ELECTROENCEPHALOGRAPHIC THETA ACTIVITY AND ELECTROMYOGRAPHIC ACTIVITY DURING LEARNING

By

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CHAPTER I

INTRODUCTION

Recent studies with animals have shown that amount of theta (4-8 Hz) positively correlates with memory (Landfield, McGaugh & Tusa, 1972) and acquisition (Thompson, 1971). Recent studies of human theta activity have shown theta occurrence to be related to efficient auditory detection (Daniel, 1967), stimulus numerosity in a visual array (Gale, Coles & Boyd, 1971; Gale, Spratt, Christie & Smallbone, 1975), and arithmetic problem-solving and reading (Dolce & Waldeier, 1974). There are, however, no previous studies designed to assess the degree of relationship between short-term recall and occurrence of theta activity in humans.

Statement of the Problem

If theta is related to performance on short-term memory tasks, then an appropriate investigation of the relationship between theta and memory will need to examine theta levels during at least four critical points in time. These are:

Pre-task. A predisposition optimal for the perception and processing of material to be stored in memory may be reflected in the percentage of theta at a time before the actual task begins.

Presentation. Percentage of theta may vary as a function of accurate perception and processing of the verbal stimuli as they are being presented.

Post-presentation. In a period between presentation of the material, theta levels may reflect the transfer of information from short-term memory to a more permanent store, or perhaps the mental rehearsal of the material.

Recall. Levels of theta activity may reflect the active retrievel of the stored material. However, theta during this period may be confounded by muscular activation required for written or verbal recall.

Significance of the Problem

Although theta activity has shown to be a correlate of memory processes in animals, there has been no attempt to demonstrate this finding in humans. This study attempts to identify such a relationship, if one exists. The findings of the study will be used to guide further research into the applications of biofeedback training for enhanced mental functioning.

The applications of biofeedback training, regardless of the feedback modality, are primarily remedial in nature and medically oriented, at present. Little has been done in the applications of biofeedback in the areas of enhanced mental functioning and emotional adjustment. The present possibilities for improvement of the human condition within those areas through biofeedback training appear limited.

In addition, if theta is a correlate of learning and memory in humans, perhaps theta measurement may lend itself to the diagonostic evaluation of learning disabilities or memory dysfunctions. Moreover, with the use of biofeedback techniques, possible manipulation of brain wave activity could result in a mental state optimal for the receptivity, processing, storage or retrieval of material to be or already stored in memory.

Limitations

The focus of the following pages is a suggested relationship between electroencephalographic (EEG) activity and short-term memory processes. It is an extension of a line of research in the area of physiological psychology which examines physiological correlates of psychological phenomena. The study is best viewed as a preliminary and exploratory step in the search for applications of EEG feedback treatment.

CHAPTER II

REVIEW OF THE LITERATURE

For the convenience of both the reader and the writer, the review of literature is divided into two sections: those studies utilizing human subjects and those using animal subjects. First, however, background information regarding placement of electrodes and a cautionary note on generalization of data obtained from animals to humans seems appropriate.

Typically, EEG studies of animal behavior utilize the permanent placement of electrodes. Subcortical areas of the brain are often the desired sites for monitoring EEG or obtaining evoked potentials. When the cortex is the area of interest, electrodes are secured to the skull with cortical screws. In these techniques, the electrode is actually in contact with the brain structure of interest; thus recordings are extremely accurate and representative of electrical activity in that area.

Such obtrusive measures are hardly feasible in the study of normal EEG in humans. Human EEG studies generally employ pad, sponge or cup electrodes temporarily attached to the surface of the scalp. Also, surface electrode placement presents problems that must be controlled. Muscle movements of the scalp and eyes create electrical impulses that confound the recordings and the representiveness of cortical activity. Added to these typical differences in electrode placement are idiosyncracies particular to the various species that prevent the cautious investigator from readily generalizing animal data to human behavior. The intention of the present writer is not to generalize the animal data presented, but rather to use the findings as a heuristic guide in the study of human psycho-physiological phenomena.

Human Studies

Investigations of human EEG theta in relation to learning and memory are indeed scarce. Schacter (1977) provides a comprehensive review of theta and psychological phenomena, but only two studies are reviewed that deal directly with learning and memory. Schacter comments:

> two possibilities are suggested by the failure to observe theta increments during learning and memory tasks. One is that since all the above studies record EEG from posterior scalp regions, theta increments might be observed in frontal areas. The other possibility is that operations which elicit theta in problem solving and perceptual processing studies are not required in the above studies of learning and memory. Research is needed to explore these and other possibilities (p. 64).

Most of the studies reviewed in this section deal with theta incidentally rather than directly. Also, recording technique and electrode placement vary from study to study.

Basic to the proposed study and to an understanding of the nature of the human theta rhythm is a clarification of an ongoing debate concerning the general mental state associated with theta. One point of view asserts that theta is reflective of a non-attending, non-aroused, passive mental posture. The other suggests that theta is related to alertness, focused attention, and selective, effortful processing. For the sake of brevity, these hypotheses will be referred to as "non-aroused" and "aroused". There is evidence for both points of view, and the following studies will be reviewed in light of this distinction.

Beatty, Greenberg, Diebler and O'Hanlon (1974) trained two groups to voluntarily regulate level of occipital theta during a visual detection task. Using biofeedback, one group was trained to augment theta activity. Subjects were instructed to either augment or suppress theta throughout the task. The results showed that the suppressed group performed better than the augmented group on the visual detection task. This finding supports the non-aroused proposition; that is, higher levels of theta indicate non-arousal, non-attending, thus explaining the poorer performance of the augment group. However, the group differences may be a function of the relative ease of suppressing theta as compared to augmenting theta. The division of attention required for the simultaneous performance of the detection task and augmenting theta may be greater than suppressing theta. An investigation of the relative difficulty of augmentation and suppression would resolve this matter.

