964, 17, 454.

Engel, G. L., Romano, J., Ferris, E. B., Webb, J. P., & Stevens, C. D. A simple method for determining frequency spectrums in the electroencephalogram. Archives of Neurology Psychiatry (Chicago), 1944, 51, 134-146.

Finley, K. H. Potentials of rapid frequency in the human electroencephalogram. Archives of Neurology Psychiatry (Chicago), 1943, 49, 308-310.

Finley, K. H. On the occurrence of rapid frequency potential changes in the human electroencephalogram. American Journal of Psychiatry, 1944, 101, 194-200.

Flugel, E. The significance of extremely fast beta waves (> 30 c.sec) in conventional surface EEG in man. Electroencephalography and Clinical Neurophysiology, 1969, 27, 624.

Freeman, W. J. Changes in prepyriform evoked potential with food deprivation and consumption. Experimental Neurology, 1962, 6, 12-29.

Friedman, S. B., & Engel, G. L. Effect of cortisone and adrenocorticotropine on the electroencephalogram of normal adults: Quantitative frequency analysis. Journal of Clinical Endocrinology and Metabolism, 1956, 16, 839-847.

Fujimori, B., Yokota, T., Ishibashi, Y., & Takei, T. Analysis of the electroencephalogram of children by histogram method. Electroencephalography and Clinical Neurophysiology, 1958, 10, 241-252.

Gault, F. P., & Leaton, R. N. Electrical activity of the olfactory system. Electroencephalography and Clinical Neurophysiology, 1963, 15, 299-304.

Gedevani, D. M. On the physiological role of a 55 c/sec rhythm produced by the olfactory bulb. Electroencephalography and Clinical Neurophysiology, 1969, 7, 709.

Gedevanishvili, D. M. The rhythm of sinusoidal potential oscillations 55 per sec. in the brain of mammals and its relation to orienting and conditioned reflexes. XXI International Congress of Physiological Sciences, Buenos Aires, Argentina, 1959, P. 106.

Gerard, R. W., & Young, J. Z. Electrical activity in the central nervous system of the frog. Proceedings of the Royal Society (London), 1937 Series B, 122, 343-351.

Giannitrapani, D. Electroencephalographic differences between resting and mental multiplication. Perceptual and Motor Skills, 1966, 22, 399-405.

Giannitrapani, D. EEG average frequency and intelligence. Electroencephalography and Clinical Neurophysiology, 1969, 27, 480-486. (a)

Giannitrapani, D. Frequency analysis of the EEG under different behavioral states. Electroencephalography and Clinical Neurophysiology, 1969, 22, 694. (b)

Gibbs, E. L., Lorimer, F. M., & Gibbs, F. A. Clinical correlates of exceedingly fast activity in the electroencephalogram. Diseases of the Nervous System, 1950, 11, 323-326.

Gibbs, F. A. Cortical frequency spectra of healthy adults. Journal of Nervous and Mental Diseases, 1942, 95, 417-426.

Gibbs, F. A., Davis, H., & Lennox, W. G. The electroencephalogram in epilepsy and conditions of impaired consciousness. Archives of Neurology and Psychiatry (Chicago), 1935, 34, 1133-1148.

Gibbs, F. A., & Gibbs, E. L. Atlas of electroencephalography. Vol. 1. Methodology and controls. (2nd ed.) Cambridge, Mass.: Addison-Wesley Press, Inc., 1950. P. 76.

Gibbs, F. A., & Gibbs, E. L. Clinical and pharmacological correlates of fast activity in EEG. Journal of Neuropsychiatry, 1962, 3, 73-78.

Gibbs, F. A., & Gibbs, E. L. Medical electroencephalography. Reading, Mass.: Addison-Wesley Publishing Company, 1967. P. 17.

Gibbs, F. A., & Grass, A. M. Frequency analysis of electroencephalograms. Science, 1947, 105, 132-137.

Gibbs, F. A., & Knott, J. R. Growth of the electrical activity of the cortex. Electroencephalography and Clinical Neurophysiology, 1949, 1, 223-229.

