

THE RELATIONSHIP BETWEEN CORTICAL ELECTRICAL
ACTIVITY AND DISCRIMINATION LEARNING
IN THE CAT

A. Thesis

Presented to
the Faculty of the Department of Psychology
University of Houston

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

By
Richard Lou Miller
August, 1968

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ABSTRACT

A detailed analysis of five band widths in the EEG of the cat was carried on the motor, visual and auditory cortices during a two-stage visual discrimination learning situation. The band widths had central frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0 cps.

Continuous EEG records were taken during acquisition of the simple and complex learning situation. These were simultaneously recorded on tape and computer analyzed.

The analysis yielded summary averages for the 10 second pre-stimulus, stimulus, and post-stimulus periods of the central frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0 for the auditory, motor, and visual cortices. The analysis also broke the trials into one of four conditions: 1-trial was a S_D with a response made; 2-trial was a S_D with no response made; 3-trial was a S_A with response made; and 4-trial was a S_A with no response made.

The results of the complete analysis were as follows:

1. The motor and auditory cortices showed no significant relationships during this learning situation. No significant differences existed between the pre-stimulus and stimulus periods in any frequency for either cortex under any of the four conditions.
2. The visual cortex analysis showed an significant inverse relationship between the 20 cps activity and 31.5, 40.0,

and 50.0 cps bands under condition one; 20 cps consistently decreased during the stimulus period from its pre-stimulus level, as the three higher bands increased.

3. Under conditions two, three, and four, in the visual cortex results varied with little significance. Condition two can only contribute doubtful conclusions because it is represented by very small sample sizes that may well be biased. Conditions three and four fail to show significant changes in the five frequencies..

It was concluded that some form of inverse relationship exists between the 20 cps activity and the 31.5, 40.0, and 50.0 cps band, the cause of which will necessitate further research in this area.

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CHAPTER I.

STATEMENT OF THE PROBLEM.

To understand behavior, one needs to understand neural and biochemical processes that are active as an organism learns. A valid, pertinent question which one might ask is whether a common mechanism or sequence of physiological events might characterize all learning. Further, one might inquire if there is an establishable relationship between or among processes during this acquisition stage.

The measureable property of neural processes is the electrical activity of the brain. And, if electrical activity as recorded by the EEG bears some lawful relationship to neural processes, then specific local EEG changes should occur during the process of concept formation or learning.

The research area investigated by this experimenter arose from findings in the University of Houston laboratory (Grandstaff, 1965) in which evidence of 40 cps electrical bursting activity was observed in the primary projection area of the visual cortex. Related to these results was earlier research locating 40 cps activity in the amygdala. (Sheer, 1961; Sheer, et al, 1963) This specific frequency varied in its contribution to the total band of power as a function of the degree of training the organism had achieved on a learning task.

Choosing the bands with central frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0, the experimenter wished to examine the contribution of each band width to the total broad band power in relation to cortical areas as a function of level of training. These areas were the motor cortex and the primary projection areas of the visual and auditory cortices.. Additionally, the experimenter had interest in uniform inter-relationships between these cortical areas during acquisition..

The EEG's for the areas were recorded on magnetic tape and analyzed for central frequency averages..

CHAPTER II.

REVIEW OF THE LITERATURE

The majority of research concerning investigation of electrophysiological characteristics of learning has one of two approaches to the problem. Either the studies are gross examinations of electrical shifts in the brain commensurate with stimulus input or acquisition of learning, with disregard for specific contributing frequencies, or the studies which relate to frequency specificity are directed toward subcortical areas such as the hippocampus, amygdala, entorhinal cortex, etc..

Relevant research in the problem area of this experimenter's interest is very slight and no immediately pertinent research could be located which elaborated on the degree to which specific frequencies contributed to the total electrical activity of the cortical areas of interest. Therefore, this review of the literature must, by necessity, concern itself with: 1) research findings of less specific studies of the electrophysiological characteristics of the cortical area of the motor, visual, and auditory systems, and 2) research relating to sub-cortical areas in as much as some manner of frequency analysis has been carried out which can be related to this research. Reticular formation research is included in each section as is relevant.

Electrophysiological Characteristics of the Cortex

Many electrophysiological studies have observed that the cortical desynchronization response to the CS which had habituated is disinhibited when paired with either an aversive or appetitive UCS (Chow, 1961; Gastaut, 1957; Jouvet and Hernández-Peón, 1957). Conditioned cortical desynchronization appears prior to observable behavioral conditioned responses and extinguishes less rapidly than the overt peripheral response when reinforcement is withheld (Segundo, et al., 1959). The CS evokes generalized desynchronization in all areas of the cortex during the initial stages of conditioning. This response becomes centralized in the motor cortex as conditioning progresses and behavioral conditioned responses begin to appear.

Rabinovitch (1958) analyzed the activity of individual layers of the motor cortex and the projection area of the sense modality monitoring the CS during conditioning. His report was that initial pairings of CS - UCS increased the amplitude and frequency of the electrical activity of all cortical layers in the motor and sensory cortices. As the behavioral motor response began to appear, the electrophysiological increases tended to occur only in layer four of the auditory cortex and layer five of the motor cortex. Concurrent with the motor response itself, slow (2 to 3 cps)

potentials were seen in layer two of the motor cortex. Rabinovitch interpreted these potentials as being indicative of some inhibitory process, since CS presentations which occurred during the presence of these slow-wave potentials did not produce conditioned responses, even in highly-trained animals.

Matsumoto (1961) investigated rhythmic activity induced by arousal stimulation. He found that when "arousal" sensory stimulation or high frequency electrical stimulation of the reticular formation was applied, the electrical activity of the cerebellum changed from a low voltage, irregular pattern to more regular rhythmic 20 - 40 cps sinusoidal waves. This finding was consistent with the research of Gualtierotti and Capraro (1941) who first reported regular rhythmic 20 - 40 cps electrical activity on the cerebellar cortex of cats following stimulation of bulbopontine structures and corresponding afferent systems.

Matsumoto recorded simultaneously from the neocortex, hippocampus and the cerebellar cortex and discovered a marked parallelism of electrical events. The neocortex manifested a low voltage, fast wave form, while the hippocampus was characterized by regular, slow waves regardless of the source of stimulation. A differential effect was not observed between "arousal" sensory stimulation and high frequency electrical stimulation of the reticular formation. Matsumoto hypothesized that the mechanism for the rhythmic oscillation

of the cerebellar activity is related to the reticular formation of the brainstem by means of the reticulo-cerebellar connection.

Sakhiulina (1955) demonstrated that during the formation of conditioned responses (CR) in "electro-defense" training, an elevated fast-frequency is manifested in the EEG of the entire cortical surface investigated during the early stages of the CR formation and later is localized in the sensorimotor area as the CR's become more stabilized.

Then, in 1961, Sakhiulina pursued a study of changes occurring in the EEG of the dog during more complex forms of CR activity: shifting the site of application of the unconditioned stimulus, CR switching, and reversal of the signal significance.

In initial training stages, the EEG was characterized by a low level of background electrical activity, and application of the conditioned stimulus did not induce significant change in the pattern.

Two to three days after these experiments had begun, waves of considerable amplitude and regular diphasic form at frequencies of 25 or 30 cps were observed bilaterally in the EEG of the cortical sensorimotor areas. As these studies continued, the area of propagation of the 25 or 30 cps waves diminished and became localized in the anterior portion of the coronal gyrus of the hemisphere ipsilateral to the leg in which the CR was being developed.

