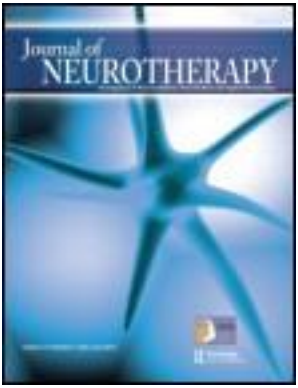

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Electrophysiology of Auditory Memory of Paragraphs Towards a Projection / Activation Theory of the Mind

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Electrophysiology of Auditory Memory of Paragraphs Towards a Projection/Activation Theory of the Mind

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ABSTRACT. *Introduction:* An investigation into the QEEG parameters of effective auditory memory for paragraphs was conducted employing sixty normal right-handed subjects.

Method: Four stories were read to the subjects. The subjects engaged in an immediate thirty-second quiet recall period, which was followed by the subjects recalling the stories outloud. A delayed recalled assessment (about forty-five minutes) followed the same methodology.

Results: The recall performances were correlated with the QEEG variables. For the input period the absolute levels of the Alpha coherence and phase generators from the left temporal lobe (T3), as well as the coherence Alpha (C3, P3, F7) were the predominant determinants of success in addition to F7 coherence Beta1 (13-32 Hz) and phase Beta1 from F8. Immediate recall was determined by the absolute levels of the projections from T3 (coherence and phase Alpha), symmetry Beta2 (32-64 Hz) at T3 and peak frequency of Beta1 at T5. Long-term recall was determined by the T3 generators (phase and coherence Alpha), F7 projections (phase Theta, coherence and phase Alpha, phase Beta1, coherence Beta2), Fp1 and F3 projections (coherence Beta2), and Fp1 phase Beta1. Degree of activation (from eyes closed) revealed additional variables relevant to success.

Discussion: These research results are integrated into previous neu-

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roscience research and implications for theories of brain function and neurotherapy applications are discussed.

KEYWORDS. Auditory memory, QEEG, memory, effective memory

INTRODUCTION

Theorists, such as Hebb (1949), Schacter and Tulving (1994), Pribram (1994) and others have pursued a theoretical framework for the understanding of the physical correlates of mental events and memory and have employed concepts such as cell assemblies, activation areas and holography. Damasio's (1989) contribution to this problem stated that the subcortical structures have their place in memory functions; however, they are only relay stations, which enable storage and retrieval, and do not contain engrams, which are assumed to be located in the cortex. Memory is not stored as wholistic units in narrowly circumscribed regions, for example as "grandma cells," but rather was sets of representational fragments in multiple and separate regions. "A memory content is accessed if these representational fragments are triggered either by perceptual input or by active memory search. In each case, triggering means that the very same activity pattern is recreated in the distributed cortical cell assemblies which was generated originally, when the entity, a face, etc., was first encountered" (Rosler, Heil, & Hennighausen, 1995, p. 301). Damasio (1989) elaborates on this approach by emphasizing that recall of entities and events "are activated in time locked fashion; synchronous activations are directed from convergence zones . . . and the process of reactivation is triggered from firing in convergence with and mediated by feedback projections. This proposal rejects a single anatomical site for the integration of memory and motor processes and a single store for the meaning of entities and events. Meaning is reached by time-locked multiregional retroactivation of widespread fragment records. Only the latter records can become contents of consciousness" (p. 25). Damasio's emphasis upon time locked regional activations places the emphasis upon activated areas. Although he speaks of projections, these projections provide the impetus for activation and are not the focus of recall. For example, he states "consciousness emerges when retroactivations attain a level of activity that confers salience" (Damasio, p. 54). Damasio does not provide specifics as to location or modern measurement technologies such as blood flow or quantitative EEG measures (QEEG). The discovery of the empirical relationships between QEEG variables and effective auditory memory has implications for theories of the mind such as Damasio's, as well as providing a direction for neurotherapy interventions. The field of neurotherapy (biofeedback of QEEG variables) has grown in interest and clinical application during the past decade due to its effectiveness in improving the cognitive and behavioral functioning of children with educational problems. EEG biofeedback has been successfully employed in the remediation of Attention Deficit Disorder (Lubar & Lubar, 1984) and in the elevation of scores on IQ tests by ten to twenty-five points (Tansey, 1991; Othmer & Othmer, 1992; Linden, Habib, & Radojevic, 1996; Thompson & Thompson, 1998) in learning disabled subjects. The interventions employed in these clinical situations have focused generally on the Cz position and the Beta frequency range of 13-22 Hertz as the critical range. If the specific QEEG variables of cognitive functioning can be empirically discovered then interventions can be designed which can potentially be more effective than previously realized and can address a wide variety of problems in cognitive functioning. In the words of Sherlock Homes, "It is a capital mistake to theorize before you have all the evidence. It biases the judgment." The integration of research addressing the same issue with different measurement technologies is an important task in the understanding of the functioning of the brain.

During the past decade there have been many advances in the field of brain imaging as summarized by Toga and Mazziotta (1996), who point out that the temporal resolution of the Positron Emission Tomography (PET) methodology is from seconds to minutes with the commonly used isotopes such as (^{15}O) water and (^{15}O) butanol, whereas the fMRI signal latency is about 4.4 seconds. The research reported in this study has a temporal resolution of one second. The Lexicor software calculates the epoch length (or temporal resolution) by the sampling rate, which was set to 256 samples per second. This introduction will focus on the fMRI, PET and electrophysiological research in this area. The issues in the research concern locations of activations, task (input, recall periods) and relationship to performance. The relationship between blood flow measures and electrophysiological measures is only partially understood. The locations of the 10-20 placement system will employ Homan, Herman, and Purdy's (1987) descriptions of the underlying anatomical sites (employing Brodman's areas) of the electrodes. Of particular relevance to this research are the anatomical locations of the T3 (overlapping middle and superior temporal gyri) and F7 (inferior frontal gyrus, rostral portion of pars triangularis).

The temporal lobes have been established as the initial cortical recipient of auditory presented verbal information. Zatorre, Evans, Meyer, and Gjedde (1992) demonstrated (in a PET study) activation of the temporal lobes (Heschl's gyrus) during hearing noise, syllables and in particular the left temporal lobe for verbal information and left inferior frontal cortex (BA 45/47) when subjects were asked to make judgements regarding syllable pairs. These results have been replicated and elaborated on by others (Berry et al., 1995; Pugh et al., 1996; Price et al., 1992). Schlosser, Aoyagi, Fulbright, Gore, and McCarthy (1998) in a fMRI study (N = 14) demonstrated a strong left inferior and left superior temporal activation while subjects listened to English sentences. They noted that activation of the left inferior frontal cortex has been implicated in a variety of language tasks involving noun reading, verb generation, silent speech and naming and that studies of single word auditory comprehension using PET methodology have shown consistent activation of the left posterior superior temporal lobe. Lechevlier et al. (1989) studied (rCBF method-regional cerebral blood flow) the response of ten subjects listening to complex narrative text and found moderate increases in the mean right CBF of both inferior parietal areas. Mazziotta, Phelps, Carson, and Kuhl (1982) were able to demonstrate activation of the left frontal, left and right posterior and transverse cortices and left thalamus when subjects listened to text.

