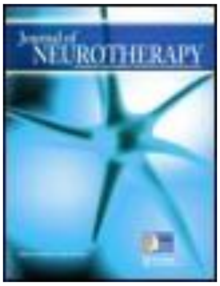

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The FIG Functional Integrative QEEG Technique and the Functional Structure of Memory Functioning in Normals and Head Injured Subjects

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The FIG (Functional Integrative QEEG) Technique and the Functional Structure of Memory Functioning in Normals and Head Injured Subjects

Kirtley E. Thornton, Ph.D.

A method was developed to simultaneously combine QEEG signals and video/audio input signals in an attempt to study how the mind processes information during memory tasks and other tasks (mathematics, emotions, visualizing, verbalization, etc.). The California Verbal Memory test was chosen as the verbal memory task. Three subjects were evaluated. One subject was a victim of a recent car accident and experienced a closed head injury. Two subjects were chosen as normal controls to evaluate differences in the processing of information. As the method represents a new methodology in the study of brain processes, it will be referred to as the FIG method (Functional Integrative QEEG). The results indicate that phenomena exist which cannot be explained by dipole analysis or other concepts currently in use. A concept of phase/coherence generators is postulated to explain these phenomena. An examination of part of the results of the memory functioning aspect of the research is presented in terms of differences between the head injured subject and the normal subjects indicating the importance of the phase concept in memory and of the complexity of mental processes. This research is an exploratory endeavor with a new methodology designed to discover how modern theories of memory processing can be related to electrophysiological functioning.

The study of brain processes has always been hampered by the nature of the method employed. Tumor studies, gunshot wound studies, etc. limit our ability to infer to the everyday working brain. PET scans, Spect scans, MEG, and fMRI have expanded our ability to analyze the mind in action. These procedures have improved greatly in spatial and time resolution over the past decade. The EEG has, however, been the only instrument which theoretically can address events in terms of milliseconds, but it too is limited due to artifact problems. The QEEG allows us more quantifiable parameters to study and understand, but is faced with similar problems of artifact control. However, despite its limitations, it allows study of factors of communication between regions through analysis of the phase and coherence measures, an aspect not possible with other current methods. Once this ability is combined with video/audio integration it becomes possible to study the second by second functioning of the brain during specific tasks and simultaneously address activation and connection issues. It also provides a finer differentiation of the meaning of activation (in terms of bandwidths). While brain processes can occur in milliseconds, the current results are limited to a more expanded time frame of one second, and as such, represent a different type of processing than occurs in standard ERP research. The results can be conceptualized in terms of the ongoing maintenance of activities or processing in tasks.

Historically, research in the area of brain electrophysiological processing during task conditions has primarily focused on the issues of relative power and nature of tasks. For example, Ackerman, Dykman, Oglesby, and Newton (1995) were able to find relative power differences in dysphonetic readers in terms of Delta and Theta activity in the right posterior parietal occipital areas. Gutierrez and Corsi-Cabrera (1988) were able to demonstrate differential patterns of Beta level activity in verbal and spatial tasks.

More recently, some research in this area has centered its attention on coherence measures. For example, Velikonja, Morrison, Williamson, and Corning (1993) were able to show differing patterns of interhemispheric coherence during arithmetic tasks and visual spatial tracking tasks in normals and schizophrenics. Lacroux et al. (1995) were able to identify increases in coherence patterns (from the F7 site) during the Wisconsin Card Sorting Test. Coherence analysis also has been successfully applied to the study of Down's Syndrome (Schmid, Tirsch, Rappelsberger, & Poppl,1992) and to SDAT patients (Baggio et al., 1990) in terms of reduced coherence. Thatcher, Krause, and Hrybyk (1986) argued for a two compartmental model of coherence consisting of long and short connections as the contributors to the coherence figures. Bressler (1994) measured coherence changes in the macaque monkey during a go-no go task on a millisecond basis and was able to demonstrate patterns of communication between frontal and visual areas. He observed that the patterns of coherences for all the frequencies generally rose and fell together.