The Beatty et al. study deals solely with self-regulated theta which may be functionally distinct from theta activity occurring naturally in normal, alert subjects. Support for the aroused proposition is found in studies of resting, non-regulated EEG activity.

Gale, Coles and Boyd (1971) found that theta abundance increased as complexity of visual stimuli increased. Theta was monitored in five conditions: 1) eyes closed, 2) eyes open in the dark, 3) viewing a blank screen, 4) viewing a black circle on a white background, and 5) viewing a black circle with eight spokes. Theta abundance was greatest in the last two conditions. Gale, Spratt, Christie and Smallbone (1975), utilizing a similar design, found theta abundance to be directly related to stimulus numerosity or complexity. The results were interpreted as a function of the arousal value of the stimuli.

Daniel (1967) examined theta activity during an auditory detection task. Subjects were instructed to press a key when a critical series of digits appeared in an otherwise random sequence of digits. He found that in the three seconds preceding and following an incorrect response there was a significant decrease in theta activity. The decrease was observed in subjects with either high and low theta as well as high and low error subjects. These results are nearly the opposite of those obtained by Beatty et al. and suggest that increments in theta accompany selective and effortful processing.

Although there are no studies available designed to examine the relationship of theta to immediate or delayed free-recall, there are number of studies of alpha (8-12 Hz) and recall. A few of these will be mentioned briefly.

Gale, Jones and Smallbone (1974), as far as this writer is aware, published the first study designed to assess alpha changes during learning and the relationship to subsequent recall. Since then others have contributed (Bauer, 1976; Warren, Peltz & Haueter, 1976). The positive results obtained in Gale et al. (1974) have not been substantiated. In fact, the Warren et al. study obtained opposite results. It was found that initial bilateral reductions in alpha were assocated with increased recall. This may be important for this study in that reductions in alpha may be indicative of increased hippocampal theta activity (Gale et al.,1974). It may be that increased hippocampal theta is also reflected in the cortical theta activity. If the above is assumed to be true, then one would expect an increase in cortical theta activity under conditions similar to those in the Warren et al. study.

Animal Studies

Landfield et al. (1972) demonstrated a positive relationship between cortical theta and memory processes in rats. Rats were trained in a one-trial footshock retention task. Samples of EEG theta were recorded over a 30 minute period following training. Two days later, the rats were tested for retention of footshock. The results indicated that rats showing greater amounts of theta during the post-trial period had higher retention scores than rats with relatively low amounts of theta. Landfield et al. concluded:

> The degree of retention of a one-trial training experience varies with the amount of theta rhythm activity recorded during the period after training. Under these circumstances, theta may be a correlate of a brain state optimum for memory storage (p. 89).

The Landfield study was criticized for the arousal effects of footshock (Klemm, 1972) which may be more important for memory storage. The amount of theta might simply reflect individual differences in arousal to the stimulus rather than active memory storage processes.

To circumvent this criticism, Nichols, Gailbraith and Lewis (1976) employed an appetative learning task (apparently the individual differences are lessened by the appetative task). The findings "reconstruct the basic relationship between retention and amount of theta reported in Landfield " (p. 490).

On the basis of these studies, it appears that amount of theta may be critical for memory storage during the period between task acquisition and the subsequent test of retention. To test this suggestion, Wetzel, Ott and Matthies (1977) experimentally increased the amount of theta in rats during this post-trial period. Increased theta was accomplished through medial-septal stimulation. A stimulus frequency of 7 Hz was applied five minutes after training in a brightness discrimination task. Retention scores were obtained 24 hours later. Results showed increased retention scores as a result of the stimulated theta rhythm. Wetzel et al. concluded that synchronization of hippocampal EEG during a critical phase after training facilitates memory processes.

It is well known that certain drugs such as strychnine and pentolentetrazol facilitate memory. Landfield (1976) conducted a study to determine the effects of such drugs on the cortical EEG of rats. Doses of strychnine and pentolentetrazol were injected intraperitoneally. Cortical EEG was recorded for 20 minutes following injection. A control group received an injection of saline to determine the effects of injection alone. The findings indicate that both drugs increase delta (2-4 Hz) and 4-6 Hz theta rhythms. An interesting aspect of these drugs is that the 4-6 Hz theta band is increased at the apparent expense of the 6-8 Hz theta band. Landfield interpreted these findings as increased regularity and synchronization of the cortical theta rhythm.

Another study particularly relevant to this proposal was conducted by Berry and Thompson (1978). The findings showed pre-task hippocampal theta to be negatively correlated with trials to criterion for conditioning of the nicatating membrane response.

Clearly the above studies do not definitively describe the relationship of theta rhythm and memory processes. And clearly the generalization of findings from these studies to human behavior is risky. However, the data do provide some basis for the formulation of hypotheses describing the relationship of human memory processes and theta rhythm activity. Referring back to the human studies reviewed earlier, it becomes apparent that theta may be a viable EEG frequency range for the investigation of learning and memory processes.

CHAPTER III

METHODS

Subjects

Thirty subjects were recruited voluntarily from General Psychology, Educational Psychology and Biology courses held during the 1978 summer term at Kansas State University. Only right-handed volunteers (which suggests left-hemisphere dominance) between the ages of 18-28 were included in the study. Fifteen males and fifteen females participated.

Materials and Apparatus

Fifteen lists of twenty words provided the free-recall stimuli. The lists were randomly derived from 594 common words comprising the Toronto word pool (Murdock & Walker,1969).

All word lists were presented to all participants, binaurally, through a single speaker centered behind the subject's head, at a rate of two seconds from word onset to next word onset. Lists were recorded on Memorex tape and played through a Sony player/recorder.