According to Homan (1987), the T3 position (Brodman's Areas (BA) 21/22) overlaps the middle and superior temporal gyri, the T5 position (BA 37) is located in the left middle temporal gyrus caudal to the termination of the sylvian fissure, while the F7 position (BA 45) encompasses the inferior frontal gyrus rostral portion of the pars triangularis. The conclusion from the studies is that the input of primary auditory and semantic information resides along the cortical F7-T3-T5 line.

If these zones are involved in the reception of verbal information, then how are the activations of these regions involved in the memory of that information? Historically, research in this area has focused on the hippocampus, thalamus and other structures as critical for memory. As one example of the focus of this type of research, Perani et al. (1993) was able to demonstrate with a group of amnesiacs and Alzheimer's patients (impaired on short and delayed visual and verbal memory tasks-PET study) hypo metabolism in the hippocampus, cingulate and frontal basal cortex. In the Alzheimer group, verbal short-term memory was best predicted by glucose metabolism in the left superior temporal, parietal, frontal associative and frontal basal areas. Long-term verbal episodic memory in the global amnesic patient was predicted by the metabolic values of the left hippocampus, thalamaus and cingulate cortex while for Alzheimer's patients the left hippocampus and cingulate areas were the critical locations. Long-term verbal eposidic memory was assessed with recall of a short story (similar to the prose passages employed in this study). It can thus be stated that low blood flow results in poor memory.

Ungerleider (1995) noted that declarative memory, which consists of the ability to store new memories of specific events (episodic memory) as well as new facts and knowledge (semantic memory) depends on medial temporal lobe structures in the hippocampal region, which includes the hippocampus, parahippocampal cortex, perirhinal cortex and entorhinal cortex. The medial temporal lobe has reciprocal connections with the dorsal and ventral stream visual areas as well as with equivalent areas in the other sensory systems. Ungerleider (1995) also noted that bilateral medial temporal lobe lesions resulted in the loss of the ability to store new memories, but not in the ability to recall old ones.

The retrieval of information presents a different pattern of results. Ungerleider (1995) summarized several studies that have noted activation of the medial aspect of the parietal lobe (precuneus or retrospenial cortex or both) during retrieval of episodic memories. Kapur, Markowitsch, Craik, Habib, and Houle (1994) demonstrated that when subjects listened to new versus old sentences the right dorsolateral prefrontal cortex (BA 10, 46, 9) and anterior portion of BA 6 were activated. Other regions activated included bilateral parietal lobes (BA 7/40), and left anterior cingulate. Bilateral decreases in blood flow were observed in the temporal lobes (BA 21/22/41/42).

Andreasen et al. (1995) studied paragraph recall (Logical Memory Scale-Wechsler Memory Scale-Revised) with subjects who had memorized story "A" one week prior and were exposed to story "B" sixty seconds prior to the PET data collection (both presented orally). Activations during free recall were quite similar with frontal, inferior temporal, thalamic, anterior cingulate and cerebellar regions involved.

Tulving, Markowitsch, Fergus, Craik, and Houle (1996) discuss the Hemispheric Encoding/Retrieval Asymmetry (HERA) pattern model which states that "(1) the left frontal lobes are differentially more involved than the right frontal lobes in the retrieval of general knowledge (semantic memory information); (2) left frontal lobes are more involved than the right in the encoding of novel aspects of incoming information into episodic memory, including information retrieved from semantic memory; and (3) right frontal lobes are more involved than left in episodic memory retrieval" (p. 71). The "novelty/encoding hypothesis" states that the left-frontal cortical regions are involved in the encoding of novel information for episodic memory storage. "Neuroimaging studies have shown that left frontal regions are differentially involved in encoding operations that determine the efficiency of subsequent retrieval" (Tulving et al., 1996, p. 76).

Desgranges, Baron, and Eustache (1998) discuss the HERA model in their recent thorough review of the literature in this area, and note the activation of the association temporal and posterior cingulate during encoding and right-sided activation of the association parietal locations, cerebellum, and posterior cingulate in the retrieval of episodic memories. Their discussion of the

HERA model and frontal lobe locations renders a more detailed accounting of how these locations and functions may be intertwined, as well as the issue of hippocampal involvement in memory. In addition, their analysis reflects an appreciation of the problem of different input modalities and different retrieval methodologies.

The left temporal lobe (T3-T5) and the left frontal (F7) are intimately involved in the input stage of auditory, verbal information into the memory system. Lesions and low blood flow in the temporal regions can negatively affect recall and there are different regions/systems that are involved in short-term recall and delayed recall. This separation of short-term and delayed recall has been a classic example of double dissociation (i.e., lesion A affects ability X, not Y and lesion B affects ability Y, not X) in the neuropsychological literature.

The functional role of the F7 position has received several hypotheses. The retrieval of auditory information involves the frontal (in particular the right frontal) and inferior temporal, parietal and precuneus cortical locations. Further exploration of the separation of the visual and auditory input aspect of the memory tasks and the input and delay aspects is required. Blood flow and glucose metabolism studies can indicate locations involved in different tasks. They are the support activities for complex electrical and biochemical events. The next step is the understanding of the relationship between the electrical activity and the mental event. Very few of the PET studies have addressed the issue of effective or successful cognitive functioning.

The relationship between QEEG variables and blood flow in one study indicated that low blood flow is reflected in discordance in the Theta (4-8 Hz) and Beta (12-18 Hz) bands (Leuchter et al., 1994). Discordance was a measure developed which analyzes the relationship between relative and absolute power of a bandwidth. However, Leuchter et al. (1994) also noted that the associations between EEG power and perfusion or metabolism vary considerably across frequency bands and sites, with some studies showing little or no association. Jibiki et al. (1994) were able to obtain significant negative correlations between blood flow (in a group of patients with partial epilepsy) and the relative power of Theta (4-7.8 Hz) and a positive correlation between blood flow and Alpha (10-12.8 Hz) in the frontal, parietal and temporal regions. Jibiki et al. (1994) also noted that in previous research there was supporting evidence for the inverse relationship between Delta and Theta activity and blood flow (studies with cerebral infarction, Alzheimer's, and Pick's disease) as well as positive correlations between Alpha power and blood flow.

In Klimesch's (1996) investigation of the electrophysiology of memory functioning, he noted previous research relating decreased Alpha peak frequency to decreased memory performance in Alzheimer's disease. Klimesch has proposed an integrative memory model, which integrates cognitive psychology, neuroanatomy and neurophysiology and focuses his research and conclusions on variations in synchronizations in the Theta and Alpha frequency. He defines type 1 synchronization as involving large cortical areas reflecting mental inactivity and type 2 synchronization as the "regular synchronous oscillatory discharge pattern of selected and comparatively small cortical areas" (p. 81). He further elaborates that "the synchronization of very large populations of neurons oscillating with the same phase and frequency reflects a state in which no information is transmitted" (p. 81). He adds, "regular type 2 synchronization is that specific oscillatory mode in all of the frequency bands that reflects actual information processing in the brain" (p. 82). He further differentiates between low Alpha (7-11 Hz) and high Alpha (10-13 Hz) and relates desynchronization in these different bandwidths to effective memory performance. Thus, high phase relationship (and presumably high coherence relationships) across broad, long distant relationships in the brain are reflective of low/no information transfer. In a previous study, Klimesch, Schimke, and Pfurtscheller (1993) were able to show that during retrieval the Alpha peak frequency (frequency range not stated) of good performers is 1.25 Hz higher than for bad performers. During retrieval, Alpha desynchronization is more pronounced for bad performers than good performers. Special cognitive tasks such as reading, classification and recognition as well as attentional demands tend to reduce the power within the Alpha band. They also noted that (1) mental tasks and task difficulty in particular lead to an increase in Alpha peak frequency but only for difficult and not for easy tasks and (2) Alpha peak frequency increases selectively in that hemisphere which is dominant for a particular task.