When the CR was switched to another foot and this switch proceeded accurately, an elevated high-frequency activity between 25 and 40 cps was steadily recorded in the anterior portion of the anterior ectosylvian gyrus of one hemisphere next to the anterior portion of the coronal gyrus.

The areas in which stably elevated high frequency electrical activity was observed coincide to some degree to those cortical points that have the densest representation of areas of projection from the brainstem and thalamic reticular formations, or the cortical points that, when stimulated, induce an arousal effect via the reticular formation. This fact suggested to Sakhiulina that the stable, tonic nature of the activity of these areas is due to the influence of the reticular formation.

Reticular and Subcortical Considerations

The reticular influence, hypothesized to be the source of cortical low voltage, fast frequency electrical activity, also influences the EEG of sub-cortical structures.

Feindel and Gloor (1954) reported that stimulation of the reticular formation of cats produced synchronous bursts of approximately 20 cps. This activity was clearly demarcated in the posterior basolateral amygdala.

John and Killam (1960) recorded from both cortical and

subcortical structures during a conditioned avoidance learning situation. The areas were the visual cortex, auditory cortex, lateral geniculate, superior colliculus, amygdala, and hippocampus. Evoked frequency specific responses to the stimulus (a 10 cps flickering light) faded and then disappeared during a habituation process. Shock was then paired with the conditioned light stimulus and all structures, except the amygdala and hippocampus, reflected the frequency specific response once again. Only during the final stages of the conditioned avoidance task did the 40 cps bursting activity become evident in the amygdala.

Lesse (1960) reported that a highly synchronous 40 - 50 cps high voltage activity could be elicited by amny stimulus situations. It was uncorrelated with arousal from sleep or alerting or attention actions. These stimuli evoked only the typical arousal response in the cortex. When an organism reacted to meaningful stimuli, such as food, reward, or aversive stimuli, the synchronous bursting occurred in the amygdala and pyriform areas. This activity was restricted to the basolateral portion of the amygdaloid nucleus and adjacent pyriform cortex and was not observable in more medial portions of the amygdala or septal nuclei. Lesse related this phenomenon to meaningful stimuli. In 1957, Lesse recorded 40 cps synchronous activity in the amygdala during a shuttle box avoidance situation. The 40 cps EEG appeared initially only in response to shock, but was later observed

in response to the conditioned stimulus..

The relationship between the amygdala and the cortex is reflected in a study by Sheer, Benignus, and Grandstaff (1963). EEG recordings were taken from bilateral electrode sights in the basolateral amygdala and temporal cortex (mid-ectosylvian) in a series of cats, subjected to a CS :: UCS learning situation in which the tone (CS) was paired with milk (UCS). Analysis of the resulting data by cross correlograms indicated the temporal cortex and amygdala showed a relationship during the first trials, with the presence of the novel, neutral stimulus, which disappeared following habituation in later trials. Early stages of learning reflected a consistent periodic relationship between the amygdala and temporal cortex which was not present after habituation.

Directly related to the Sheer, et al. results are the findings of Grandstaff (1965), in which she showed that in the visual cortex, a dominant band width, of which the central frequency is 40.0 cps, is associated with visual stimuli if the stimuli contain arousal properties. A neutral visual stimulus did not elicit 40 cps. activity, consequently a more meaningful association must be made to the stimulus through its formation as a secondary reinforcer.

CHAPTER III.

METHODS AND PROCEDURES

Subjects

The subjects were two mature male cats secured from the city pound. Their weights varied between eight to twelve pounds. Upon selection from the pound each animal was inoculated with a standard dosage of Feline Distemper Vaccine and placed in isolation for a period of seven days. Permanent housing for the animals was provided in the vivarium at the psychology laboratory. Normal diet consisted of dry food pellets and free access to water prior to training. Water deprivation for the animals during training operated on a 23 ½ hour schedule, the half hour of free access provided immediately after daily training sessions..

Electrodes

Bipolar Electrodes. All electrodes were cortical in nature and utilized a bipolar construction. The electrode shafts were 30 gauge nichrome wire, which was pre-insulated by the manufacture. Proper electrical insulation was achieved by dipping in Epoxylite varnish and baking 45 minutes at 325°. For added security this procedure was repeated three

times.. The shafts of the two electrodes in the bipolar paralleled one another, with a separation of approximately one millimeter separating the two tips.. An area of approximately one millimeter was scraped away from the tip of the upper electrode and a surface area of one-half millimeter from the lower one, with care taken not to break the insulation between the two shafts. Approximately two inches of nichrome was allowed for contact to the AMP microminiature connector..

Connector. An AMP microminiature fifty-lead connector was used for terminal contact to the electrode leads.. To affect adequate contact, gold pins were crimped to the two inch electrode leads, which were then inserted into the connector plug. The entire assembly was then attached to the skull by means of two stainless steel screws which were anchored by means of a keyhole technique and then secured with dental acrylic.

Surgery

Electrode Implantation. All instruments were sterilized in zephiran chloride solution to minimize the possibility of infection.

Sodium pentobarbitol was injected into the liver, or diffused in the peritoneal cavity. Dosage of the drug was determined on the basis of the cat's body weight. To

maximize protection against infection, the animal was given an injection of 300,000 units of dystricillin prior to surgery.

The incision site was bared with electric clippers, scrubbed with surgical soap, and cleansed with alcohol. Two c.c. of 2.5% Procaine Hydrochloride, a local anesthetic was injected subcutaneously into the incision area.

The animal was placed in a Johnson stereotaxic instrument and injected with one c.c. of Klot, a blood coagulant. A medial sagittal incision was made, baring the medial cranium. All periosteum was scraped laterally to expose the desired areas. These areas were precalculated according to the stereotaxic atlas of Jasper and Ajmone-Marsan (1954) and previous research by Grandstaff (1965). Coordinates were marked on the skull by pen, which was secured in the carriage of the stereotaxic instrument. Trephinations for the cortical electrodes were made with a two millimeter dental drill burr. All sites were drilled prior to the onset of implantation. The procedure for implantation of the electrodes was as follows: each electrode was lowered to the point of contact with the dura mater. Then further penetration was made until two millimeters of the shaft were implanted in the cortex. The electrode was then secured to the skull with dental acrylic cement. Upon completion of all electrode implantations, the two stainless steel anchor

screws were cemented into their keyhole openings. The pins on the terminal ends of the electrodes were inserted into the connector plug in a predetermined pattern.

The connector was then attached to the anchor screws and fastened with nuts. All area beneath the connector was filled with dental acrylic. Scalp and tissue were then cleaned well with saline solution and alcohol, and then muscle layers and scalp were sutured anteriorly and posteriorly of the plug.

Bilateral placements were used, with placements in the striate cortex (Visual I), middle ectosylvian gyri (auditory I) and the motor cortex.

A recovery period of ten days was allowed for post-operative recovery before testing began.

Experimental Apparatus

Testing chamber. The experimental chamber was composed of a shielded, sound-proofed compartment located in a room adjacent to the recording facilities. One wall of the chamber was constructed with one-way vision glass so that the experimenter working with recording apparatus could observe the subject.

The custom-designed experimental box had inside dimensions of approximately 30 X 48 inches. Inside structure was white plexiglass and the outside was covered with formica.