Electromyographic activity (EMG) was monitored over the frontal area (forehead) using two active electrodes placed approximately 2 cm. above each eyebrow. A ground was centered with the bridge of the nose and horizontally located between the active electrodes. These sensors are imbedded in a rubber headband and secured around the head with velcro strips. An Autogen 1500 EMG in conjunction with an Autogen 5100 Digital Integrator was used to average and amplify EMG activity over the epochs of interest.

Theta EEG was recorded from the left hemisphere over the parietal cortex. Monopolar recordings were referenced to the left earlobe and grounded to the right earlobe. The active electrode was comparably placed at P_3 of the International 10-20 System (Jasper, 1958). An Autogen 120 Encephalograph Analyser was used to amplify and compute percentage of theta.

All instruments were battery operated ensuring no danger from electrical shock. These instruments have been used in the KSU Counseling Center's Applied Biofeedback Lab for four years.

Procedure

All volunteers were individually contacted and times for participation were arranged. Morning and afternoon sessions were conducted in a sound attenuating room. Subjects were tested individually and each required approximately 90 minutes.

Upon arrival at the laboratory the subjects were informed as to the nature of the recordings to be obtained and the memory task. Informed consent was obtained at this time (see Appendix A for the informed consent statement and the introduction to the study).

Placement sites (earlobes, forehead and scalp) were scrubbed with an abrasive jelly and wiped clean with alcohol. Both EMG sensors and EEG electrodes were cleansed in water and lightly scrubbed with a toothbrush. In addition, the scalp electrode was dipped in a saline solution to ensure proper contact. Then all electrodes were filled with Redux electrode paste and secured to the appropriate sites described earlier. Electrodes were checked for resistance values and replaced if above 10K ohms.

Repeated single-trial free-recall procedures were employed in three conditions. Recall conditions and instructions were as follows:

Immediate free-recall (IFR). Subjects were instructed to attend to each word in each of the lists as he/she would be asked to recall as many of the items as possible in any order. Five lists were presented. The first list served as warmup to assure the investigator that the participant understood the task.

Delayed free-recall (DFR_{30}). In this condition there was a 30-second delay between last word and beginning of written recall. Five lists were presented with one warmup.

Delayed free-recall (DFR_{60}). Condition DFR_{60} has a 60-second delay between the last word and the cue signalling recall. Again, five lists were presented, the first discounted.

For all conditions, the experimenter saying "recall" was the cue to begin written recall. Also, the phrase "ready for the next list" introduced the following list. Verbatim instructions for the tasks may be found in Appendix B.

Every recall condition followed every other approximately an equal number of times. The counter balancing of tasks controls for any fatigue, practice, or order effects.

Following each word list an inter-trial interval of 40 seconds provided a period for a leveling of muscle activity, which may have occurred as a result of the written recall, and a rest pause for the subjects before the next trial.

Recording of EMG and EEG required the subjects to be seated comfortably in a cushioned chair. Subjects were instructed to maintain a comfortable position, keep eyes open at all times, and to avoid all movement, particularly of the face, head and neck, throughout the recording session.

Theta was recorded every 10 seconds during a 15-minute baseline period, the presentation of the word lists, the delay periods (30 and 60 seconds), recall, and during the inter-trial interval (ITI_{40}).

Averaged frontalis EMG was recorded every 30 seconds over all of the above epochs.

All data were manually recorded readings taken from the Digital Integrator readout and EEG Analyser percent/time meter. Adjustable filters incorporated into the EEG Analyser were set at 4-8 Hz and the amplitude set at zero. Thus, all theta activity above zero amplitude registered on the percent/time meter.

Hypotheses

1) Mean number of all words correctly recalled is not related to mean percent/time theta obtained during baseline.

2) Mean number of words correctly recalled in IFR is not related to mean percent/time theta obtained during the presentation of word lists to be immediately recalled.

3) Mean number of words correctly recalled in DFR_{30} is not related to mean percent/time theta obtained during presentation of word lists.

4) Mean number of words correctly recalled in DFR_{60} is not related to mean percent/time theta obtained during the presentation of word lists.

5) Frontal EMG across all conditions is not related to percent/time theta across all conditions.

6) Number of words recalled in DFR_{30} is not related to mean percent/time theta during the delay of the corresponding list.

7) Number of words correctly recalled in DFR_{60} is not related to mean percent/time theta obtained during the delay period of the corresponding list.

Analyses

To test the above hypotheses Pearson product-moment correlations were computed. The .05 level was set for rejection of the hypotheses. In addition, graphic representations of theta activity and muscle activity during baseline and recall trials were drawn.

CHAPTER IV

RESULTS

Percentage theta (the time theta is dominant in the EEG, divided by the total time, multiplied by 100) was recorded every 10 sec during each of the following intervals: (a) baseline, (b) word presentation, (c) the intratrial inverval, (d) written recall, and (e) the intertrial interval. This procedure was followed for each of the 12 free-recall trials. Figure 1 presents the mean percentage theta for the baseline and each of the four portions of the trials. Figure 2 depicts the mean percentage theta for each one minute interval.

Measures of EMG were taken every 30 sec rather than every 10 sec, as was theta. For this reason, the mean EMG during the free-recall trials (as was recorded and plotted) are not discrete measures paralleling the intervals of the trials. Each point plotted represents the mean EMG for the preceeding 30 seconds. This measure was provided by the instrumentation used and overlap between the intervals was unavoidable. Mean EMG was recorded during baseline (Figure 3) and during various portions of the free-recall trials (Figure 4).

Mean percentage theta for the total trial was also derived. There were a total of seven percentage theta scores for each subject. Table 1 presents the group means for the above theta measures.