Leuchter et al. (1994) employed a cordance method in analyzing the responses of eleven subjects during a memory task in his attempt to understand the relationship between QEEG variables and effective auditory memory. The subjects were shown slides of pen and ink drawings of common objects for five seconds. QEEG data was collected during presentation. Subjects were asked to spontaneously recall the items at both a three-minute lapse and again at seven minutes post testing. The results were analyzed according to his cordance system and further scored on overall recall ability. He defines cordance by the relationship between the absolute power and relative power of a bandwidth. When these figures are not consistent (as defined by a midpoint or selected base) there is discordance. For example, when the relative power of Alpha is high versus its selected base as well as its amplitude, then there is a condition of cordance. If Alpha relative power is high, but its amplitude is low, then discordance exists. In his study he demonstrated that the concordance of the Alpha frequency (8-12 Hz) in the left temporal lobe was associated with good visual memory performance. A good memory performance was associated with left temporal concordance, while a poor performance was distinguished by a shift to the right temporal concordance. Leuchter notes that cordance provides information on perfusion (blood flow activity) in that there is a strong relationship between mean perfusion and concordance in the Alpha frequency range.

Gevins, Smith, McEvoy and Yu's (1997) study of the Alpha and Theta frequencies during activation tasks examined the easy-difficult and initial-practiced dimensions of verbal and spatial working memory tasks with high resolution (115 channels) EEG and MRI recordings. They found increases in frontal midline Theta with increased difficulty and a decrease in parietocentral slow Alpha with increasing task difficulty (with no differences between the types of material). As practice increased the Theta and slow Alpha increased in amplitude. They did not measure the effectiveness of working memory.

The integration of PET studies and QEEG studies in relationships to verbal recall ability is beset with the problems of different tasks, measures, methodologies and results. The cortical involvement pattern of results, however, has indicated a pattern of left hemisphere involvement (frontal, temporal, parietal) and right frontal during delayed recall with poor performance reflected in low blood flow or dominance of the lower EEG frequencies. All of the research has focused on the issue of activation (increases in values) in regions. Very few research studies have addressed the issue of connectivity patterns or the role of the other QEEG parameters, which are available. In addition, the research has not focused on the difference between immediate and delayed recall or examined all cortical locations during the memory task. This research was designed to explore the full range of QEEG variables and cognitive function (and by implication blood flow) in a task, which is ecologically relevant for rehabilitation purposes (the recall of verbally presented material).

METHOD

Subjects. A total of sixty normal (no history of psychiatric problems, brain injury, neurological problems or learning disability) subjects (over the age of thirteen) underwent the experimental procedure. This group of sixty was part of a larger group of one hundred and fifty subjects (consisting of head injured, learning disabled, and children under the age of thirteen) who underwent a procedure lasting about one and one-half hours, during which eighteen cognitive tasks were administered. Table 1 represents the demographics of the subjects involved in this research. Subjects were paid $25 for their participation and their parents (when subjects were under the age of eighteen) signed an informed consent form as required in human research situations.

TABLE 1. Descriptive Data on Subject Population

	Male	Female	Combined	P level
Number	31	29	60	
Age (Yrs.)	28.6 (18)	33.5 (16.4)	30.9 (17.4)	.28
Education	11.5 (4)	12.5 (3.3)	12 (3.7)	.32
Shipley Scale				
Raw Verbal	29 (6.5)	30.8 (5.4)	29.9 (6)	.26
Raw Abstraction	29.8 (5.8)	30.3 (5.2)	30 (5.5)	.77
Verbal IQ*	115.7 (4.9)	114.5 (4.8)	115 (4.8)	.45
Abstraction IQ	106 (11.7)	105 (11.4)	105.6 (11.4)	.75
Short-Term Memory	41 (11.8)	41 (11.7)	41 (11.6)	.94
Long-Term Memory	19.5 (10)	22 (11.6)	20.7 (11)	.38
Savings	.47 (.21)	.52 (.2)	.49 (.2)	.40
Total Memory	60.5 (19.6)	63.2 (21.6)	61.8 (20.5)	.61

No significant differences (t-tests) between the sexes on any variable. P level of t-test indicated in right column.
*Employed Paulson, M. J. and Lin, T. (1970) formulas in estimation of IQ for subjects age 15 and over as formulas developed for subjects over age 15.
Standard Deviations noted in parenthesis

Four subjects were on blood pressure medication at the time of the testing as well as one subject on heart medication and another on an antidepressant.

Apparatus. While the subjects underwent the experiment, they were videotaped and recorded. The recording device combines a computer, video, audio recording equipment and allows an experimental recording session to be saved to a hi 8 mm tape with all pertinent information. The videotape, which is saved, is a split screen videotape, with the left side reflecting the EEG recording with the appropriate epoch number and the right side of the screen showing the subject during the experiment. The epoch number refers to a one-second period of time. Thus, epoch number one is the first one-second period of the recording and epoch number sixty is the sixtieth second of the recording. This device enables the experimenter to review the tape to check and confirm the scoring of the subject's responses during the experiment.

The EEG recording equipment of Lexicor Medical Technology, Inc. (NRS-24) was employed. The sampling rate was set to 256 to allow for examination of up to the 64-Hertz range with a 60-Hertz notch filter. In the system employed in this study, filtering is accomplished in the software. The signals passed are between .5 and 64 Hz (3dB points). The signals, which pass, are then subjected to a Fast Fourier Transform (FT) using Cosine-tapered windows which output spectral magnitude in microvolts as a function of frequency. The bandwidths were divided according to the following division: Delta: .00-3.5 Hertz, Theta: 4-7.5 Hertz, Alpha: 8-12.5 Hertz, Beta1: 13-31.5 Hertz, Beta2: 32-63.5 Hertz. This equipment provides for the collection of data in the standard 10-20 system (ear linked references) format of EEG data collection. Impedances below 5 Kohms (and within 1.5 K of each other) were obtained on all locations. Gain was set to 32000 and the high pass filter was set to off. The earlobes and forehead were prepped with rubbing alcohol and Nu-Prep. An Electro-cap was employed and spaces filled with Electro-gel. The data was visually analyzed and marked for deletion when artifact was evident.

All measurements available through the software provided by Lexicor Medical Technology, Inc. were employed. These included the following for each bandwidth and employed the peak-to-peak method.

Activation Measures

Absolute Magnitude: The average absolute magnitude (as defined in microvolts) of a band over the entire epoch (one second).

Relative Magnitude: The relative magnitude of a band (absolute magnitude of the particular band divided by the total microvolts generated at a particular location by all bands).

Peak Amplitude: The peak amplitude of a band during an epoch (defined in microvolts).

Peak Frequency: The peak frequency of a band during an epoch (defined in frequency).

Symmetry: The peak amplitude symmetry between two locations in a particular bandwidth–i.e., defined as $(A - B)/(A + B)$.

Connectivity Measures

Coherence: The average similarity between the waveforms of a particular band in two locations over the one-second period of time. Conceptualized as the strength/number of connections between two positions.

Phase: The time lag between two locations of a particular band as defined by how soon after the beginning of an epoch a particular waveform at location #1 is matched in location #2.