The phase concept has received less attention. However, Thatcher, Cantor, McAlaster, Geisler, and Krause (1991) demonstrated that phase in a group of head injured subjects was the best predictor of eventual return to work.

Psychological Theories of Memory

Psychological theories of memory can be divided into four general areas: cognitive psychology, physiologically/physically oriented models (neural networks, honogram theory, Per Roland's modular theory), neuropsychological (Luria), and Gestalt theories of field dynamics.

Neuropsychological theories of memory functioning have focused on deficit concepts and localization issues and have overlapped with cognitive theories on occasion.

The role of subcortical involvement in memory functioning has been summarized by Crosson (1992) and related to cognitive models of memory. He states that "there is no widely accepted theory of cortical involvement in memory upon which to build...in many respects, subcortical functions may subserve cortical functions." (p. 292)

Cognitive psychology has provided dichotomies of memory functioning (i.e., short versus long term memory , episodic versus semantic, implicit versus explicit, etc.).

Tulving (Gazziniga, 1995) proposed a model or organization of memory in which cognitive memory systems are related to one another in terms of the principal processes of encoding, storage, and retrieval. The central assumption of his SPI model (Serial, Parallel, Independent) is that the relationship among systems are process specific. Information is encoded into systems serially, encoding in one system is contingent on the successful processing of the information in another system, information is stored in different systems in parallel, and information from each system can be retrieved independently of information in other systems. His model assumes that the nature of the relationship among different cognitive systems is process specific and the relations among systems depend on the nature of the processes involved.

Baddeley (Gathercole & Baddeley, 1993) has defined working memory in terms of three components. They are the central executive which governs the control of information flow within working memory , the retrieval of information from the different memory systems, and the processing and storage of information. This central executive is aided by two components which are called slave systems. The phonological loop maintains verbally coded material (for 1-2 seconds) and the visual-spatial sketchpad is involved with visual/spatial items. The digit span test of the WAIS-R is a classic example of the working memory in action. Amnesics will show adequate performance on this task but not on episodic memory (Gazzaniga, 1995). The theory has a subcortical looping hypothesis connecting the two involved regions.

Physiologically Based Theories

Pribram (1991) outlined his holonomic theory of brain functioning by stating that a "microprocess is conceived in terms of ensembles of mutually interacting pre and postsynaptic events distributed across limited extents of the dendritic network. The limits of reciprocal interaction vary as a function of input (sensory and central) to the network—limits are not restricted to the dendritic tree of a single neuron." "This type of economical encoding, is achieved by an ensemble of receptive fields. The advan - tages of such coding are critical. Transformations between frequency spec - trum and spacetime are readily accomplished because the transform is invertable. This makes the computing of correlations easy. In addition, the property of projecting images away from the locus of processing (as by a stereo system and by a hologram) and the capacity to process large amounts of information are inherent in holonomic processing." (p. 16)

MacLennan (1993) summarized the basic tenets of Pribram's theory by stating that "(1) the neural (axonal) net is regular and sparsely connected...axon bundles make topology preserving projections from one area to another; (2) the dendritic net (neuropil) is randomly and densely connected; (3) the function of the axons is communication, since they make regular projections and impulses are ideally suited to long distance transmission; (4) function of the dendrites is computation, since they are ideally suited to subtle, spatiotemporal analog interactions; (5) dendritic net may be viewed as a medium for linear wave interactions; and (6) nonlinearity enters only at axon hillock." (p. 168)

His theory moves between levels of physiological analysis and proposes that as the level of processing moves from cells to macroprocessing in terms of groups of cells, the field effects become the important mode of interaction. Perceptual events (and by implication thinking) are "represented not by single neurons but by patterns of polarizations across ensembles of synapses." (Pribram, 1991, p. 168) This "volume of isopotential contours or convoluted surfaces is a hyperneuron." (Thatcher & John, 1977, pp. 305-306) In Pribram's theory it is the transformations that occur between the levels of analysis which is one of his central concerns.