Gibbs, F. A., & Lorimer, F. M. Clinical correlates of exceedingly fast (30-40 per sec) activity appearing chiefly in drowsiness. Electroencephalography and Clinical Neurophysiology, 1950, 2, 226.

Gibbs, F. A., & Maltby, G. L. Effects on the electrical activity of the cortex of certain depressant and stimulant drugs - Barbiturates, morphine, caffeine, benzedrine, and adrenalin. Journal of Pharmacology and Experimental Therapeutics, 1943, 75, 1-10.

Gibbs, F. A., Williams, D., & Gibbs, E. L. Modification of the cortical frequency spectrum by changes in Co, blood sugar, and 02. Journal of Neurophysiology, 1940, 3, 49-58.

Gloor, P. Hans Berger on the electroencephalogram. Electroencephalography and Clinical Neurophysiology, 1969, Suppl. 28, 227-228, 316, 282, 86, 73.

Goldstein, M., & Nicotra, L. Spectral analyser for EEG. Electroencephalography and Clinical Neurophysiology, 1961, 13, 475-477.

Grandstaff, N. W. The relationship between 40 cps EEG activity and learning in the cat. Unpublished doctoral dissertation, University of Houston, 1965.

Grass, A. M., & Gibbs, F. A. A Fourier transform of the electroencephalogram. Journal of Neurophysiology, 1938, 1, 521-526.

Grindel, O. M. Evidence from analysis of the human electroencephalogram. Electroencephalography and Clinical Neurophysiology, 1965, 19, 419.

Hall, R. A., Yeager, C., & Yarbrough, R. B. Observation on high frequency electroencephalograms. Electroencephalography and Clinical Neurophysiology, 1967, 22, 262-265. (a)

Hall, R. A., Yeager, C., & Yarbrough, R. B. Preliminary observations on high frequency EEGs. Electroencephalography and Clinical Neurophysiology, 1967, 22, 291. (b)

Hernandez-Peon, R., Lavin, A., Alcocer-Guaron, C., & Marcelin, J. P. Electrical activity of the olfactory bulb during wakefulness and sleep. Electroencephalography and Clinical Neurophysiology, 1960, 12, 41-58.

Hix, L. B. 20 and 40 c/sec power functions in the visual, motor, and auditory cortices of the cat during three levels of performance in a successive visual discrimination task. Unpublished masters thesis, University of Houston, 1969.

Hoefer, P. F. A., Markey, C., & Schoenfeld, R. L. A method for automatic analysis of the electroencephalogram. Electroencephalography and Clinical Neurophysiology, 1949, 1, 357-363.

Hughes, J. R., Hendrix, D. E., Wetzel, N., & Johnston, S. W., Jr. Correlations between electrophysiological activity from the human olfactory bulb and the subjective response to odiferous stimuli. Electroencephalography and Clinical Neurophysiology, 1970, 28, 97-98.

Hughes, J. R., & Mazurowski, J. A. Studies on the supracollosal mesial cortex of unanesthetized conscious animals. II. Monkey. B. Responses from the olfactory bulb. Electroencephalography and Clinical Neurophysiology, 1962, 14, 635-645.

Il'Ianok, V. A. A method for studying high-frequency potentials of the electroencephalogram. Biophysics, 1960, 5, 555-561.

Irger, I. M., Koreisha, L. A., & Tolmass Raya, E. S. The electrical potentials of the cerebellum in man. Voprosy Neirochirurgicii, 1949, 5, 34-38.

Jasper, H. H. Electrical potentials from the intact human brain. Science, 1935, 81, 51-53.

Jasper, H. H. Electrical signs of cortical activity. Psychological Bulletin, 1937, 34, 411-481.

Jasper, H. H., & Andrews, H. L. Human brain rhythms: I. Recording technique and preliminary results. Journal of General Psychology, 1936, 14, 98-126.