PROCEDURE

The subjects were read the four stories (one at a time) from the Rivermead Behavioral Memory Test (1991) while their eyes were closed. They were instructed at the end of each story (when the examiner said "end") to start recalling the story in as much detail as possible, silently to themselves. At the end of a thirty-second period, the examiner placed the recording on pause and asked the subject to open their eyes and repeat outloud the entire story they recalled during the quiet thirty-second period. Following the reading and recalling of the first story, the second story was read, then the third, etc. Following about forty-five minutes of other demanding cognitive tasks, the subjects were asked to close their eyes and silently recall anything they could recall from all of the four stories for thirty seconds. At the end of the thirty seconds, the recording was paused and the subject was asked to recall the stories out loud. Scoring for the stories followed the recommendations of the Rivermead manual, but added the possibility of half points for partial answers.

Data Analysis. The raw data, once artifacted, was analyzed with the Exporter program available from Lexicor Medical Technology. The Exporter software solves the cumbersome time problem of obtaining the required figures from the raw data file. The program generates the values for the variables under consideration from the raw data file and generates ASCII, comma delimited files, which can then be imported into Excel or CSS Statistica. One CSS spreadsheet was generated for each subject. Every epoch of the spreadsheet was labeled according to the experimental condition, which was occurring at the time. Once the labeling was completed, the file underwent a series of t-test comparisons, i.e., auditory attention versus listening to paragraphs. A t-value was generated for all 2,945 variables for each of the comparisons conducted. These comparisons were placed into Excel spreadsheets. Each subject had an Excel spreadsheet containing all of the comparison results. Once all the comparisons were completed, the results from the Excel spreadsheet were transferred to a CSS statistica file containing similar comparisons for the other subjects. Thus, one CSS file would contain all of the information for listening to paragraphs. The CSS files for each comparison would consist of three files. For example, in the immediate recall of paragraphs, one file would contain the absolute levels of the condition, another file would contain the degree of activation values from the relevant comparison condition (eyes closed), and a third the t-values of the differences between eyes closed and silent recall (not presented in results). Some of the figures indicate fifty-eight or fifty-nine subjects, as the data was not available for all conditions for all subjects.

Description of Figures. The circles represent the areas activated (magnitude, relative power, peak frequency, and amplitude asymmetry) to a significant level according to the previous discussion of significance. The lines represent the significant levels of the respective phase and coherence levels. Circles enclosed with a hatch pattern represent significant relationships at the .10 level with the connecting position. These relationships were only included when there was a clear pattern of other significant relationships at the .05 level. The positive and negative correlations are noted on the top of each set of figures. Each head figure is labeled on top with the parameter under consideration, according to the following nomenclature. For each figure the relevant nomenclature is listed below the figure.

T: Theta	A: Alpha	B1: Beta1	B2: Beta2
M: Absolute Magnitude		R: Relative Magnitude	
PKA: Peak Amplitude		PKF: Peak Frequency	
Sym: Symmetry		P: Phase	
C: Coherence			

The following examples are provided for clarification.

PA: reflects phase Alpha.

CT: reflects coherence Theta.

RPB2: reflects relative power of Beta2

MB1: reflects magnitude of Beta1

PKAA: reflects peak amplitude of Alpha

PFKB2: reflects peak frequency of Beta2

SymB1*: would reflect Asymmetry of Beta1 band

* Symmetry measures employ the combination method. A particular location's symmetry measure is calculated in reference to all other positions and is calculated only for the beta bands. The formula for symmetry is (A − B)/(A + B).

RESULTS

Statistical Considerations. The Bonferroni correction was not considered appropriate for the analysis as it fails to take into account the different categories of information. Setting the Alpha level to .05 would result in one hundred and forty-seven significant findings (of the 2,945 variables under consideration) by chance alone. To reduce this statistical problem to manageable levels, the following considerations were taken into account.

Epochs with minor Delta activity (defined as between 40-70 microvolts) were included in the data analysis for two reasons: (1) Eye movement (the predominant Delta activity artifactual concern) may relate to cognitive functioning as rightward eye movements activate the left posterior and vice-versa and (2) the need to obtain as many epochs of a short thirty-second period of time as possible to increase statistical power. However, the Delta band itself from these epochs was not included in the analysis for two reasons: (1) the inclusion of Delta activity could be misleading as to the nature of the underlying brain activity and (2) the effective QEEG parameters were focused in the higher bandwidths, thus minimizing the probability that Delta activity is an effective cognitive measure.

Critical values for statistical significance were adapted to each variable under consideration so as to minimize both type I and type II errors. For example, in one of the activation measures (relative power, etc.) there are nineteen locations and four bands (eliminating Delta), resulting in seventy-six possible significant findings. An Alpha level of .05 would produce approximately 3.8 significant findings by chance alone. Significant activations are reported if there are: (1) two or more in adjacent positions, (2) involve different bands or types of activations in the same location or (3) significant phase and coherence activity at that location. The total number of activation variables resulting from nineteen locations, four bandwidths and four parameters (excluding symmetry) is three hundred and four. The symmetry measures produce six hundred and seventy-four variables. The total number of connection measures resulting from nineteen locations, four bandwidths and two parameters is 1,368. The resulting total number of variables (after elimination of Delta activity) under consideration was 1,672. If an Alpha level of .05 were employed with the relationship variables (coherence and phase), there would be thirty-four significant findings by chance alone (for each relationship variable). To reduce this probability, the experimenter required an additional three relationships in a single band, single measure (phase or coherence) and from a single location to be significant at an Alpha level of .05 before significance is accepted. If the assumption is made that the thirty-four significant findings are distributed randomly, then there will be 8.5 significant findings in each of the four bands and measure.

Thus, the probability of one significant finding from a particular location is 8.5/19 or 45%, the probability of two significant relationships is .45*7.5/19 or 17.6%, and the probability of three significant relationships is .45*.17*6.5/19 or 6%. The probability of a fourth is .0175. The criterion for inclusion was set to four significant relationships at the .05 level.

To understand the effect of the inclusion of frontal Delta activity upon the results, correlational analysis was conducted with selection criteria that eliminated subjects whose F1 relative power of Delta was greater than forty. The effect on the data was a reduction in sample size but no significant change on the overall pattern of results. Conversion of summary variables (T3 coherence values to frontal locations) to logarithmic values also did not result in significant changes in the patterning of results.

This study focused on the ability of an individual to verbally recall information from four short prose passages (containing twenty to twenty-four pieces of information each) presented auditorily with an immediate and delayed recall condition. The integration of the results of this research and previous PET and QEEG studies requires presentation of both the degree of activation of the group as a whole from the relevant comparison condition (as that is the standard methodology in many designs) as well as the results of relationship to successful recall. The following discussion presents these comparisons.

During the collection of data, spreadsheets were created which contained all the relevant data for individual subjects for a particular comparison (i.e., auditory attention versus listening to paragraphs). The values for each subject included the means of both conditions and the t-values. The t-values could be averaged across all normal subjects. A criteria of the average t-value greater than 2.02 (Ferguson, 1971) was employed, when available, for the analysis of the auditory attention versus hearing words condition. For the remainder of the comparisons discussed, this type of data was not collected in this manner. To assess the degree of change for these variables, the average values and standard deviations for the comparison condition (for example, auditory attention) was obtained and the average values for the same subjects for the comparison condition (hearing paragraphs) were obtained. Employing the means and standard deviations for the auditory attention, the Z score difference for the hearing paragraphs was calculated for the positive Z scores (indicating activation). A greater than .50 standard deviation activation was selected as the criteria for discussion.