The father of neural network thinking was Hebb (1971) with his cell assembly theory and neural plasticity. Modern neural network theory has moved from a connec - tionist viewpoint to principles of organiza - tion and as such have brought back the thinking of Gestalt psychologists in a different framework. Arbib (1995) states that "two ideas that are so basic to the modern theory of neural networks - neural networks are dynamic systems; and neural networks are adaptive systems that change with experience." (p. 3)

The parallel processing emphasis of neural networks states that "the functional expression of the brain' s activity is best explored through a parallel processing methodology in which large populations of elements are simultaneously active, and 'adapting' by changing the strength of their connections as they do so." (Arbib, 1995, p. 29).

A related physiologically-based theory is based on the work of Roland (1993) which puts forward a modular approach. This approach will be discussed in the section on PET studies.

The pattern of theorizing about brain dynamics has moved from individual neu - ronal dynamics to more global processes and principles of self organization.

These different theoretical orientations to the problem of human memory functioning which address different phenomena and attempt to explain these phenomena with different theoretical concepts pose a problem for integration of knowledge. The present research is an attempt to empirically integrate across some of these levels of analysis as it examines a cognitive psychology measure of memory functioning (CVLT) with all its differentiations between free recall, cued recall, recognition, intrusions, etc. to psychophysiological variables with implications for neural networks and principles of underlying brain organization in a neuropsychological comparison of the effects of head injury on brain functioning. It was envisoned that with this research's emphasis upon the empirical correlates of these categorical variables the search for patterns in underlying brain electrical dynamics might lead to the discovery of the empirical self organization principles of brain functioning and thus point to intervention protocols which could be beneficial to brain functioning.

PET Studies of Working Memory

PET activation studies of working memory (Jonides et al., 1993) have demonstrated the involvement of the frontal lobe in this aspect of mental functioning. Paulesu, Frith, and Frackowiak (1993) while employing the PET methodology concluded that the articulatory loop of working memory contains two components with visual presentations: (1) a phonological store localized to the supramarginal gyrus on the left, and (2) a subvocal rehearsal system associated with Broca's area on the left.

Previous PET studies in humans have shown a selective bilateral increase in regional blood flow in the dorso-lateral prefrontal cortex associated with working memory tasks (Burbaud et al., 1995). Stein et al. (1995) found that a spatial working memory task activated middle, inferior, and premotor frontal cortex with predominant activation on the right side. The memory task also resulted in anterior cingulate and posterior parietal activation bilaterally.

Owen, Evans, and Petrides (1995) found support for a two-stage model of spatial working memory processing within the lateral frontal cortex while employing the PET methodology. Specifically, the mid-ventrolateral cortex appears to be involved when working memory tasks require comparisons with, or reproduction of, stored information. By contrast, the mid-dorsolateral frontal cortex becomes involved when active decisions about the occurrence or non-occurrence of stimuli from a given set are required.

Schumacher et al. (1996) used the PET methodology to challenge the assumption that "modality specific representations are translated into phonological representations before entering the working memory system." They were able to demonstrate that whether stimuli was presented in the visual or auditory mode, there was activation of the dorsolateral frontal, Broca's area, SMA, and premotor cortex in the left hemisphere as well as bilateral superior, and posterior parietal cortical areas as well as anterior cingulate and the right cerebellum.