The wall adjacent to the one-way window was clear plexiglass as was the removable partition which subdivided the chamber into two smaller cubicles..

The EEG cable passed through a metal sleeve centered in the ceiling of the right subdivision. The cable was held taut by a spring suspension system and a slip-ring which was mounted above the cubicle. This area above the cubicle (but still a part of the experimental chamber) housed the slip-ring assembly, two junction boxes for EEG leads, and assorted apparatus relevant to the cubicle.. The entire experimental assembly was effectively grounded from electrostatic interference by enclosure with copper screens..

Lights for illumination were mounted in the ceiling. Photic stimulators and auditory speakers were mounted on the end walls. The liquid feeder and bar were wall-mounted just below the photic stimulator.

Liquid feeder system. Milk was delivered to the cup in the experimental chamber through an external siphon system, controlled by a Skinner Electric solenoid valve. The valve had a 0.25 inch internal diameter and was company-rated at 10 psi. The liquid container and valve was located in the recording room and reached the chamber by plastic tubing extending from the solenoid valve into the box. The valve was operated by 24 volts, induced either manually or by lever press of the bar in front of the feeder cup. The lever,

when pressed triggered a micro-switch contact, closing the circuit to the solenoid valve. The valve allowed a .3 c.c. of liquid to be released with each contact.

Photic stimulator. The stimulator was a Grass model PS. 2. The stimulator produces flashes of controllable frequency and intensity. The photic stimulator was triggered by a Rheem Tape reader, for a reinforced frequency (S_D) of 7 cps and a non-reinforced frequency (S_A) of 3cps. The duration of the photic stimulation was ten seconds for each period. The intensity was 2.0 for both S_D and S_A events.

EEG cable. The EEG cable was a microminiature coaxial, steel center cable, manufactured by Microdot, Inc. The specific cable used, a miniature Trivax, reduced the self generated noise in cables to a scale greater than 100 to 1. The EEG cable was three feet long and contained fifty leads extending from the male connector, which made connection with the female plug on the cat's head, to the EEG junction box.

Control and timing apparatus. Programming was done on Foringer and Grayson-Stadler automatic control and timing equipment in conjunction with a Rheem Tape Reader. Digital counters recorded the behavioral responses and stimulus events for each testing session.

Rheem tape programmer. The Rheem Tape Reader was a commercially available model RR-301-RB, which is a photo cell tape reader for use with 5, 7, or 8 channel tape as an input. The tape reader activates circuits by an electronic signal

as the perforated tape passes under the focused beam of the reading lamp which covers the area of the photo cell. As a perforation appears, the photo cell is activated and in turn activates a corresponding circuit by means of an amplified signal. All events occurring in the experimental test situation were programmed in conjunction with the tape reader, Foringer equipment, and Grayson-Stadler programming equipment.

Electroencephalographic recorder. The electroencephalograph was a Grass, Model III D, seven-pin recording unit. In addition, two binary event pins were added, one to record the onset and termination of the photic stimulus events and the other to record bar pressing responses made by the cat.

Magnetic tape recorder system. The magnetic tape recorder system used was designed and constructed in this laboratory under supervision of the designer (Benignus, 1967) for recording bio-medical data which may be readily analyzed by electronic computer. The magnetic tape recorder's capacity was seven channels of analog information and eight channels of binary data. Each channel of analog information was represented by a specific frequency modulated carrier signal on tape. Each channel's signal was distinct with respect to frequencies of other channels. Direct signal recording was used for binary data channels.

Computer Analysis. The analysis of the EEG were performed on a hybrid computer system developed in the

University of Houston laboratory. Input to the computer was from an Ampex SP-300 tape recorder, which has seven analogue channels, as well as, modulation and demodulation facilities for eight event channels. The event channels record identification of pre-stimulus, stimulus, or post stimulus periods, number of behavioral responses, S_D or S_A trial identification, as well as, latency of the first response with a stimulus period.

Computer analysis was in two forms: 1) a Brush recorder model Mark 280 which has two analogue channels and three pins as event markers for indicating onset and termination of stimulus periods, and behavioral responses which occur contiguously with the EEG analysis on the analogue write-out; 2) a Hewlett-Packard digit voltmeter and related apparatus necessary for analog to digital conversion and digital printout to a mechanism which controls an IBM 026 card punch. The cards are automatically punched for further analysis in a SDS Sigma 7 computer.

The hybrid computer provided normalized power spectra at specified frequency bands with center frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0 cps for pre-stimulus, stimulus, and post-stimulus periods, each of which was 10 seconds in duration.

Experimental Procedure

There was one group of animals consisting of two male cats with electrode implantations. These animals were designated MVA I and MVA II.

Preliminary training as well as testing on Phase I (S_D) and Phase II (S_D/S_A) was automated with the use of Foringer, Rheem Tape Reader, and other equipment. Stimuli periods were of ten second durations and were presented on a variable interval schedule. The intertrial interval varied from 22 seconds to 38 seconds, with the average period being 30 seconds. The S_D was a 7 cps flashing light and the S_A was a 3 cps flashing light. Intensity level for both was 2.0. During Phase II, presentations of the stimuli occurred on a random basis with a 50/50 probability of the S_D occurring. The positive reinforcer was milk and was available only when the animal depressed the bar during the S_D presentation.

The animals were each tested on the same schedules. Both behavioral data and simultaneous EEG records (with accompanying magnetic tape recording) were taken for both Phase I and Phase II. For computer analysis, the data was recovered from the magnetic tapes.

Preliminary training. Deprivation schedules were maintained throughout training and testing. The cats each weighed 10 pounds and were given $\frac{1}{2}$ cup of dry pellet food daily. Liquid was withheld with the exception of that fluid received in training and testing sessions. When reinforced for appropriate response, the animal received 0.3 cc of milk

in the feeder cup.

During shaping, a small box designed to restrain inappropriate movement was inserted into the experimental cage. Bright overhead illumination was available until shaping criterion was satisfied. A masking tone was present in the experimental chamber throughout all testing at an intensity level of 65 decibels. Successive approximation was used in shaping bar pressing behavior in the animals. Shaping continued each session until response decrement was observed, but not to the point of satiation. Following the animal's successfully making two series of twenty consecutive self-reinforced bar presses, he was moved on to a continuous reinforcement (CRF) schedule.

With the onset of a CRF schedule, illumination in the cage was shifted to a dim, more distally located source, the shaping box was removed and the following criterion introduced: on day one, the animal was shifted to a fixed, ratio (FR) of 3 for 200 additional reinforcements after 100 CRF responses had been made; on day 2, after 50 CRF responses, the animal was shifted to a FR 5 for 250 additional reinforcements on a FR 5 schedule; on day four, the animal was on a FR 5 schedule for 300 reinforcers. Criterion was complete when the animal had completed the total series of schedules.

Testing: Phase I - Sp. Phase I consisted of the presentation of 50 Sp periods in each session. Each session began with the immediate onset of a reinforcement period. Daily

records of 1) total number of trials, 2) total number of responses, 3) total number of reinforcements, and 4) number of resets. The ten second period prior to the onset of the stimulus was the reset period. If the animal exceeded the designated number of responses in this reset period, a timer clock would reset for an additional ten seconds until a period lapsed without excessive responding.

The schedule of testing was established to the following criterion: on day one, all trials were presented with no reset; on day two, a FR 5 reset was installed; on day three and all subsequent sessions, a FR 3 was used.