The comparisons include eyes closed vs. auditory attention, auditory attention and eyes closed vs. hearing words, and auditory attention vs. listening to paragraphs. The auditory attention condition required the subject (with eyes closed) to raise their index finger slightly every time they heard the sound of a pen hit the table (approximately one every one to two seconds). The hearing words condition required the subject (eyes closed) to listen to a prerecorded tape of the investigator reading a list of words.

The comparison of eyes closed to the auditory attention condition ($N = 60$) indicated increases (greater than .50 SD) in the auditory attention condition for the following variables: T3 (relative power of Beta2, peak frequency of Beta1, symmetry measures of Beta1 and Beta2) and T4 (relative power of Beta2, peak amplitude of Beta2, magnitude of Beta2, symmetry of Beta1 and Beta2). Deactivations were obtained at P3 and P4 for the symmetry Beta2 measures. Thus, the auditory attention task activates predominantly the temporal locations. There was no characteristic pattern of connectivity activation.

Thus, like the Zatorre, Evans, Meyer and Gjedde (1992) study both temporal lobes were activated over baseline (silence) in response to noise bursts. The Zatorre (1992) study indicated a Z score greater than 3 (of blood flow increases) in the left transverse temporal gyrus (Heschl). Similar Z values were obtained in the anterior superior temporal gyrus. Although there are inherent problems interpreting across studies, it is of some interest to note that a blood flow increase to the order of 3 standard deviations is equivalent (in this analysis) to a .5 increase in activity in predominantly the temporal Beta2 bands (relative power Beta2 and symmetry Beta1 and Beta2 at T3 and T4). However, this type of comparison has inherent problems due to unequal stimulus conditions.

An additional comparison was built into the methodology, that of hearing words with no memory requirement, similar to the Price et al. (1992) and Petersen and Fiez (1993) experiments that found activations in Wernicke's area related to the comprehension of words. The Petersen (1993) study compared passive presentation of words to rest condition and found bilateral activations along the superior temporal gyrus, as well as the left temporoparietal cortex. Part of the research design involved subjects passively listening to words. When the data from the present study was analyzed along similar comparisons (eyes closed vs. passive listening to words, N = 28) there were decreases (less than −.5 SD) in relative power of Beta1 at Fp1 and Fp2, relative power of Theta at F7, F3 and P4 as well as symmetry of Beta2 at P4. Increases (greater than .50 SD) were evident on the following variables: relative power of Beta2 at T4 and T5, F7 peak amplitude and magnitude of Beta2 and F3 magnitude Beta2, peak frequencies of Beta1 at T5 and peak frequencies of Beta2 at F8, T3, T4, T5, P3, and O1. There were also strong patterns of connectivity patterns (four or greater relationships which were .5 SD or greater) from C4, T4 and T6 (coherence Alpha), C3 (coherence Beta1), phase Theta (F7, F8, F3, F4, T3, T4), phase Alpha (T3, T4), phase Beta1 (F4) and phase Beta2 (F4, C3). Thus the hearing words conditions activates temporal, left and right frontal and left posterior areas, as well as activating a number of connectivity patterns from the right hemisphere, frontal and temporal areas. The results are consistent and elaborative on the previous research.

When comparing the auditory attention to hearing words conditions (N = 28), there were decreases (average t value less than −2) in the relative power of Beta1, Beta2, and symmetry (Fp1, Fp2, F8) and decreases in relative power of Beta1 at F8 and Beta2 at T3. The following variables demonstrated significant increases (t value greater than 2): peak amplitudes of Theta (Fp1, Fp2), peak amplitudes of Alpha (T5, T6, P3, P4, O1, O2, Pz), peak amplitudes of Beta1 (T5, T6), peak amplitudes of Beta2 (F3, C3, P4, O1, O2), magnitudes of Alpha (T5, P3, P4, O1, O2, Pz), magnitudes of Beta1 (F7, T5, T6, P3, P4, O1, O2, Pz) and magnitudes of Beta2 (F7, F3, C3, T5, T6, P3, P4, O1, O2, Cz, Pz). The overall pattern involved increases in activations in the left frontal and posterior regions. There was no significant increase in connectivity patterns.

The comparison between auditory attention and listening to paragraphs (N = 60) resulted in predominantly a relaxation of the frontal locations. There were decreases (less than −.50 SD) in frontal relative power of Beta1 (Fp1, Fp2, and F8), increases (greater than .50 SD) in peak amplitudes and magnitudes of Theta (Fp1, Fp2), decreases in peak frequencies of Theta (Fp1, Fp2, F8) and an increase in magnitude and peak amplitude of Beta2 at F8. There was also a decrease in relative power of Theta at Cz, an increase in magnitude of Beta2 at C3 and an increase in peak frequency of Beta2 at Fp2. There were no significant connectivity patterns.

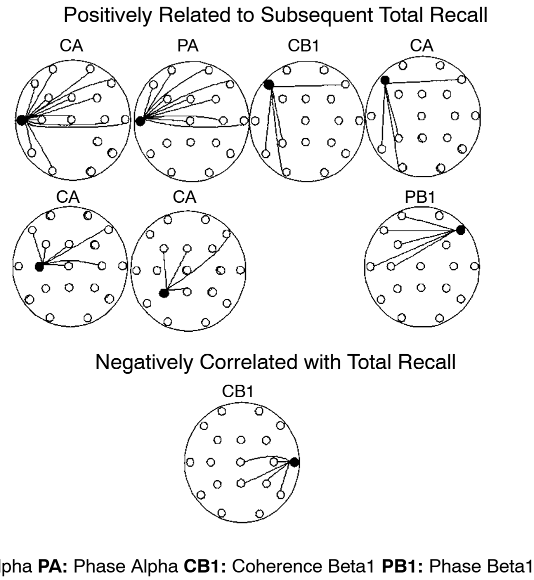
The hearing words condition was not employed as the appropriate comparison condition due to the possible effect on memory functioning. Subjects will be able to recall some words if asked following a presentation, even if not initially asked to memorize.

The comparison of differences between activations during the listening condition and immediate recall condition indicated no significant differences. The difference between immediate recall and delayed recall indicated only increases (greater than .50 SD) at F7 in peak amplitudes and magnitudes of Beta2. The comparison of long-term recall versus the listening condition indicated increases in peak amplitudes of Beta2 at Fp1, F7 and Fz as well as an increase in magnitude of Beta2 at Fp1. There was no significant pattern of connectivity differences. The HERA model of encoding vs. retrieval is not supported as there was no difference between the immediate recall and input conditions and a left frontal focus to delayed recall versus input conditions.

Input Stage. Figures 1 and 2 present the results of the listening condition. Figure 1 presents the absolute value of each variable for the period when the subjects were hearing the paragraphs. The figures present both the positive correlations and the negative correlations with the total memory score following the previous discussion of significance. The total memory score combines both short-term recall and long-term recall. Figure 2 presents the degree of activation from the auditory attention condition. The purpose of this control condition was to separate the effect of auditory attention from memory.