Gevins and Smith (1995) using only an evoked potential methodology found that "comparison of the spatial location of a brief stimulus to the location of previously seen stimuli produced a signal that reached maximum amplitude over right hemisphere dorsolateral frontal cortex 305 msec after stimulus onset. This signal was not observed during an otherwise identical task requiring working memory for verbal stimuli, or during spatial or verbal control tasks. One-hundred forty-five milliseconds later, another signal was maximal over left hemisphere dorsolateral frontal cortex for both spatial and verbal working memory tasks, but not for the control tasks. This was immediately followed by a prolonged signal maximal the over right parietal cortex in both working memory conditions..." (p. 415) They concluded that "different representational working memory strategies recruit functionally specialized regions of prefrontal cortex. The subsecond sequence of cortical electrical 'hot spots' further indicates that the neural processes of working memory involve rapid functional coordination between prefrontal and posterior regions of association cortex. There is little evidence in these results of brain systems which directly embody the metaphorical psychological description of working memory as consisting of verbal and visuospatial storage buffers and an executive reasoning processor." (p. 415)

Cohen et al. (1994) found activation of the middle and inferior frontal gyri during a working memory task. Dolan et al. (1995) found that "visual imagery in episodic recall is associated with activation of the precuneus. By comparison, recall of non-imageable word-pair associates is associated with a predominant activation in the inferior frontal gyrus suggesting alternative processes for non-imageable recall. Activation of the precuneus, without activation of early visual processing areas, in association with visual imagery implies that coherent image generation does not necessarily require activation of brain regions involved in perceptual processes." (p. 417) The precuneus is located in the general region of PZ and Broadman's area 7.

Roland (1993) elucidated his theory of the modular functioning of brain process which postulates that "the cerebral cortex participates in brain work in awake human subjects by activating multiple cortical fields. Each activated field has an area of a few square centimeters...each covering some $800mm^3$ to $3,000\ mm^3$ of the cortex." (p. 105) In terms of memory functioning he notes that "the dorsolateral prefrontal cortex and the cingulate cortex, then, are the most likely candidates to address the (stored) memories." (p. 323) He elucidates some of the problems, however, incumbent with the PET methodology. "Macroscopically, the active fields mark the regions that talk together or are simultaneously active. This is a consequence of the fields being connected by mutual excitatory connections...It is not possible with tracer techniques to judge whether the different fields participating in a single task appear in time sequences or are simultaneously active. Consequently one cannot judge exactly which of the fields are talking to each other. (p. 423)

Of particular relevance to this research are several studies, one of which was done by Andreasen et al. (1995) in which the subjects learning a 15-word list were studied with PET methodology. The study showed decreased activations with practice, novelty effects of increased activation in the left frontal regions. They concluded that the human brain contains a "distributed multimodal general memory system. Nodes on this network include the frontal, parietal and temporal cortices, the thalamus, the anterior and posterior cingulate, the precuneus, and the cerebellum. There appears to be a commonality of components across tasks (e.g. retrieval, encoding) that is independent of content." (pp. 284-295) A previous study (Becker et al., 1994) had addressed the same problem of recalling a 12-word list. They found increased activation of the frontal area, area 10 of the prefrontal cortex, in the cingulate cortex, and extension of activation into the inferior frontal lobes. Fletcher et al. (1995) using the PET methodology found that the prefrontal cortex and retrosplenal area of the cingulate cortex was associated with encoding of episodic memory while retrieval from episodic memory was associated with activation of the precuneus (Broadman Area 7) bilaterally and of the right prefrontal cortex. They did not find any hippocampal activation associated with either encoding or retrieval conditions. In a single case study design of a transient global amnesia, Baron et al. (1994) using PET methodology found reduction in blood flow and oxygen consumption over the entire lateral frontal cortex on the right side.

Research Goals

Studies of working verbal memory have implicated the frontal, temporal, and precuneus areas of the brain in terms of the cortical areas which are assessed by the QEEG technique. There are several goals of this research: (1) to establish the electrophysiological correlates of verbal working memory as determined by PET studies, (2) to determine the effect of a head injury upon this process, (3) to determine the underlying electrophysiological correlates of the distinctions made in cognitive psychology, and (4) to determine the correlates of superior memory functioning.