Criterion was a ratio score between total responses and reinforcements. When the animal achieved an average ratio of 2.0 over three consecutive days, he was run three additional sessions and then shifted to Phase II.

Testing: Phase II -- S_D and S_Δ. Each session was initiated with three consecutive S_D periods to strengthen response perseveration. Sixty trials were run in each session without the use of the reset facility. Following the three S_D periods, the balance of the sixty trials were random presentations of either S_D or S_Δ characteristics. At the conclusion of the sixty trials, the cat had been presented thirty S_D periods and thirty S_Δ periods.

Daily records were kept for the following: 1) total number of responses, 2) total number of S_D and S_Δ trials,

3) number of responses during S_D periods, and 4) the number of responses during the S_A period. Behavioral characteristics of the animals during the sessions were also recorded.

Criterion was designated as a ratio score between the responses for the S_D periods and the responses for the S_A periods. When the animal has successfully averaged 3.0 for three consecutive days, criterion had been met.

CHAPTER IV

RESULTS

The data will be reported in two sections: 1) behavioral data, describing observable characteristics during acquisition in Phases I and II in the learning situation; 2) computer analysis data on comparisons between motor, auditory, and visual cortices, as well as, computer analysis data on comparisons between the five band widths, of which the central frequencies are 20.0, 25.0, 31.5, 40.0, and 50.0 cps.

Behavioral Data

The learning situation was comprised of two stages. In the first stage, the criterion to be met was three consecutive sessions which had an average ratio based upon intertrial responses over S_D responses of 2.0 or less. The measure of rate of acquisition was number of trials required to meet the above condition plus three additional blocks of 50 trials required for criterion. The rate of acquisition for the two animals on Phase I corresponded with expected results from previous studies. The animals required a mean of 600 trials to reach criterion. However, in Phase II, the behavioral characteristics of the two animals departed from

the expected results..

In Phase II, the criterion was an average ratio of 3.0 on the S_D responses over the S_A responses for three consecutive sessions. The measurement of learning was the number of trials required to reach criterion..

The average number of trials required to complete the task was 270, and the minimum possible number of trials to criterion was 180..

Computer Analysis of EEG Data

EEG records, as well as, electromagnetic tape recordings were taken throughout both Phase I and Phase II.. These magnetic tapes were then processed through the use of computer techniques. The analogue EEG leads for the visual, motor, and auditory cortices were fed through band width filters, 20.0, 25.0, 31.5, 40.0, and 50.0 center frequencies. The output of these filters was integrated for the three ten-second periods which represent pre-stimulus, stimulus, and post-stimulus durations. The total band width power was also integrated for the same periods to be used to specify relative contributions of each of the five band widths. These outputs were plotted on a two-channel Brush recorder, as well as, routed through an analogue-to-digital interface. The data were then punched onto IBM cards by an 026 key punch, automated by the A-D interface.. Further analysis

was carried out on a SDS Sigma 7 computer. The SDS analysis compiled the data and specified the averages for both frequencies and brain areas over a block of either 50 or 60 trials. The logic for the program for analysis, developed by R. B. Hoffman, can be found in Appendix A, and an example of summarized data is seen in Figure 1.

The computer program analyzes the trials based upon four conditions: trials in which the animal is confronted by a 7 cps stimulus (S_D) and responds; trials in which the animal does not respond when presented a 7 cps stimulus; trials in which a three cps stimulus (S_A) elicits a response; and trials in which a S_A stimulus does not elicit a response. For ease of future reference, the following code will be used throughout the balance of this paper: condition one = S_D with response; condition two = S_D wo/response; condition three = S_A with response; and condition four = S_A wo/response.

Only one of the three cortices under examination showed significant changes in the contributions of the frequencies in the broad band during S_D periods in which responses were recorded. (This condition was selected because it resulted in the greatest shifts in frequency contributions.) Both the motor cortex and the auditory cortex reflected non-significant shifts during the crucial stages of learning the discrimination tasks. Representation of these results can be seen in Figures 2 and 3. The abscissa in these

SUMMARY OF PROCESSED DATA FROM PROGRAM 1 FOR PRO						
AREA	COND	FREQ	-----BAND POWER-----			
		AVERAGES	PRE	STIM	POST	
MC L		--20.0--				
	1		0.63	0.57	0.57	
	2		0.55	0.72	0.62	
	3		0.64	0.58	0.64	
	4		0.66	0.65	0.58	
MC L		--25.0--				
	1		0.65	0.67	0.63	
	2		0.67	0.70	0.52	
	3		0.64	0.62	0.68	
	4		0.69	0.68	0.62	
MC L		--31.5--				
	1		0.69	0.67	0.66	
	2		0.77	0.65	0.62	
	3		0.65	0.64	0.69	
	4		0.70	0.67	0.66	
MC L		--40.0--				
	1		0.59	0.59	0.59	
	2		0.57	0.60	0.60	
	3		0.60	0.52	0.61	
	4		0.57	0.52	0.59	
MC L		--50.0--				
	1		0.46	0.48	0.46	
	2		0.55	0.47	0.42	
	3		0.42	0.46	0.46	
	4		0.48	0.46	0.46	