The auditory condition (vs. eyes closed) and the listening condition (vs. auditory attention) did not activate any significant connectivity patterns, but did demonstrate characteristic patterns of activations. As these results indicate, these characteristic pattern of activations are not related to recall ability. The successful input of auditory information is determined predominantly by the absolute level of Alpha coherence and phase activity emanating from the left temporal lobe (T3). Additional important activity patterns and locations include C3 and P3 (coherence Alpha to the frontal region), and frontal in-

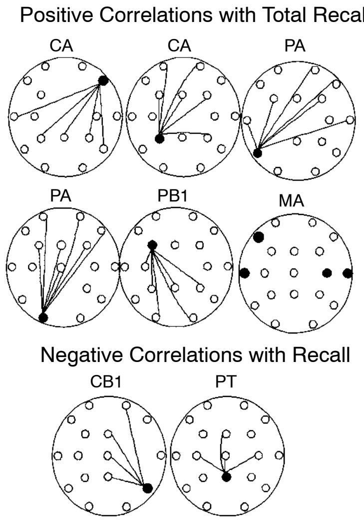
FIGURE 1. Listening to Paragraphs-Level of Activation (N = 59) (Hatched Areas p = .10)



volvement with respect to F7 Alpha coherence, coherence Beta1 to the left posterior and F8 phase Beta1 activity to the frontal/temporal areas. Significant degree of activation variables include frontal coherence Alpha activity from the F8 position, phase Beta1 activity from the F3 position to the posterior regions and magnitude of Alpha at T3, F3, T4 and C4. Right hemisphere connectivity patterns are negatively related to recall. There were no consistent specific patterns between the absolute level analysis and the degree of activation analysis.

Immediate Silent Recall. Figures 3 and 4 present the results of the immediate silent recall condition. Figure 3 presents the level of activation analysis, while Figure 4 presents the degree of activation from eyes closed. Immediate recall is determined by the absolute level of coherence and phase connectivity patterns emanating from the left temporal lobe (T3) to the frontal regions. Symmetry of Beta2 activity at T3 and Peak Frequency of Beta1 at T5 are important contributors to success. The degree of activation from eyes closed condition indicates an increase in posterior Theta activity (relative power, peak amplitude, and magnitudes) as well as an increase in Beta activity (peak amplitude Beta1-P3, Fp1, Fp2: peak amplitudes Beta2-C3, Cz, and Pz: T3 magnitudes of Beta1 and Beta2 as well as symmetry of Beta1). Other factors

FIGURE 2. Listening to Paragraphs–Degree of Activation from Auditory Attention (N = 60)



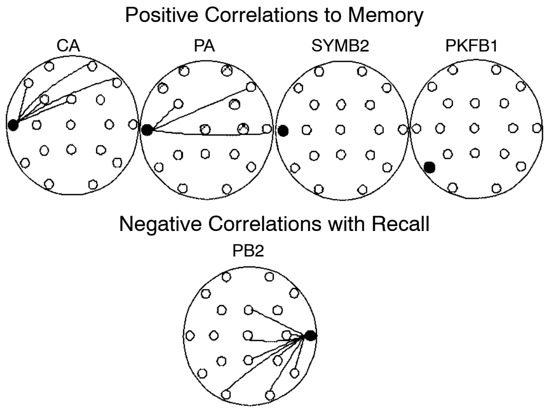
CA: Coherence Alpha **PA:** Phase Alpha **PB1:** Phase Beta1 **MA:** Magnitude Alpha **CB1:** Coherence Beta1 **PT:** Phase Theta

included frontal peak amplitudes of Alpha, and right temporal magnitude and peak amplitudes of Alpha activity. Negative relationships were evident with the right hemisphere peak frequencies of Alpha and Beta2, right hemisphere T6 symmetry measures of Beta activity, posterior relative of Beta1 and Fp2 phase Alpha. The only overlapping result between the absolute level analysis and degree of activation was symmetry of Beta1 at T3.

Long-Term Delayed Recall. Figures 5 and 6 present the results of the delayed recall condition, with Figure 5 presenting the absolute level of the variable which correlated with recall, while Figure 6 presents the degree of activation from eyes closed condition. Although there were sixty subjects available for the study, some of the data were not available for all the comparisons.

The successful delayed recall of the information was predominantly determined by the absolute level of left temporal Alpha phase and coherence activity to the frontal regions and left frontal coherence and phase Beta activity to the posterior regions. Other relevant F7 connectivity patterns (coherence Alpha and Beta1, phase Theta, Alpha and Beta1), predominantly to the posterior regions. Coherence Beta2 activity from Fp1 and F3 as well as Fp1 phase Beta1 to the posterior regions were also relevant. Degree of activa-

FIGURE 3. Immediate Silent Recall-Level of Activation (N = 60) (Hatched Areas p = .10)

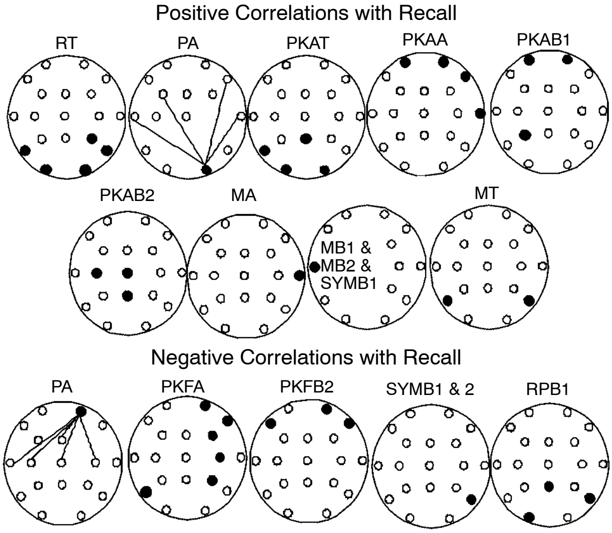


CA: Coherence Alpha **PA:** Phase Alpha **SymB2:** Symmetry Beta2 **PKFB1:** Peak Frequency Beta1 **PB2:** Phase Beta2

tion from eyes closed condition indicated relevant occipital (O1, O2) projection patterns (coherence Alpha) to the frontal areas as well as coherence Beta1 from O1 and magnitude Beta1 at O1. Frontal generators focused on the coherence Beta2 activity from the Fp2 and F3 positions and phase Beta1 activity from the F7 position. The T4 phase Theta activity was also relevant. There were patterns of increased activations in the Alpha and Theta range in the anterior and posterior portions of the head. Negative relationships included right frontal (F4, Fz, and F8) increases in Beta activity (frequency, symmetry, and amplitude). The overlapping results between the two methods of analysis (absolute and degree of activation) were Fp1 and F3 coherence Beta2 and F7 phase Beta1.