Method

Apparatus

A method was developed to simultaneously record to an 8 mm video tape both QEEG signals and video/audio signals. The Lexicor Neurosearch software and digital recording equipment of Lexicor Medical Technologies was employed as the instrument used to collect the QEEG information. The QEEG signal was fed onto a computer screen on the left side and the video image of the subject was placed on the right side of the screen. This combined image was then sent to a recording device which has a separate audio input to record the audio signal (subject's voice) onto the recording tape. In this manner all three sources of information (audio, visual, QEEG data) are preserved on the tape. The tape can then be analyzed and epochs labeled according to what was occurring at the time. The Lexicor software allows the saving of the QEEG information by epochs, down to a .5-second period of time depending upon sampling rate (at 512 samples per second to enable a .50-second epoch). A sampling rate of 256 was chosen, which results in a one second period of time for each epoch and enables the examiner to sample up to the 64-Hz range.

Subjects

One subject had been the recent victim of a car accident while at work. He was a 32-year-old white male who had experienced a closed head injury one month prior to the experiment. His only recall of the accident was of a loud sound. He was a left-handed individual who had completed high school. The MRI was negative for clinical findings. He will be identified as TBI in the discussion. The study was completed within one month following the accident. The second subject was a 23-year-old white female who had just graduated from college and was pursuing an acting career. This second subject will be identified as YN (young normal subject) for subsequent discussions. A third subject was a 49-year-old white male with no history of head injury. He will be identified as ON (older normal subject). TBI was evaluated at one year postaccident to evaluate the change in QEEG variables which accompany the expected changes in his neuropsychological functioning.

All subjects had available eyes closed conditions data which could be evaluated by the Life Span Normative database. The two normal subjects had tested IQ's in the 130 range. TBI's estimated IQ (Shipley Institute for Living scale) was 89 following the accident. However, the high school records obtained for the subject indicated average performance, thus indicating a more probable average or higher level of intelligence. The Shipley was conducted one year postaccident and resulted in an estimated IQ of 124. The initial deflated Shipley score was thus probably due to the effects of the head injury.

Informed consent was obtained from all three subjects in compliance with the U.S. Department of Health and Human Services and set forth most recently as a common Federal Policy for the Protection of Human Subjects.

Procedure

With this procedure two subjects underwent a standard memory task which is employed in neuropsychological studies (California Verbal Memory Test [CVLT]). The third subject (ON) underwent a similar type of assessment with a different word list. The subjects were blindfolded during the experiment to help reduce the amount of eye movement artifact which could occur. They were also instructed as to the nature of artifact and its manifestations.

Data Collection and Analysis

The general purpose of this experiment was to devise a method to study how the brain functions under memory task conditions. However, it is necessary to describe the general parameters of brain functioning in terms of these variables prior to a meaningful discussion of particular tasks. This article focuses only on the empirical findings of brain organization of function and theoretical implications.

The data was recorded during two separate periods for TBI and YN and four periods for ON, as the CVL T requires a 20-minute waiting period between the short and delayed recall conditions. The intervening time was filled with resting and conversation and the recording of an eyes closed condition for TBI.

Once the data were collected, the video tape was reviewed and each epoch labeled according to what was occurring at the time. The bandwidths chosen for the analysis were as follows and were based upon factor analysis reports as reported in Niedermeyer and DaSilva (1992).

Delta: 0-6 Hz; Theta: 6-9 Hz; Alpha1: 9-10.5 Hz; Alpha2: 10.5-12.5 Hz; Beta1: 12.5-15.5 Hz; Beta2: 15.5-18.5 Hz; Beta3: 18.5-38 Hz; Beta4: 38-64 Hz.

The first six bandwidths were chosen on the basis of previous factor analysis studies as reported in Niedermeyer and Da Silva (1992). The remaining hertz range available (above 18.5) was divided equally between the Beta3 and Beta4 bandwidths as there have been no factor analysis studies which can delineate how these bandwidths are organized. Yet there is considerable research on the 40-Hz gamma range. With these definitions of the bandwidths, relative power figures as well as peak frequency and peak amplitudes were generated for all of the 19 locations of the standard 10-20 system. Impedance measurements for all locations was maintained under .50 kOhms.