IBS-ESS FORMS, INC. - BEAUMONT, TEXAS 77706

FIGURE 1

AN EXAMPLE OF THE SUMMARY TABLE GENERATED
BY THE COMPUTER ANALYSIS PROGRAM
FOR THE SDS SIGMA 7

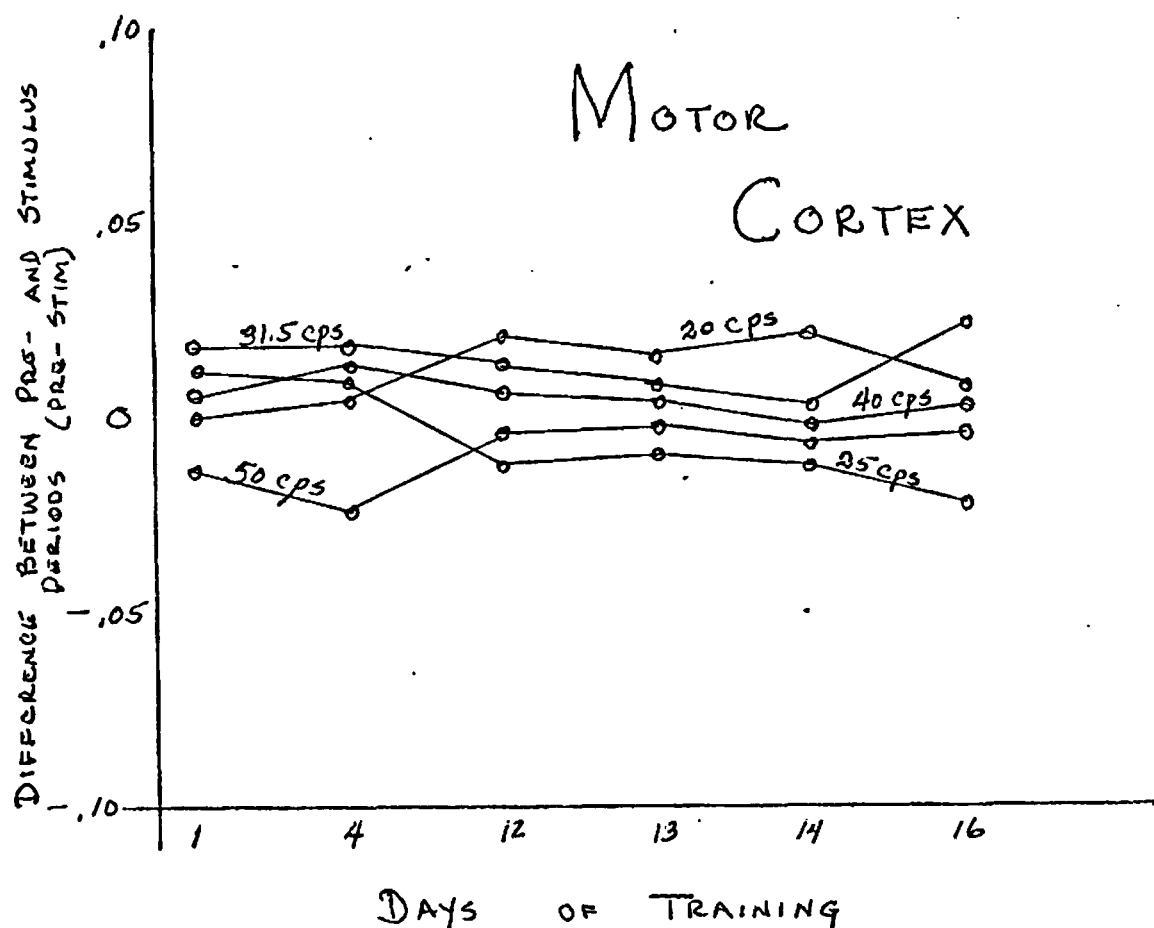


FIGURE 2
FREQUENCY ANALYSIS OF THE MOTOR CORTEX, SHOWING THE
DIFFERENCES BETWEEN STIMULUS AND PRE-STIMULUS
PERIOD FREQUENCY AVERAGES FOR FIVE
FREQUENCIES UNDER CONDITION ONE

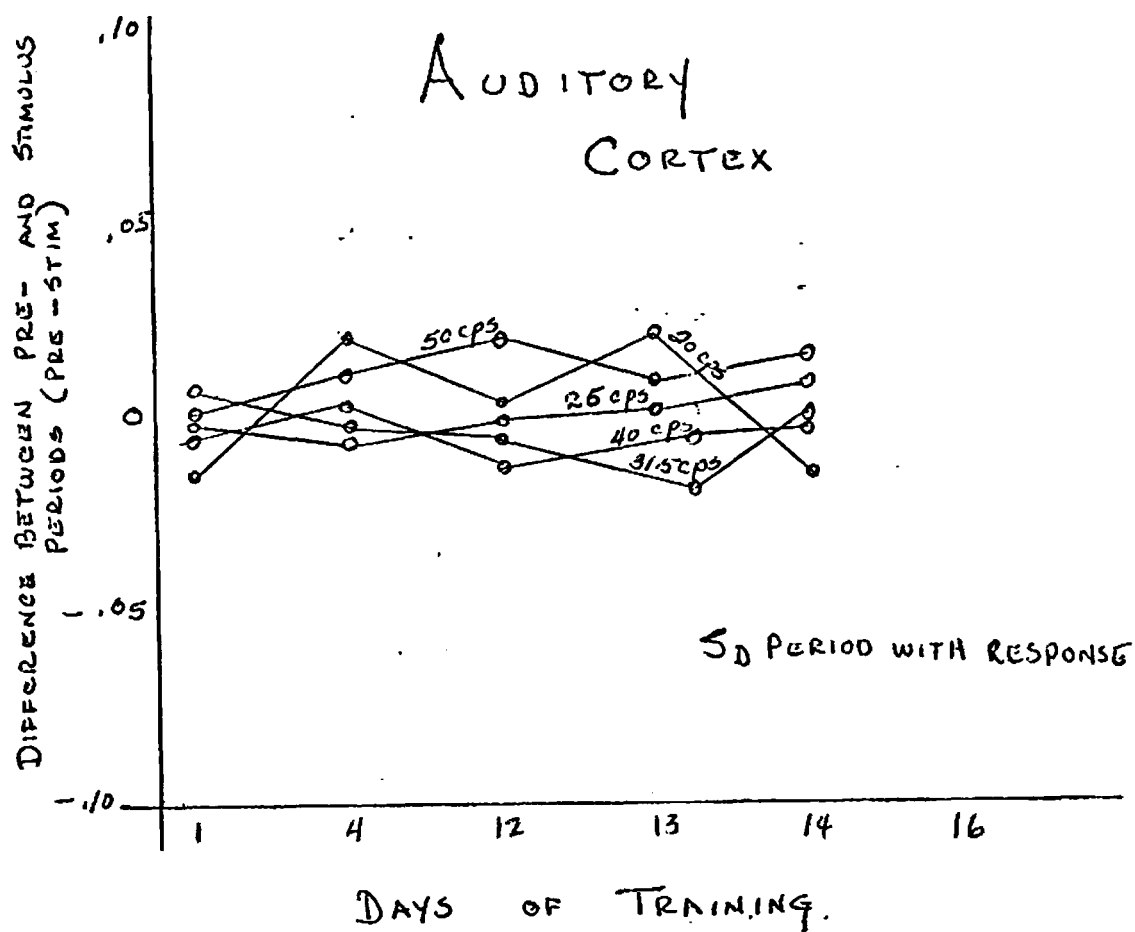


FIGURE 3

FREQUENCY ANALYSIS OF THE AUDITORY CORTEX, SHOWING
THE DIFFERENCE BETWEEN STIMULUS AND PRE-
STIMULUS FREQUENCY AVERAGES FOR FIVE
FREQUENCIES UNDER CONDITION ONE

figures represents the days of training in Phase I and Phase II. Days one through 12 are Phase I and represent the range of total training to the task. Day one reflects total unfamiliarity and day 12 is the last day of criterion; days 13 through 16 are Phase II, day 13 being the only day that criterion level was not met. The ordinate represents the difference between the normalized contribution of pre-stimulus period minus the stimulus period. As can be seen, no clear division exists between the relative contributions of the five frequencies over the full 16 days of training in either the motor cortex or the auditory cortex. Both pre-stimulus frequency averages and stimulus averages remained closely aligned under condition one. Consequently all further discussion will be directed toward the visual cortex in which significant results were found.