Jasper, H. H., & Andrews, H. L. Electro-encephalography: III. Normal differentiation of occipital and pre central regions in man. Archives of Neurology and Psychiatry, 1938, 39, 96-115.

John, E. R., & Killam, K. F. Electrophysiological correlates of avoidance conditioning in the cat. Journal of Pharmacology and Experimental Therapeutics, 1959, 125, 252-274.

Kaufman, L., & Price, R. The detection of cortical spike activity at the human scalp. IEEE Transactions on Bio-Medical Engineering, 1967, BME-14, 84-90.

Kennard, M. A., Rabinovitch, M. S., & Fister, W. P. The use of frequency analysis in the interpretation of the EEGs of patients with psychological disorders. Electroencephalography and Clinical Neurophysiology, 1955, 7, 29-38.

Kennard, M. A., & Schwartzman, R. E. A longitudinal study of changes in EEG frequency pattern as related to psychological changes. Journal of Nervous and Mental Diseases, 1956, 124, 8-20.

Khavkina, N. N. Functional characteristics of centre in relation to the formation of a dominant state in man. Sechenov Physiological Journal of the USSR, 1958, 44, 834-842.

Knott, J. R. Brain potentials during silent and oral reading. Journal of General Psychology, 1938, 18, 57-62.

Knott, J. R. Automatic frequency analysis. Third International EEG Congress, 1953, 17-25.

Knott, J. R., Correll, R. E., & Shepherd, J. V. Frequency analysis of electroencephalograms of stutterers and nonstutterers. Journal of Speech and Hearing Research, 1959, 2, 74-80.

Knott, J. R., Gibbs, F. A., & Henry, C. E. Fourier transforms of electroencephalogram during sleep. Journal of Experimental Psychology, 1942, 31, 465-477.

Knott, J. R., & Travis, L. E. A note on the relationship between duration and amplitude of cortical potentials. Journal of Psychology, 1937, 3, 169-172.

Knott, J. R., Woolery, A., & Randall, J. Construction notes on an equivalent of the Walter analyser. Electroencephalography and Clinical Neurophysiology, 1951, 3, 91-96.

Kozhevnikov, V. A. Some methods of automatic measurement of the electroencephalogram. Electroencephalography and Clinical Neurophysiology, 1958, 10, 259-278.

Leese, H., Heath, R. G., Mickle, W. A., Monroe, R. R., & Miller, W. H. Rhinencephalic activity during thought. Journal of Nervous and Mental Diseases, 1955, 122, 433-440.

Loomis, A. L., Harvey, E. N., & Hobart, G. Electrical potentials of the human brain. Journal of Experimental Psychology, 1936, 19, 249-279.

MacLean, P. D., & Delgado, J. M. Electrical and chemical stimulation of frontotemporal portion of limbic system in waking animals. Electroencephalography and Clinical Neurophysiology, 1953, 5, 91-100.

Mark, D. D. Electromyographic interference in the human electroencephalogram. A study of the effect of mild curarization. American Journal of Physiology, 1947, 149, 538-548.

Matoušek, M. Automatic analysis in clinical electroencephalography. Psychiatric Research Institute, Research Report, Number 9, Prague, 1967, P. 37.

Matoušek, M. Frequency analysis of routine electroencephalography. Electroencephalography and Clinical Neurophysiology, 1968, 24, 365-373.

Meister, M., Schwab, R. S., Petersen, E., & Grass, B. S. Simultaneous two channel frequency analyzer with non-electronic (passive) filters. Electroencephalography and Clinical Neurophysiology, 1959, 11, 594-600.

Miller, R. G., Jr. Simultaneous statistical inference. New York: McGraw-Hill, 1966. Pp. 172-175.

Mil'shtein, G. I. A combined electrophysiological investigation on the effect of physical exercise on the functional state of the central nervous system. *Pavlov Journal of Higher Nervous Activity*, 1960, *10*, 536-543.

Motokizawa, F., & Fujimori, B. Fast activity and DC potential changes of the cerebral cortex during EEG arousal response. *Electroencephalography and Clinical Neurophysiology*, 1964, *17*, 630-637.