Coherence and phase figures were generated (by bandwidth) for all intra-hemispheric pairs of electrodes, homologous pairs (similar positions in opposite hemisphere), and nonhomologous interhemispheric pairs (right and left frontal to right and left central/posterior). Phase, coherence, peak amplitude, and peak frequency measures were all defined, calculated, and produced by the Lexicor software. The positions Fz, Cz, and Pz were not analyzed in terms of coherence and phase relationships to the remainder of the positions. For example, one variable would be the phase relationship of Alpha1 between F3 and T3. This procedure produced approximately 2,250 variables (phase and coherence relationships, relative power, peak frequency, and peak amplitudes) covering some 2,500 epochs (seconds) each for the two subjects (TBI and YN) for the two recording sessions which lasted about 40 minutes in total and about 7,000 epochs for the third subject (ON). The first two subjects generated about 5-million numbers and the third subject about 15 million, as there was more extensive testing of this subject.

Microsoft's Excel 7 was employed as the original spreadsheet program. The data were then transferred to CSS Statistica for Windows (version 5) where the statistical analyses (t tests) could be performed. Initial attempts to factor analyze the data was met with software limitations of 300 variables which could be entered into a factor analysis. Multiple attempts were made to analyze different subsets of the data. The pattern that emerged was one of the data grouping themselves around the issues of coherence and phase in the different bandwidths. To allow for maximal validity of the factors across both hemispheres, the data were arranged in terms of the phase and coherence values of the different bandwidths and factor analyzed by these groups. As 50 factors would emerge from the analysis for each grouping (due to the limitation set by the software) with Eigenvalues over 1, the resulting factors numbered some 400-500, for all the possible phase and coherence relationships as well as relative power, peak amplitude, etc. Figure 1 represents the types of patterns which emerged for the phase and coherence relationships.

Additional variables were constructed for the three subjects in terms of Theta and Beta activity. The ratio of the relative power of Theta to the two lower Beta bands (Beta1&2) and to the two higher Beta bands (Beta3&4) were calculated. These comparisons will be presented in the discussion and referred to as Theta/Beta low and high, respectively. Additional variables for the subjects were constructed which reflected intra-hemispheric and homologous phase and coherence relationships as well as general global activation patterns. For example, for each subject the phase relationships of all possible relationships in the left and right hemisphere were constructed separately for each band width. In addition, the homologous phase and coherence relationships were calculated for all band widths. Global activation patterns (across all locations) in terms of the respective band widths were calculated for each bandwidth in terms of relative power, peak frequency, and peak amplitude.

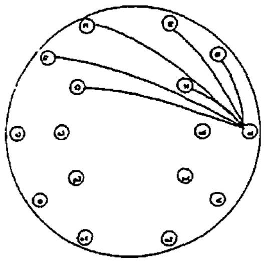
Editing

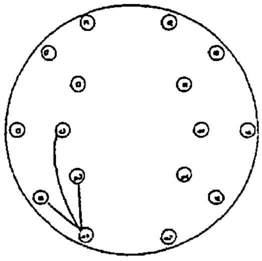
All QEEG records were edited for noncerebral events. Each epoch which constituted a noncerebral event was labeled in the spreadsheet, thus allowing for subsequent analysis to exclude those epochs. The predominant editing selection criterion was directed toward eye movements. Possible EMG artifacts occurring in the T3 and T4 or O1 and O2 positions were not eliminated. There were several reasons for this approach. First, for one subject (YN) there was a considerable amount of possible EMG contamination at T4, almost eliminating the subject as a viable subject. Attempts to reduce the EMG were only partially successful. Second, it was of some interest and clinical importance to understand how the EMG artifact affected the other variables under consideration and in what bandwidth it may be focused. Third, memory continues to operate under artifact conditions. Fourth, some of what has been traditionally considered artifact may constitute relevant brain signals. Additional measures were developed to follow possible muscle artifact. This measure was based on previous research in the area of artifact. It consisted of an analysis of the factor patterns of muscle artifact, identification of those factors which could represent muscle artifact, generation of factor scores for these factors and placing them in the spreadsheet for simultaneous analysis.