The visual cortex frequencies showed a different pattern of contribution under condition one. Figure 4 shows the changes in frequency from day to day. The legend for Figure 4 is the same as that for Figure 2 and 3. Following a relative "bunching" of frequencies on day one, the contributions of the frequencies strongly departed in succeeding days. The central frequency of 25.0 cps made little change from pre-stimulus to stimulus levels throughout the learning task; however, 20.0 cps activity declined significantly with training. As was expected from prior results (Grandstaff, 1965), the 40 cps electrical activity increased

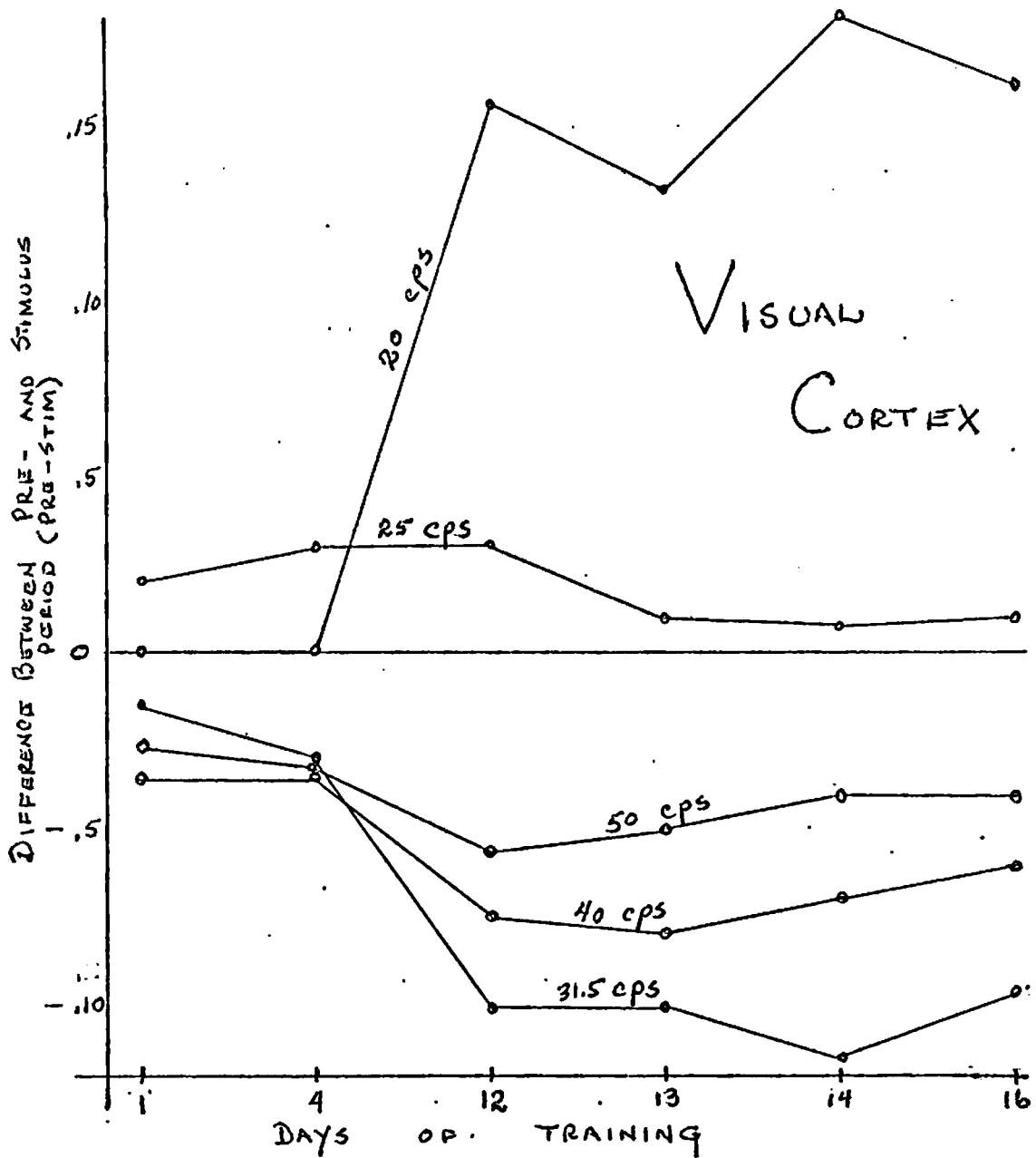


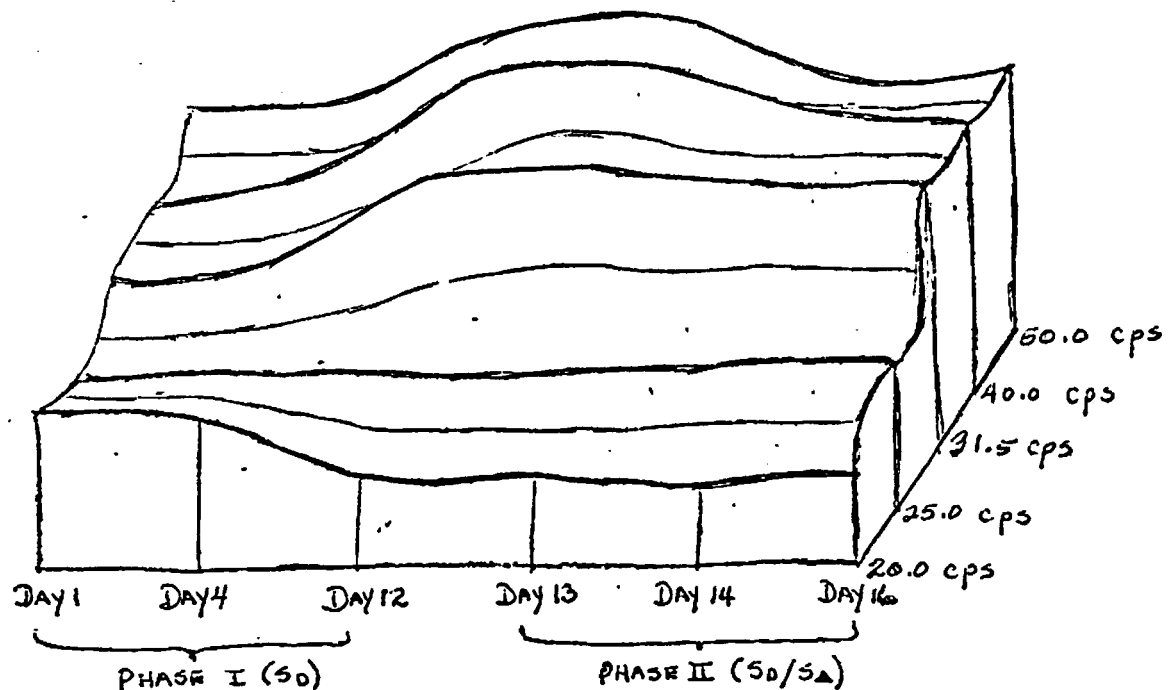
FIGURE 4

FREQUENCY ANALYSIS OF THE VISUAL CORTEX, SHOWING
THE DIFFERENCE BETWEEN STIMULUS AND PRE-STIMULUS
FREQUENCY AVERAGES FOR FIVE FREQUENCIES
UNDER CONDITION ONE

as acquisition of the learning set was made; however, both 31.5 and 50.0 cps activity also continued to increase appreciably.

Figure 5 examines these relationships between frequencies in the visual cortex by a slightly different measurement operation. The figure presented is a three-dimension representation of the frequency relationships from select days. The horizontal axis represents the span of days on which the EEG recordings were taken, and the diagonal axis represents the central frequencies considered. The vertical dimension represents the ratio of normalized stimulus averages over normalized pre-stimulus averages for condition one (SD with response).. As can be graphically seen by the figure, both band widths of 40 cps and 50 cps increased as the 20 cps activity decreased. The 25.0 cps band showed almost no variation, but the 31.5 activity increased slightly.