Figure 1

Mean Percent Theta Over 10 Sec Intervals
For 0, 30, and 60 Sec Delayed Trials

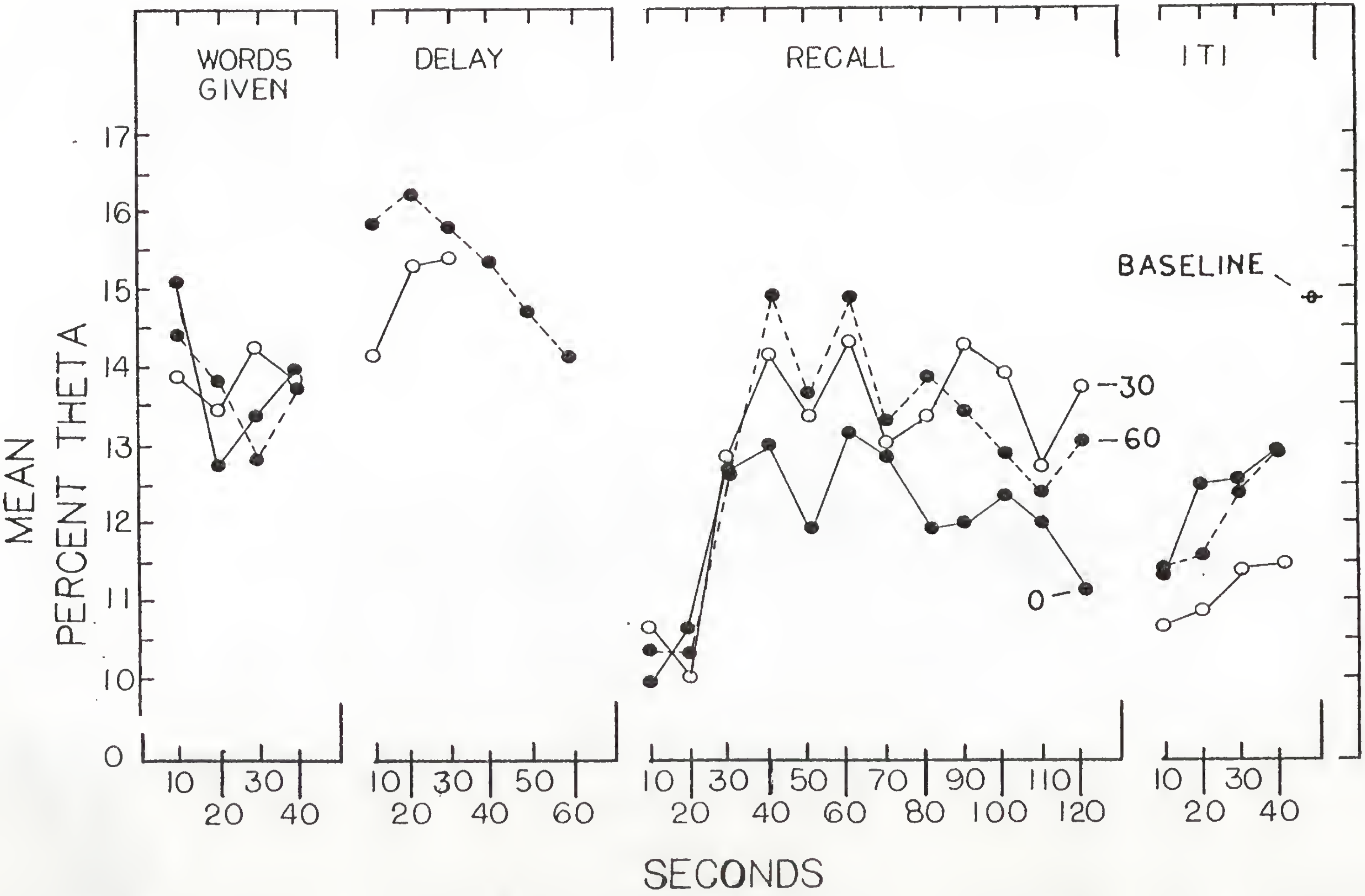


Figure 2

Mean Percentage Theta Over Baseline