Mundy-Castle, A. C. Theta and Beta rhythm in the electroencephalograms of normal adults. *Electroencephalography and Clinical Neurophysiology*, 1951, *3*, 477-486.

Mundy-Castle, A. C. Electrical responses of the brain in relation to behavior. *British Journal of Psychology*, 1953, *44*, 318-329.

Mundy-Castle, A. C. The electroencephalogram and mental activity. *Electroencephalography and Clinical Neurophysiology*, 1957, *9*, 643-655.

Pagano, R. B. The effects of central stimulation and nasal air flow on induced activity of olfactory structures. *Electroencephalography and Clinical Neurophysiology*, 1966, *21*, 269-277.

Pagano, R. B., & Gault, F. P. Amygdala activity: a central measure of arousal. *Electroencephalography and Clinical Neurophysiology*, 1964, *17*, 255-260.

Pavlov, L. P., & Tochilov, K. S. The electroencephalographic characteristics of paired functioning of the cerebral hemispheres of man during muscular work. *Sechenov Physiological Journal of the USSR*, 1960, *46*, 907-917.

Peneul, T. L., Corbin, F., & Bickford, R. G. Studies of the electroencephalogram of normal children: Comparison of visual and automatic frequency analysis. *Electroencephalography and Clinical Neurophysiology*, 1955, *7*, 15-28.

Perez-Borja, C., Bickford, R. G., Tyce, F. A., & McDonald, C. Depth electrographic studies of a focal fast response to sensory stimulation in the human. *Electroencephalography and Clinical Neurophysiology*, 1961, *13*, 148. (a)

Perez-Borja, C., Tyce, F. A., McDonald, C., & Uihlein, A. Depth electrographic studies of a focal fast response to sensory stimulation in the human. *Electroencephalography and Clinical Neurophysiology*, 1961, *13*, 695-702.

Plutchik, R. Frequency analysis of electroencephalographic rhythms in humans exposed to high intensity intermittent auditory inputs. *Perceptual and Motor Skills*, 1966, *23*, 955-962.

Rappoport, D. A. RNA conformation with olfactory stimulation in fish. *National Institute of Health Progress Report*, Bethesda, Maryland, 1965.

Regan, D. A high frequency mechanism which underlies visual evoked potentials. Electroencephalography and Clinical Neurophysiology, 1968, 25, 231-237.

Rusinov, V. S. On the electroencephalographic reflexion of the process of irradiation and of the reciprocal relationships prevailing during closure of a temporary connexion. Sechenov Physiological Journal of the USSR, 1960, 46, 1592-1604.

Sakhialina, G. R., & Mukhamedova, Ye. A. Changes in the electroencephalogram of man in the process of motor habit formation. Pavlov Journal of Higher Nervous Activity, 1958, 8, 459-466.

Sem-Jacobsen, C. W., Bickford, R. G., Dodge, H. W., & Petersen, M. C. Human olfactory responses recorded by depth electrography. Proceedings of the Staff Meetings of the Mayo Clinic, 1953, 28, 166-170.

Sem-Jacobsen, C. W., Petersen, M. C., Dodge, H. W., Jacks, Q. D., Lazarte, J. A., & Holman, C. B. Electrical activity of the olfactory bulb in man. American Journal of Medical Science, 1956, 232, 243-251. (a)

Sem-Jacobsen, C. W., Petersen, M. C., Dodge, H. W., Jr., Lazarte, J. A., & Holman, C. B. Electroencephalographic rhythms from the depths of the parietal, occipital, and temporal lobes in man. Electroencephalography and Clinical Neurophysiology, 1956, 8, 263-278. (b)

Sem-Jacobsen, C. W., Petersen, M. C., Lazarte, J. A., Dodge, H. W., & Holman, C. B. Electroencephalographic rhythms from the depths of the frontal lobe in 60 psychotic patients. Electroencephalography and Clinical Neurophysiology, 1955, 7, 193-210.