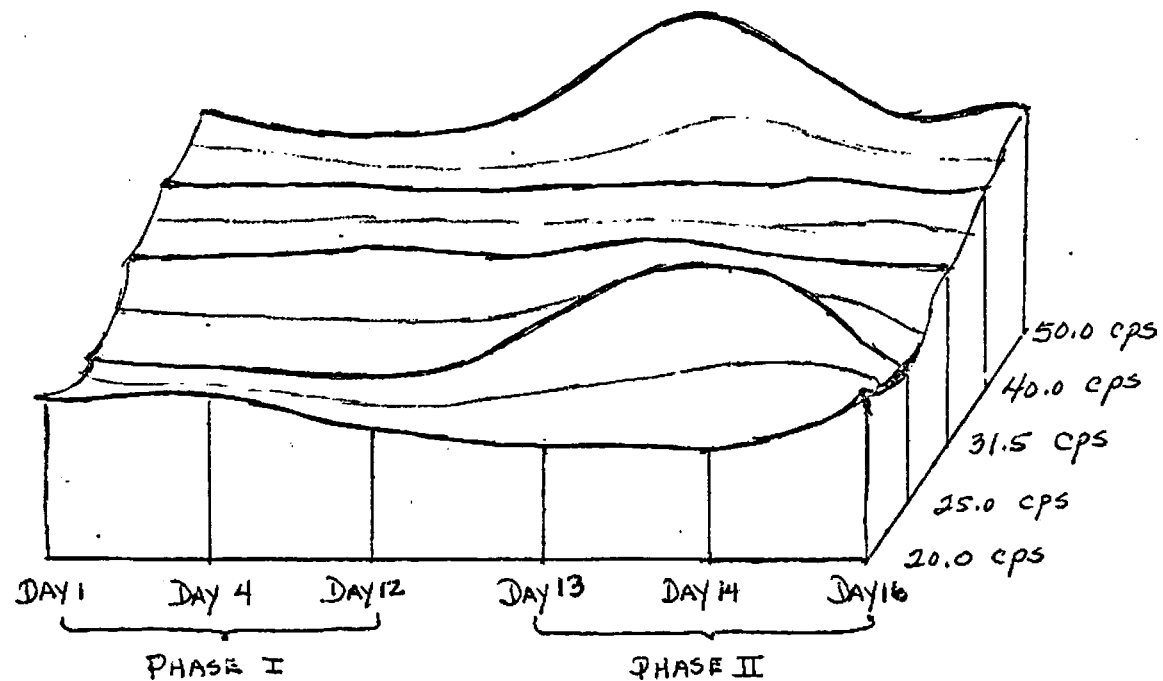
Analysis of condition two (SD with no response) in the visual cortex is seen in Figure 6. The legend again is the same as in Figure 5. The band width of 20 cps continues to show decline during advancing days, although not so dramatically. The 25.0 cps shows increase during days 13 and 14, which were the first two days of Phase II. Under condition two, 31.5 cps activity manifests no change, as is also the case in the 40.0 cps band width. Fifty cps activity remains high; however, none of the three highest bands resembles its dimension as seen in condition one, as represented in Figure 5.



VISUAL CORTIX
 S_0 WITH RESP.

FIGURE 5

THREE-DIMENSIONAL REPRESENTATION OF THE FREQUENCY SHIFTS
 IN THE VISUAL CORTEX UNDER CONDITION ONE. THE HORIZONTAL
 AXIS REPRESENTS FREQUENCIES, AND THE
 VERTICAL DIMENSION REPRESENTS A RATIO
 OF THE NORMALIZED FREQUENCY AVERAGE FOR THE STIMULUS PERIOD
 OVER THE PRE-STIMULUS
 PERIOD

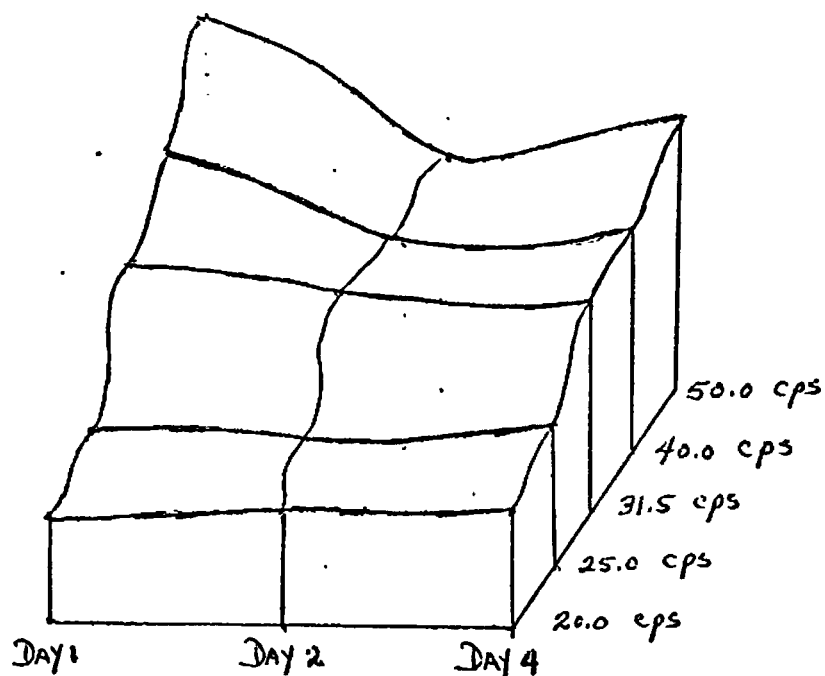


VISUAL CORTEX
SD WITHOUT RESPONSE

FIGURE 6

THREE-DIMENSIONAL REPRESENTATION OF THE FREQUENCY
SHIFTS IN THE VISUAL CORTEX BETWEEN THE PRE-
STIMULUS AND STIMULUS PERIODS UNDER
CONDITION TWO.. THE LEGEND IS
THE SAME AS FOR FIG. 5

Figures 7 and 8 are representative of the frequency averages of the visual cortex obtained for S_▲ trials with and without recorded responses. The results for the two figures are reasonably uniform; neither one reflects frequency shifts such as those seen under S_D conditions. The general dominance of the higher frequencies over 20 and 25 cps can be seen, as was evident in Figure 5. However, the clear separation between the upper band widths of 31.5, 40.0 and 50.0 cps remains more conspicuous in S_D trials with subject response than in S_▲ trials.



VISUAL CORTEX

5A WITH RESPONSE
PH. II

FIGURE 7

THREE-DIMENSIONAL REPRESENTATION OF THE
FREQUENCY SHIFTS IN THE VISUAL CORTEX
UNDER BETWEEN PRE-STIMULUS AND STIMU-
LUS PERIODS UNDER CONDITION THREE..