Relationship Between Demographic Variables and QEEG Success Related T3 Variables. Table 2 presents the correlations between the demographic variables and the relevant T3 projection (absolute phase and coherence values) systems involved in success recall. The T3 projections were employed as they were relevant in all the absolute level conditions. For example, in the listening condition the Alpha coherence and phase frontal projections and Alpha coherence posterior projections are averaged and correlated with the demographic variables. The silent immediate and delayed recall conditions employed only the frontal projections of phase and coherence from T3. There was a consistent positive relationship across all three conditions between the T3 projection systems and education, raw verbal score of Shipley, long-term and total memory (short-term recall plus long-term recall) and the savings

FIGURE 4. Recall Paragraphs–Degree of Activation from Eyes Closed (N = 58)



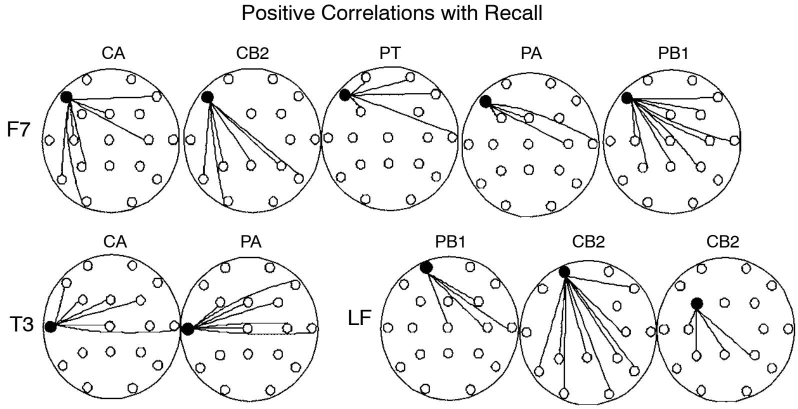
RT: Relative Power of Theta **PA:** Phase Alpha **PKAT:** Peak Amplitude of Theta **PKAA:** Peak Amplitude of Alpha **PKAB1:** Peak Amplitude of Beta1 **PKAB2:** Peak Amplitude of Beta2 **MA:** Magnitude Alpha **MB1:** Magnitude Beta1 **MB2:** Magnitude Beta2 **SYMB1:** Symmetry Beta1 **MT:** Magnitude Theta **PKFA:** Peak Frequency Alpha **PKFB2:** Peak Frequency Beta2 **SYMB2:** Symmetry Beta2 **RPB1:** Relative Power Beta1

score which is calculated as long-term recall divided by short-term recall. Of interest to note is the lack of correlation with sex, age or abstraction raw score. The question of cause vs. effect between education and verbal ability and the T3 projection patterns cannot be answered with this data.

DISCUSSION

The results presented in this research indicate that the projection patterns are the critical factor in effective cognitive functioning and activation measurements represent a secondary consideration. The results confirm previous research indicating the role of the left temporal and dorsolateral left frontal area in verbal processing and memory tasks, as discussed in the introduction (Zatorre, Evans, Meyer & Gjedde, 1992; Berry et al., 1995; Pugh et al., 1996; Price et al., 1992; Schlosser, Aoyagi, Fulbright, Gore & McCarthy, 1998; and Lechevlier et al., 1989). They do not confirm the role of the right frontal lobe in the recall of the information. The results do not support Damasio's (1989)

FIGURE 5. Long-Term Silent Recall–Level of Activation (N = 59)

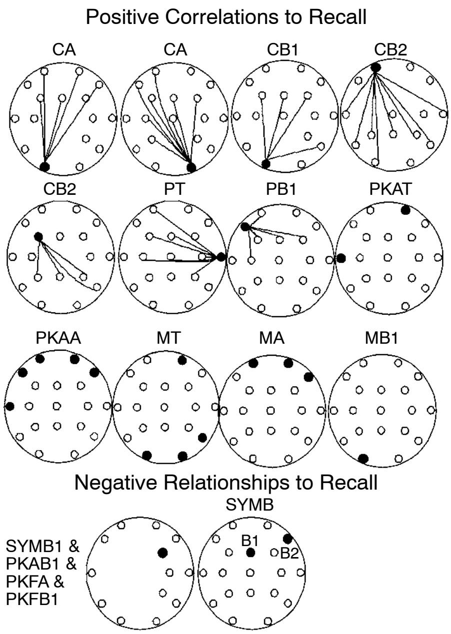


CA: Coherence Alpha **CB2:** Coherence Beta2 **PT:** Phase Theta **PA:** Phase Alpha **PB1:** Phase Beta1

hypothesis regarding projections resulting in activations, as the data indicate in many situations only projection activity. The results do support a projection/activation model of mental functioning. The results do not support Leuchter's et al. (1994) hypothesis regarding the electrophysiology of effective memory with respect to activation of frequency ranges. Klimesch, Schimke and Pfurtscheller's (1993) and Klimesch's (1996) hypothesis that increased phase synchronization is a state of no information transfer is proven inaccurate by the data, as the phase relationships are intimately involved in successful memory. The issue of the lower frequencies being negatively related to recall is addressed in Figure 4, which indicates a positive relationship between posterior Theta increases and recall.

Input Stage. If there is a particular bandwidth, which is effective under auditory memory conditions, then that bandwidth will be the effective bandwidth no matter what the condition of the subject. If a medication, head injury or learning disability interferes with the functioning of that bandwidth, then memory will decrease. Under this assumption, the full sample (N = 150, subjects under the age of thirteen included as well as head injured, left-handed subjects, etc.) was analyzed to see if the results correspond to the results for the normal right-handed sample. The results indicated a striking similarity of finding in that there was a strong pattern of the absolute levels of Alpha coherence and phase activity emanating from the T3 and the C3 positions which related to effective memory. In addition, there were similar coherence patterns in Alpha emanating from F7, F8, F3 and T5 positions. An analysis of the remaining comparisons (activation from comparison conditions, short-

FIGURE 6. Long-Term Recall–Degree of Activation from Eyes Closed (N = 59)



CA: Coherence Alpha **CB1:** Coherence Beta1 **CB2:** Coherence Beta2 **PT:** Phase Theta **PB1:** Phase Beta1 **PKAT:** Peak Amplitude Theta **PKAA:** Peak Amplitude Alpha **MT:** Magnitude Theta **MA:** Magnitude Alpha **MB1:** Magnitude Beta1 **SYMB1:** Symmetry Beta1 **SYMB2:** Symmetry Beta2 **PKAB1:** Peak Amplitude Beta1 **PKFA:** Peak Frequency Alpha **PKFB1:** Peak Frequency Beta1

and long-term recall) revealed similarities in results. Employing the values for the relationships depicted in Figure 1 in a forward stepwise multiple regression equation resulted in a R^2 of .85 with 30 variables in the normal right-handed group (subject/variable ratio = 58/30 or 2/1). Using the variables with one-half of the full group (over the age of thirteen, but including one-half of the normal group, one-half of the brain injured group, one-half of the group of left-handers, etc.) resulted in a R^2 of .97 for a group of sixty-three subjects (over the age of thirteen) and .85 with another similarly composed group of sixty-four subjects. This approach is not the standard split-half approach as it employs the normal group in both groups. It was reasoned that different brains may be employing different approaches to obtain success. To measure the overall effectiveness of a different approach to that of the normal right-handed group, it is necessary to include both groups in the analysis. An additional approach would be analysis by groups. A normal

TABLE 2. Relationship Between QEEG Variables and Demographic Information Between T3 Relevant Summated Phase and Coherence Values

	Listen	Immediate Recall	Delayed Recall
Age	.26	.21	.23
Sex	.21	.14	.17
Education	.48*	.43*	.41*
Shipley			
Raw Verbal	.41*	.33*	.39*
Raw Abstraction	.24	.16	.24
Short-Term Memory	.24	.14	.21
Long-Term Memory	.40*	.29*	.44*
Savings	.35*	.27*	.41*
Total Memory	.35*	.24	.35*

* = Marked correlations are significant at $p < .05$

distribution is assumed in this analysis. These stepwise results are presented for exploratory purposes only, as the subject to variable ratio is too low for use in cross validation.