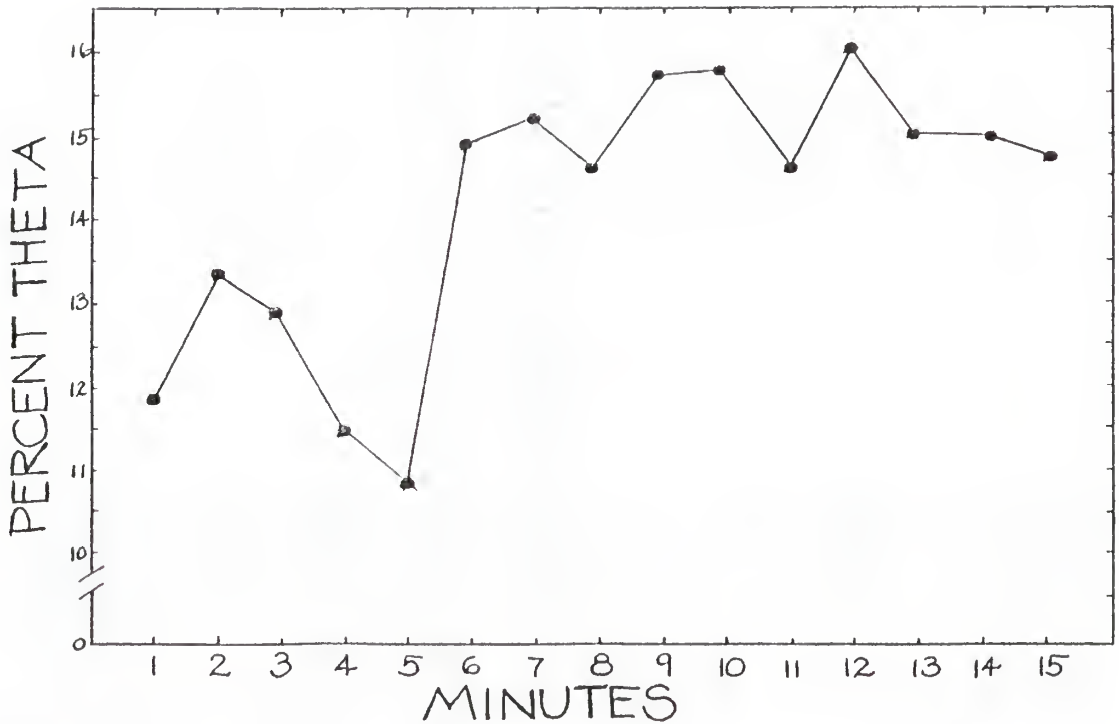


Figure 3

Mean EMG During Baseline

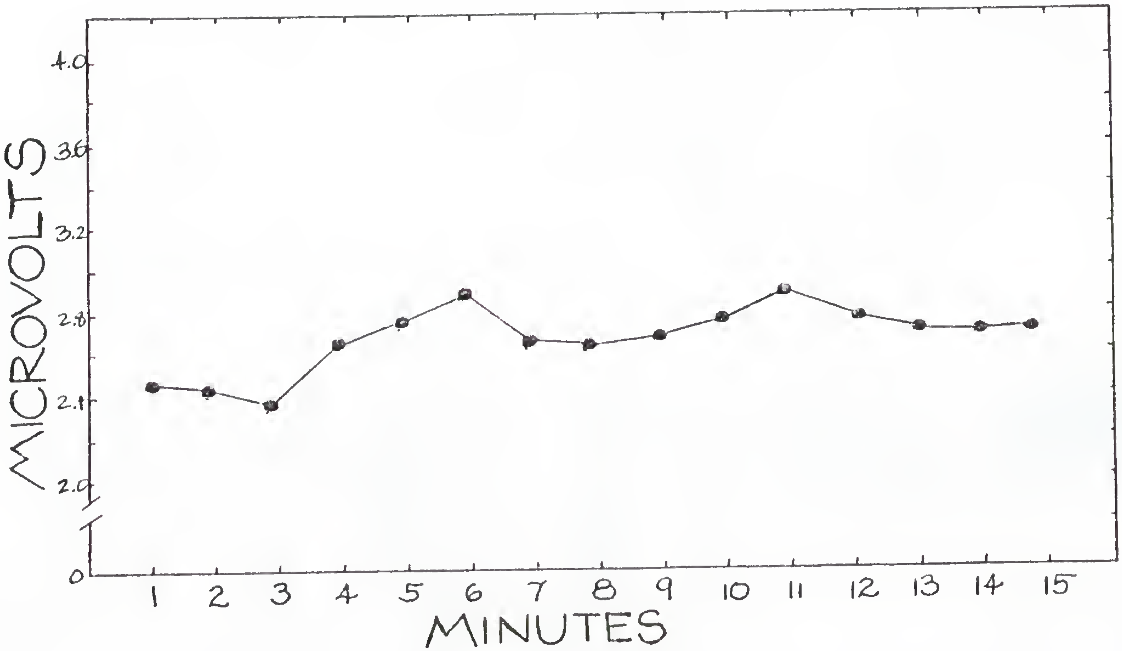
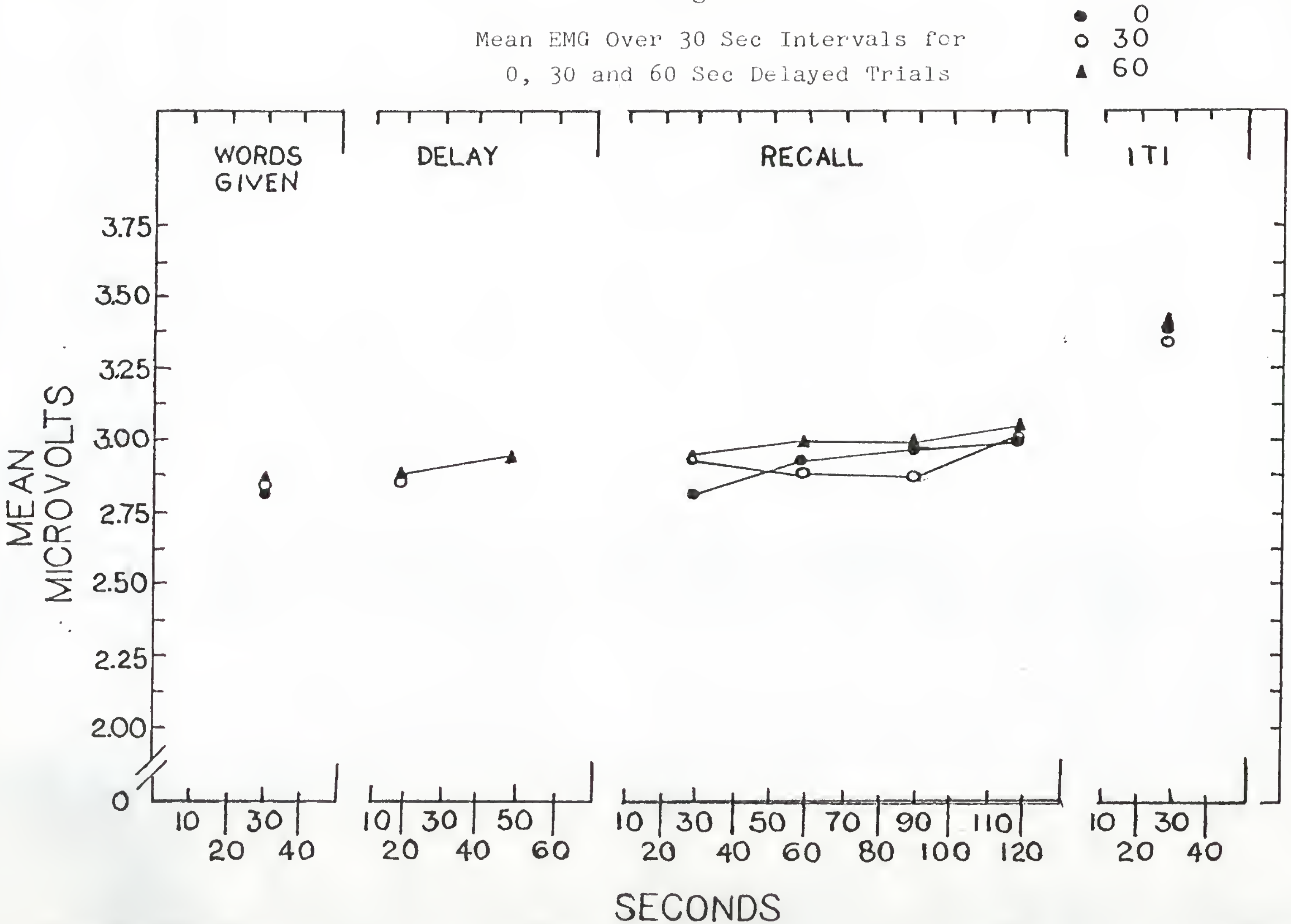