THE LEGEND IS THE SAME AS FOR
FIG. 5

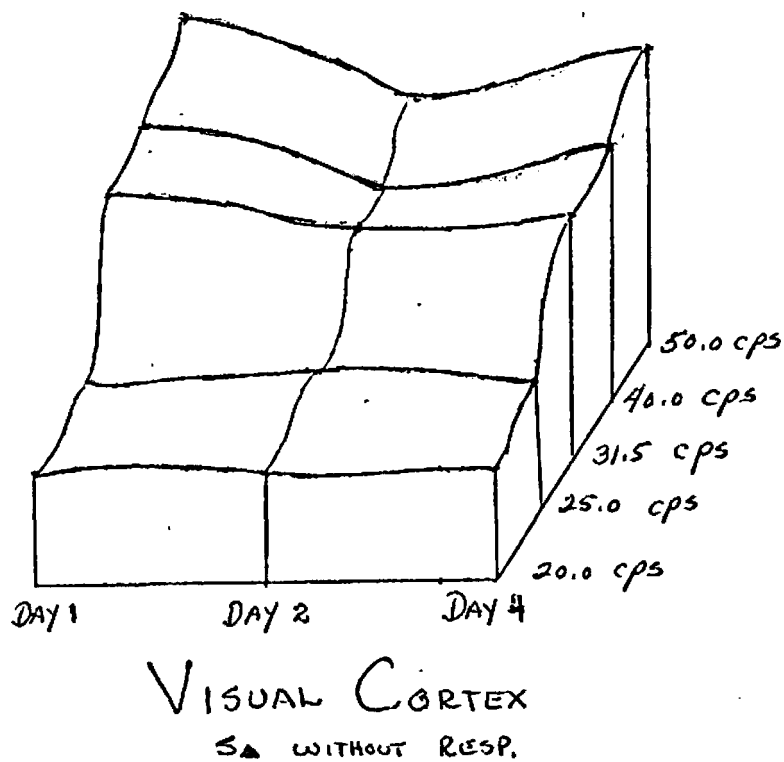


FIGURE 8

THREE-DIMENSIONAL REPRESENTATION OF THE
FREQUENCY SHIFTS IN THE VISUAL CORTEX
BETWEEN PRE-STIMULUS AND STIMULUS
PERIODS UNDER CONDITION 4

CHAPTER V.

DISCUSSION

The major aspects of the present study were the determination of meaningful relationships between frequency bands during pre-stimulus and stimulus periods, and supportable relationships between cortical areas during acquisition of the visual discrimination task.

The electrographic recordings obtained during these learning situations give little support to a meaningful relationship among the visual, motor, and auditory cortices. The only observable evidence of influence from this particular learning task on either the auditory or motor cortex was a slight increase in overall power as a function of the presence of the visual stimulus. This result was most likely attributable to a "photic driving" effect. The motor cortex remained very stable throughout the learning situation. Neither cortical driving by the stimulus or "meaningfulness" of the stimulus produced appreciable change between the pre-stimulus and stimulus period within or across days. The auditory cortex reflected similar results, consequently no substantial relationship could be established between or within the two cortices.

The frequency bands in the visual cortex proved to be the most fruitful areas of analysis. A reciprocal relationship

was observable between the 20.0 cps activity and the higher band widths, notably, 31.5 and 40.0 cps. To some extent, the 50 cps activity varied inversely to the 20.0 cps band also.

The rise during the stimulus period in 40 cps and 50 cps activity in the final stages of Phase I and early stages of Phase II, as well as, their slight decline on the last day of Phase II would support a theory for a rise of higher frequencies in the critical stages of acquisition as the animal forms strong secondary reinforcement properties, and a slight decline, as the animal habituates to the task.

The steady decline of the 20 cps activity also appears correlated with stage of learning. As the animal becomes more familiar with the task, there is an observable decline in the activity in that frequency band during the stimulus period in which the animal is rewarded. Unlike the higher frequencies, there was no slight recovery from the trend of the early acquisition days in the 20 cps band. The frequency remained at its lowest level throughout the last five days. Apparently, slight habituation does not aid recovery toward the earlier level, at which point, criterion in Phase I had not yet been met.

Analysis of conditions two, three, and four indicate that some measure of difference between stimulus period power levels and pre-stimulus period power levels is attributable to neural driving from the presence of the photic

stimulator; however, condition two should be cautiously approached before making definitive statements from its data. The animals missed responding in very few S_D trials, and when the period was bypassed, a variety of reasons could be offered. The lack of response in condition two came occasionally from satiation, lack of attention, or distraction. Any of these factors could distort the picture of the frequency outputs.

The present study indicates as its most prominent finding some form of reciprocal inverse relationship between the higher frequencies and the 20.0 cps band width. An explanation for the phenomenon is not available in this study. The experimenter can only suggest that comprehensive research in this area is necessary to elucidate a cause-and-effect relationship within the frequency bands.

CHAPTER VI

SUMMARY AND CONCLUSIONS.

A detailed analysis of five band widths in the EEG of the cat was carried on the motor, visual and auditory cortices during a two-stage visual discrimination learning situation. The band widths had central frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0 cps.

In Phase I of the learning task the animals were required to press a bar to obtain a milk reinforcer only in the presence of a 10 second, 7 cps S_D flickering light. The flickering light was presented on a VI schedule of thirty second duration. Sessions were run daily with 50 trials per session until the criterion of an average of 2.0 for three consecutive days was met. The 2.0 is a ratio of intertrial responses over S_D responses. Results recorded were: 1) number of trials to criterion; 2) number of intertrial responses; and 3) number of S_D responses.

In Phase II, the animals were forced to discriminate between a 7 cps and 3 cps (S_A) photic stimulus. Reinforcement was given only when a bar press took place during the 10 sec., 7 cps stimulus, at which time the animal received 0.3 cc of milk per bar press. The 7 cps and 3 cps stimuli were randomly and equally presented until 60 trials had occurred per day. The animals were run until they met criterion of an average of 3.0 for three consecutive days on

a ratio of S_D responses over S_A responses. The recorded results were: 1) number of trials to reach criterion; 2) number of S_D responses; 3) number of S_A responses; and 4) number of intertrial responses.

Continuous EEG records were taken during acquisition of the simple and complex learning situation. These were simultaneously recorded on tape and computer analyzed.

The analysis yielded summary averages for the 10 second pre-stimulus, stimulus, and post-stimulus periods of the central frequencies of 20.0, 25.0, 31.5, 40.0, and 50.0 for the auditory, motor, and visual cortices. The analysis also broke the trials into one of four conditions: 1-trial was a S_D with a response made; 2-trial was a S_D with no response made; 3-trial was a S_A with response made; and 4-trial was a S_A with no response made.

The results of the complete analysis were as follows:

1. The motor and auditory cortices showed no significant relationships during this learning situation. No significant differences existed between the pre-stimulus and stimulus periods in any frequency for either cortex under any of the four conditions.
2. The visual cortex analysis showed a significant inverse relationship between the 20 cps activity and 31.5, 40.0, and 50.0 cps bands under condition one; 20 cps consistently decreased during the stimulus period from its pre-stimulus level, as the three higher bands increased.

3. Under conditions two, three, and four, in the visual cortex results varied with little significance. Condition two can only contribute doubtful conclusions because it is represented by very small sample sizes that may well be biased. Conditions three and four fail to show significant changes in the five frequencies..

It was concluded that some form of inverse relationship exists between the 20 cps activity and the 31.5, 40.0, and 50.0 cps band, the cause of which will necessitate further research in this area..

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APPENDIX A.

FLOW CHART LOGIC FOR PROGRAM ANALYSIS.

D I M E N S I O N E D V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
BPWR	300	TOPWR	300	XNPWR	300	INR	300	XLAT	300
ICOND	300	ITRND	300	SPREB	65	SPRET	65	SPREN	65
PSTM3	65	PSTHT	65	PSTMN	65	PPREB	65	PPRET	65
PPREN	65	JS	20	A	10	ASPRE	3	APSTM	3
APPRE	3	ITEMP	4000	ABPWR	3	ATPWR	3	ANPWR	3
1STM	100	IDTRN	65	SAVP	504	SAVD	504	ICS	65
IBA	7	ICC	160	FRQ	10				

DOUBLE PRECISION IBA