What is the purpose, then, of the projections from F7 to the posterior portion of the head? It is also of some interest to note that the positions to which the F7 position project (three in the left posterior positions and F8) are all effective correlates of memory performance when degree of activation from the auditory attention variables are examined (Alpha phase and coherence variables). Is it the purpose of the F7 projections to activate these projections? Only a detailed millisecond analysis could answer this question.

The degree of activation from auditory attention indicate relevant activations in the left posterior region (Alpha phase and coherence activity), frontal activations (Beta1: Fp1, F3, and F4) phase activity as well as F8 coherence Alpha activity. Thus, the pattern for both results are Alpha temporal and left posterior projections to the frontal areas and simultaneously Alpha and Beta1 frontal projections to the posterior regions.

Immediate Recall. The immediate recall of the information is predominantly determined by Alpha coherence and phase projections from the T3 position, an increase in symmetry Beta2 activity at the T3 location (from eyes closed condition) and peak frequency of Beta1 at T5. It is possible that the temporal lobe has stored the information necessary to recreate the projection onto the frontal regions. The temporal lobes are the location of auditory information as well as semantic information. It would appear that the semantic information is represented in auditory format and projected to the frontal lobes.

The degree of activation variables point to the importance of activation variables at T3 (magnitude Beta1 and Beta2, symmetry Beta1), peak amplitude Beta1 at P3, Fp1, and Fp2 and peak amplitude of Beta2 at C3, Cz, and Pz. The Theta activations can be perceived as the relaxation or lack of involvement of these locations in retrieval efforts. Of some interest to note are the right hemisphere activation patterns which interfere with memory. A stepwise multiple regression equation employing only the variables in Figure 3 indicated a R^2 of .53 for the group.

Long-Term Delayed Recall. The delayed recall condition offers a unique perspective on the problem. The delay period is about forty-five minutes. While this length of time is not the same as recalling from childhood, it is a reasonable period of time for a long-term memory test.

The patterning of change over time for successful recall appears to move from predominantly a temporal lobe frontal projection system (Alpha coherence and phase activity-immediate recall) focus to a temporal lobe frontal projection system and frontal to bilateral posterior projection system (coherence and phase) in the Beta frequencies, which emanate from the left frontal region. The frontal projection system is predominantly in the coherence activity of Beta2 to the posterior association areas. The degree of activation variables point to occipital Alpha coherence activity to the frontal lobes, left posterior coherence Beta1 activity predominantly to the frontal lobes and frontal to posterior coherence Beta2 activity. It is the long distance connections (inter-cortical as well as intra-cortical) which are the predominant determinants of effective long-term memory retrieval.

Five of the ten absolute level projection systems emanate from the F7 position and three from the left frontal location (indicated as LF in Figure 5). Degree of activation variables indicated a more posterior focus (all of the posterior projection systems from the occipital regions). Additional activation variables include frontal and posterior increases (from eyes closed) in the Theta and Alpha range as well O1 magnitude Beta1. The pattern of negative relationships to recall indicates that a right frontal pattern of increased activity in the Beta range is negatively correlated with recall, a finding in direct contrast to the HERA model. A stepwise multiple regression equation employing only the variables in Figure 5 indicated a R^2 of .98 for the group with forty-four variables.

The results indicated that more than one frequency accounted for the success pattern. While these results begin to offer an opening into the understanding of the importance of the electrical patterning of successful auditory memory, there are many questions raised and unanswered in this research. For example, is it possible to narrow down the particular frequency which is responsible for successful auditory memory? A subgroup of subjects (N = 12) were analyzed with single one Hertz frequencies in the Alpha range. The results indicated that it was not a single frequency, which was accounting for the success pattern. How do these electrical patterns relate to the blood flow measures? While there are some overlapping findings (in particular the temporal lobe and the prefrontal dorsolateral positions) there are some findings that do not find a correlate in the blood flow studies. Differences in methodology may be contributing to these differences.

Many of the blood flow studies focused on immediate recognition measures and very few on the delayed recall task and fewer still on the issue of effectiveness. The overlapping locations common to both studies are the frontal and temporal lobes. An additional theoretical problem is the question of how the degree of activation from eyes closed or auditory attention should be relevant to success. Occipital projections may provide the visual information to the semantic label, thus rendering recall more likely. Implicit in this research, though not easily defined, is the problem of consciousness. As the variables highlighted in this research are relevant to effective memory, they are also relevant to consciousness. Consciousness has to access the memory for the word for it to be recalled.

An additional problem concerns the temporal lobe projections during the input stage. It is not self-evident why the activations of these projection systems during the input stage should be relevant to success. Both the immediate and delayed recall conditions reflect the importance of these projections during these recall periods. Two semi-viable hypotheses are (1) the projections serve as a practice run and (2) the projections serve to activate the other connectivity patterns, which are related to later recall. Examination of Figure 1 indicates projection activity from F7 to the left posterior positions (P3, T5, and O1). These left posterior positions are the same positions in Figure 2 that are significantly activated and related to recall and in the same frequency range (Alpha) as one of the projection patterns. Is it the purpose of these projections to activate these posterior projection systems?

The classical distinction in neuropsychology between short- and long-term recall finds its correlate in this research, as short-term recall is predominantly dependent upon the T3 projections and long-terms recall dependent upon both the T3 projections and the frontal projections to the posterior regions. It is often commented upon in the literature that short-term memory can be selectively impaired while long-term recall remains relatively unaffected. This was particularly evident in the famous case of H.M., with a lesion of medial temporal lobe and hippocampus (Scoville & Milner, 1957). H.M. was significantly impaired in his short-term memory ability but unaffected in long term recall ability. These results provide an electrophysiological explanation of that common finding.

Most of the projection locations are lateral positions (i.e., T5 vs. P3) and most of the receiving locations from the frontal projections are in the posterior association areas (P3, Pz, P4, etc.). These results present a picture of a top-down and bottom-up interactive medium.

There are two additional relevant issues. One involves the relationship between connections (phase and coherence) and activations (relative power, magnitude, etc.). If memory is dependent upon activations at one or several locations, then it could be argued that the connection activations serve to activate a location. Almost all the connectivity patterns are not associated with significant activations in the locations where they meet. In several situations, activations are related to unsuccessful recall. One implicit assumption behind PET studies is that activations are somehow related to successful functioning. The second issue concerns whether memory resides in some unmeasurable biochemical event. It has often been the assumption that the Hebbian network is the correlate of cognitive functioning, such as memory. While changes in synaptic structure and function most probably do relate to memory functioning, it is not self evident that they are the most closely related physiological correlates of memory. This is an issue in the area of philosophy of science, which concerns the level of analysis. We cannot state that a certain physiological event is a psychological event, but can only state a correlation exists between the events. The waveforms of EEG tracings are representations of complex biochemical and electrical events. The waveforms are not the events themselves. We cannot reduce a patterning of electrical events to a particular biochemical event, as the meaning of the pattern may reside in the patterning of the relationships. This research does not negate or contradict previous research on subcortical involvement in memory functioning.

It is hoped that the delineation of the electrophysiology of effective cognitive abilities will lead to more effective interventions for individuals experiencing problems in these areas. The rehabilitation approach would examine the subject's values on the relevant electrophysiological variables. The intervention protocols could address the problematic areas. This type of approach has proven useful in the rehabilitation/improvement of memory functioning in normals, learning disabled and head injured subjects with preliminary results indicating improvement in paragraph recall ranging from 33% to 187% (N = 14) (to be published research).

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