Sheer, D. E. Electrophysiological correlates of memory consolidation. In G. Ungar (Ed.), Molecular mechanisms in memory and learning. New York: Plenum Press, 1970, in press.

Sheer, D. E., Benigus, V. A., & Grandstaff, N. W. 40 c/sec electrical activity in the brain of the cat: V. Pattern relations between visual cortex and behavioral response learning. Paper presented at the Symposium on Higher Nervous Activity, IV World Congress of Psychiatry, Madrid, 1966. (a)

Sheer, D. E., & Grandstaff, N. W. Computer-analysis of electrical activity in the brain and its relation to behavior. In F T. Wycis (Ed.), Current research in the neurosciences. Switzerland: Karger Press, 1969, Vol. 10.

Sheer, D. E., Grandstaff, N. W., & Benignus, V. A. Behavior and 40 c/sec electrical activity in the brain. Psychological Reports, 1966, 19, 1333-1334. (b)

Shtiurmer, E. B. Importance of the process of rate assimilation in the formation of a motor stereotype in man as shown by the results of electroencephalographic analysis. Sechenov Physiological Journal of the USSR, 1958, 44, 821-828.

Siegel, S. Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill, 1956. Pp. 166-173.

Soloqub, E. B. Changes in the EEG of man produced by muscular work. Sechenov Physiological Journal of the USSR, 1960, 46, 917-928.

Soloqub, E. B., Lefsgart, P. F., Ukhtomskii, A. A., & Zhdanov, A. A. Regular spike rhythm in the EEG of man. Sechenov Physiological Journal of the USSR, 1961, 47, 29-35.

Spilker, B., Kamiya, J., Callaway, E., & Yeager, C. L. Visual evoked responses in subjects trained to control alpha rhythms. Psychophysiology, 1969, 5, 683-695.

Sundestein, J. W., & Sawyer, C. H. Electroencephalographic evidence of osmosensitive elements in olfactory bulb of dog brain. Proceedings of the Society for Experimental Biology and Medicine, 1959, 101, 524-527.

Takagi, S. F., & Shibuya, T. Studies on the potential oscillations appearing in the olfactory epithelium of the toad. Japanese Journal of Physiology, 1961, 11, 23-27.

Thompson, L. W., & Obrist, W. D. EEG correlates of verbal learning. II. Period Analysis. Electroencephalography and Clinical Neurophysiology, 1963, 15, 159.

Thompson, L. W., & Obrist, W. D. EEG correlates of verbal learning and overlearning. Electroencephalography and Clinical Neurophysiology, 1964, 16, 332-342.

Travis, L. E., & Knott, J. R. Brain potentials from normal speakers and stutterers. Journal of Psychology, 1936, 2, 137-150.

Verdeaux, G., Verdeaux, J., & Turmel, J. Statistic study of the frequency and reactivity of the EEG in the elderly. Canadian Psychiatric Association Journal, 1961, 6, 28-36.

Volavka, J., Matousek, M., & Roubíček, J. Mental arithmetic and eye opening. An EEG frequency analysis and GSR study. Electroencephalography and Clinical Neurophysiology, 1967, 22, 174-176.

Walter, D. O. Spectral analysis for electroencephalograms: Mathematical determination of neurophysiological relationships from records of limited duration. Experimental Neurology, 1963, 8, 155-181.

Walter, W. G. An automatic low frequency analyzer. Electronics and Engineering, 1943, 16, 3-13.

Walter, W. G. Technique-Interpretation. In D. Hill and G. Parr (Eds.) Electroencephalography: A symposium on its various aspects. New York: The MacMillan Company, 1963. P. 87.

Wooley, D. E., & Timiras, P. S. Prepyriform electrical activity in the rat during high altitude exposure. Electroencephalography and Clinical Neurophysiology, 1965, 18, 680-690.

Yoshii, N., & Hockaday, W. J. Conditioning of frequency-characteristic repetitive electroencephalographic response with intermittent photic stimulation. Electroencephalography and Clinical Neurophysiology, 1958, 10, 487-502.