Figure 4

Mean EMG Over 30 Sec Intervals for
0, 30 and 60 Sec Delayed Trials



The theta percentage scores were included in a correlation matrix along with the mean EMG scores, and also with mean number of words recalled per trial for the 0, 30 and 60-sec free-recall trials. Mean EMG during baseline was 2.74 uV, $\sigma = .89$ uV. Mean EMG over the total trials was 2.99 uV, $\sigma = 1.17$. Means for number of words correctly recalled per trial (there were a total of four trials per delay with 20 words per trial) were 9.02, 8.59 and 8.23 for the 0, 30 and 60-sec delays respectively. The grand mean across delays was 8.62, $\sigma = 2.16$. This mean is below means attained in other studies (Watkins & Watkins, 1974).

Pearson product-moment correlations were computed to determine the degree of relationship between the mean percentage theta, mean EMG, and the mean number of words recalled. Table 2 provides the nonredundant coefficients for these variables. The correlations between theta measures and words recalled measures were consistently low and nonsignificant. All comparisons are two-tailed and significance levels were determined using Students' T with 28 degrees of freedom.

The first hypothesis of no relationship between baseline percentage theta and mean number of words recalled was not rejected. As treated, the observed values appeared nonrelated, $r(28=.12, p>.05$. The coefficient obtained for

Table 1

Mean Percentage Theta for

Time Intervals Scored

Interval	$\bar{x}$	σ
Baseline	14.9	12.3
Word presentation		
0-delay	13.8	11.9
30-delay	13.9	12.5
60-delay	13.4	12.5
Intratrial delay		
30-delay	15.0	14.1
60-delay	15.2	13.5
Total-trial	13.5	11.3

Table 2

Correlation Coefficients for Measures of Theta, EMG, Age, and Words Recalled

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	82													
3	81	79												
4	94	92	93											
5	17	17	02	12										
6	10	23	- 08	08	68									
7	03	14	- 18	- 01	68	95								
8	13	19	- 10	07	71	94	94							
9	00	16	- 16	- 01	71	92	96	93						
10	06	16	- 10	03	76	92	95	95	95					
11	- 36	- 38	- 45	- 43	- 15	- 19	- 14	- 12	- 15	- 16				
12	- 29	- 19	- 22	- 25	- 37	- 29	- 27	- 33	- 27	- 30	- 18			
13	- 38	- 29	- 34	- 37	- 26	- 18	- 23	- 27	- 31	- 24	- 03	48		
14	04	18	- 14	01	76	93	96	95	98	97	- 14	- 33	- 28	

1 - $\bar{x}$ of recall for (IFR)
2 - $\bar{x}$ of recall for (DFR_{30})
3 - $\bar{x}$ of recall for (DFR_{60})
4 - $\bar{x}$ of total recall
5 - $\bar{x}$ % theta for baseline
6 - $\bar{x}$ % theta for word presentation(IFR)
7 - $\bar{x}$ % theta for word presentation(DFR_{30})
8 - $\bar{x}$ % theta for word presentation(DFR_{60})
9 - $\bar{x}$ % theta for intratrial delay (30)
10 - $\bar{x}$ % theta for intratrial delay (60)
11 - age
12 - $\bar{x}$ EMG uV for baseline
13 - $\bar{x}$ EMG uV for total trials
14 - $\bar{x}$ % theta for total trials

Note: decimals omitted

the mean number of words recalled immediately (0 sec delay) and the mean percentage theta during the presentation of those words was nonsignificant, $r(28)=.10, p>.05$ and hypothesis 2 was not rejected. Hypothesis 3, mean number of words recalled after a 30 sec delay and the mean percentage theta during the presentation of those words are not related, $r(28)=.14, p>.05$; and hypothesis 4, mean number of words recalled after a 60 sec delay and the percentage theta score accrued during the presentation of those words do not share direction of variance, $r(28)=.10, p>.05$, both failed rejection. Hypothesis 5 states that the mean EMG uV level over all trials and the percentage of theta over all trials are not related. The hypothesis was not rejected, $r(28)=-.33, p>.05$. Hypothesis 6 specifies no relationship between the number of words recalled for the 30 sec delay trials and the mean percentage theta during the delay, $r(28)=.14, p>.05$. Hypothesis 7 predicts no observed relationship between number of words recalled for the 60 sec delay trials and the mean percentage theta during the respective delay periods. The hypothesis was not rejected, $r(28)=-.10$, $p>.05$.

Some unplanned correlations between EMG and other measures were significant. A negative relationship was demonstrated between mean baseline EMG and mean baseline percentage theta, $r(28)=-.37, p<.05$. The probability that this result occurred by chance appears to be lessened in light of the consistently negative coefficients between baseline EMG and the other percentage theta means which all approached significance (see Table 2). In addition, total-trial mean EMG correlated significantly with total mean number of words recalled, $r(28)=-.37, p<.05$, and with mean number of words recalled for the 0-delay trials, $r(28)=-.38, p<.05$.

Males and females did not differ significantly on mean baseline percentage theta as tested by the Wilcoxon-Mann-Whitney Sum of Ranks Test, $T(15)=211, p>.05$.

The reliability of theta measurement appears to be quite high for the technique and instrumentation used. Correlations between the various measurements of mean percentage theta range from $r=.68$ to $r=.98$. Baseline theta correlates lowest with measures of theta during the trials, while intratrial measures correlate highest (see Table 2).

CHAPTER V
DISCUSSION

Frontal EMG and left hemisphere theta were recorded while 15 male and 15 female college students (mean age was 22.6 years) participated in immediate and delayed free-recall tasks. A counter-balanced ordering of four immediate recall trials, four delayed (30 sec) recall trials, and four delayed (60 sec) recall trials were given to each subject.

Correlations were computed between all of the following measures: (a) mean number of words recalled for the immediate free-recall trials, (b) mean number of words recalled for the 30 sec delayed recall trials, (c) mean number of words recalled for the 60 sec delayed recall trials, (d) grand mean number of words recalled, (e) mean percentage theta during baseline, (f) mean percentage theta during two periods (word presentation and intratrial delay) of the free-recall trials, (g) mean percentage theta across all recall trials, (h) mean EMG during baseline, (i) mean EMG across all recall trials. No significant relationship was demonstrated between the mean percentage theta and the mean number of words recalled (see Table 2). A slight negative relationship was observed between baseline percentage theta and EMG during baseline. Also, total-trial EMG levels were found to correlate with number of words recalled for immediate recall and total-trial recall. The findings are discussed as implications for further research. These include: (a) theta as a co-variate of cognitive processes involved in learnings and memory, (b) the manipulation of theta activity for facilitation of learning and memory, and (c) levels of theta activity as a predictor of rate of learning and/or memory span.

Conclusions

The inability to demonstrate a relationship between percentage of theta and number of words recalled, in this study, may be a result of (a) the location of the electrodes for the recording of theta, (b) the operational definition of theta, (c) the cognitive operations involved in the free-recall tasks, (d) the type of subjects sampled, or (f) various combinations of the above.

The parietal location was picked for this study because of its proximity to the hippocampus (which is known to have high theta level) and because the structure appears to be involved in learning and memory (Berry & Thompson, 1978). The location of the active electrode in this study was placed laterally between the occipital and frontal regions over the parietal cortex. Previous studies of theta have typically recorded from the occipital region (Beatty et al., 1974; Daniel, 1967). Perhaps a relationship would have been demonstrated if theta had been recorded from frontal regions as suggested by Schacter (1976). The frontal areas are generally thought to be involved in learning and memory processes.

Relationships between theta and learning have only been found in animals (Berry & Thompson, 1978; Landfield, 1976; Landfield et al., 1972). Perhaps the functional qualities of human theta are separate and distinct from that of lower order vertebrates. However, to draw this conclusion would be premature, particularly in light of differences in electrode placement technique.

Percentage of theta, as defined in this study, is the amount of time theta is dominant in the EEG, divided by the total time, and multiplied by 100. Berry and Thompson (1978) defined percentage of theta as a ratio of 2-8 Hz activity and all activity above 8 hertz. This type of ratio measure may be more appropriate in the investigation of learning and memory.

The operations involved in free-recall tasks basically involve the following: (a) encoding of the auditory stimuli, (b) the storage of the encoded stimuli, and (c) the retrieval of the learned and stored information. The correlational analyses, used in the present study, although descriptive, were not sufficient to adequately examine the relationship of the above operations involved in short-term memory and the theta activity paralleling, in time, the performance of those operations. Visual inspection of Figure 3 is enough to warrant this conclusion. The fluctuations of theta over the total-trial appear to be related to the phases (word presentation, delay, recall, and intertrial interval) of the recall tasks. It is interesting to note the U-shaped curve of mean percentage theta during the presentation of the words. This curve is similar in shape to typical serial position curves. This phenomena would appear to merit closer attention.

Also, the negative results of the correlational procedure may be due to the relative homogeneity of the population sample. College students are certainly atypical with respect to the general population. Increased heterogeneity of the population sampled, most probably, would lead to greater variance of the variables in question.

Suggestions for Research

In the present study, using theta as a predictor of retention of common words for short-term memory was ineffectual. Future investigations of this type may benefit from multiple measures of theta lending themselves to alternative percentage or ratio measurements.

A primary concern at the outset of this study was one of determining an appropriate point in time for the manipulation of theta to enhance learning. More specifically, would increments or decrements in theta be more appropriately applied during the encoding, storage or retrieval of the learned material? Failure to observe any significant relationship through correlational analysis leaves this question unanswered. The problem, as a topic for future research, may be elucidated by manipulating theta during these intervals for comparison with a control group. A 3 x 4 factorial design is suggested where the effects of increased, decreased and normal theta levels on recall are examined for each of the trial phases: word presentation, intratrial delay, recall, and the intratrial interval.

Theta activity, when viewed in the aroused or nonaroused frame of reference may be too parsimonious. The results cannot be adequately explained from either point of view. Whether theta is reflective of selective, effortful processing of information or of nonattending, nonprocessing orientation cannot be determined. From the above points of view, one would expect persons low in percentage of theta during word presentation and during the intratrial delays to either recall more words or less words than those persons with relatively high percentage of theta. Theta, as analysed, provide no basis for distinguishing attending versus nonattending behaviors. This problem may be best examined by providing a gradient of learning tasks requiring various levels of attending.

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APPENDIX A

INFORMED CONSENT

The purpose of this study is to investigate two physiological processes: muscle tension and low frequency brain wave activity. Of particular interest is the relationship of these processes to verbal learning and memory. To meet the above purpose, it is necessary to temporarily attach surface electrodes to your forehead, earlobes and scalp. These sensors will pick up minute electrical impulses that are occurring in those areas. The instruments used to amplify the impulses are battery-operated so there is no danger of electrical shock. Every effort will be made to insure your comfort throughout the recording session.

While the recordings are being made you will be asked to listen to several lists of words. During the presentation of the word lists you will just sit quietly without moving. It is important that you avoid all movement during this time so that the recording instruments may obtain accurate readings. If there is an emergency such as illness, please bring this to the attention of the person in the lab. He will be present at all times and will see that you are attended by a qualified counselor or taken to Student Health if necessary.

It is hoped that through your contribution of time -- about 90 minutes -- that something will be learned about those physiological processes being examined. Any questions you may have will be answered fully at the conclusion of the recording session. You may obtain the results of the study, when completed, by writing to:

Stephen Allen
612 N. 14th, Apartment 3
Manhattan, Kansas 66502

You have the right to withdraw your consent and discontinue participation at any time without penalty. All the data will be reported as group data and no individual names will be used. The data and names are kept separate and confidential.

I have read the above statement and have been fully advised of the procedures to be used in this project. I understand the potential risks and I hereby assume them voluntarily.

Date:__________________ Signature:________________

APPENDIX B

INTRODUCTION TO THE EXPERIMENT

Let me tell you about the experiment and some of the things you will be expected to do as a participant. You may have heard some of this at the time you volunteered.

First of all, the study is interested mainly in the fluctuations of brain wave activity while you are learning some lists of words.

This instrument here (points) amplifies tiny electrical impulses occurring on the surface of your scalp. This instrument here (points) amplifies the electrical activity of your forehead muscles.

For the instruments to pick up those tiny impulses we need to temporarily attach these sensors (points) to your scalp, forehead and earlobes. But before the sensors are attached, we must prepare the surfaces to which they are going to come into contact. This is done by cleaning the areas with an abrasive paste. This paste is just a salt paste and is easily removed when dried. It will not harm your skin or hair. Do you have any questions?

After the sensors are attached you will be asked to sit in this chair and get as comfortable as possible. It is important that you get as comfortable as you can because any movement after the recording begins will affect the readings on the instruments. Please be particularly careful not to move your head, face and upper body during the recording. Also keep your eyes open at all times during the experiment.

You will sit quietly in the chair for about 15 minutes. After that I will turn on a tape recorder which will give you more specific instructions. You will then hear several lists of words. At the end of each list you will be asked to write down as many of the words as you can remember from that list. You may write them down in any order that you wish. You will be given enough time to write down all the words that you can remember.

After the last set of word lists has been completed, I will help you "unhook" the sensors and you may then ask more questions.

APPENDIX C

TAPED INSTRUCTIONS

PRECEDING THE RECALL TASKS

Through the speaker behind you, you will hear some lists of words. Each list consists of 20 words. At the end of each list you will hear me say "recall". When you hear me say recall, write down as many of the words as you can remember from that list. You may write them down in any order that you wish. You will be given enough time to write down all the words that you can remember. If you are not sure of a word feel free to guess.

After the last word of each of the lists, you will hear me say recall. Remember that means to write down as many words as you can in any order you wish. However, there will be different delay times after the last word. I will say recall sometimes immediately following the last word, sometimes 30 seconds after the last word, and sometimes 60 seconds after the last word. Please do not begin writing until you hear me say recall.

When you hear me say "stop", slide your paper off the desk and onto the floor. Please do this with as little movement as possible. Then resume your comfortable position.

When you hear me say "ready" the next list will follow immediately.

O.K., let's go over that one more time. You will hear me say recall after the last word of the list. It is important that you do not begin writing until you hear me say recall. Sometimes I will say recall immediately after the last word, 30 seconds after the last word, or 60 seconds after the last word. After sufficient time to write down all of the words, you will hear me say stop. When you hear me say stop just slide your paper off the desk and onto the floor. The beginning of the next list will be signaled by the word ready. When you hear the word ready, the next list will follow immediately. Remember to avoid all movement as much as you can. The minimum amount of movement for writing the words and sliding the paper off the desk is all that is required. Especially refrain from movement in the face, neck, and upper part of the body.

O.K., remember that recall means begin writing, stop means slide your paper off the desk, and ready means the next list will immediately follow. Are there any questions?

ELECTROENCEPHALOGRAPHIC THETA ACTIVITY AND ELECTROMYOGRAPHIC ACTIVITY DURING LEARNING

By

STEPHEN E. ALLEN

B.S., Kansas State University, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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Frontal EMG and left hemisphere theta were recorded while 15 male and 15 female college students (mean age was 22.6 years) participated in immediate and delayed free-recall tasks. A counter-balanced ordering of four immediate recall trials, four delayed (30 sec) recall trials, and four delayed (60 sec) recall trials were given to each subject.

Correlations were computed between all of the following measures: (a) mean number of words recalled for the immediate free-recall trials, (b) mean number of words recalled for the 30 sec delayed recall trials, (c) mean number of words recalled for the 60 sec delayed recall trials, (d) grand mean number of words recalled, (e) mean percentage theta during baseline, (f) mean percentage theta during two periods (word presentation and intratrial delay) of the free-recall trials, (g) mean percentage theta over and across all recall trials, (h) mean EMG during baseline, (i) mean EMG across all recall trials. No significant relationship was demonstrated between the mean percentage theta and the mean number of words recalled. A slight negative relationship was observed between baseline percentage theta and EMG during baseline. Also, the total-trial EMG levels were found to correlate with number of words recalled for immediate recall and total-trial recall. The findings are discussed as implications for further research. These include: (a) theta as a co-variate of cognitive processes involved in learning and memory, (b) the manipulation of theta activity for facilitation of learning and memory, and (c) levels of theta activity as a predictor of rate of learning and/or memory span.