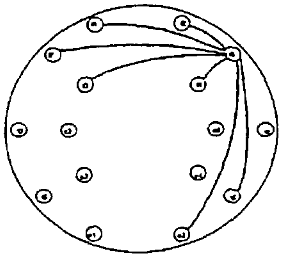
California Verbal Memory Test (CVLT)

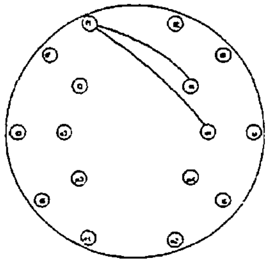
The CVLT is a well researched instrument which employs a 16-word list (with 4 words in each category , i.e., fruit, tools, clothes, spices, and herbs) which is presented five times (at a rate of one word per second), followed each time by immediate recall by the subject. Following the five presentations, an additional 16-word list is presented (also containing four categories) and the subject is asked for immediate recall. The subject is then requested to recall the first list (free recall) and then asked to recall the words in a particular category (supplied by the examiner). Following a delay of 20 minutes, the subject is again asked to freely recall the list. Again, the subject is provided with the categories and asked to recall. The last part of the test requires the subject to identify whether a word (of 40) presented aurally by the examiner was on the first list. In this modification of the above testing protocol, the subject was allowed one second following the word to process the word. As the examiner could view the collection of data on a projection screen, it was a relatively minor task to present a word during a particular second, pause for one second, and then present the next word. Two of the subjects (TBI and YN) were presented the CVLT in the standard format while a third subject (ON) was presented a similarly structured list in a different format of presentation.

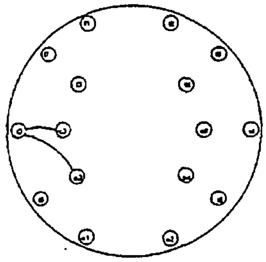
Figure 1
Phase/Coherence Factor Structure Connections

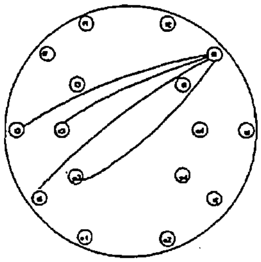

T4-Simple Anterior Cross Beam

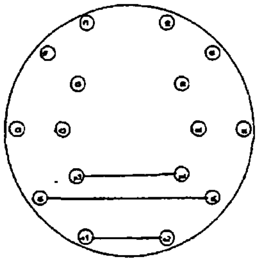

O1-Simple Uncrossed Short Anterior Beam

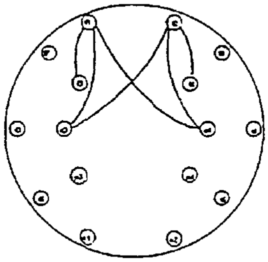

F8-Simple Wide Anterior Posterior Beam

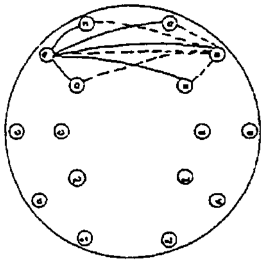

F1-Simple Narrow Cross Beam

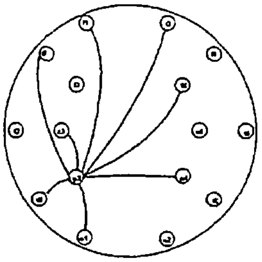

T3-Simple Short Beam

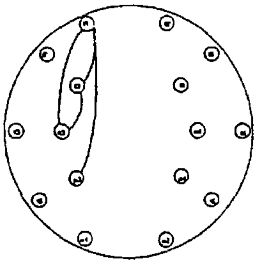

F8-Simple Cross Long Posterior Beam

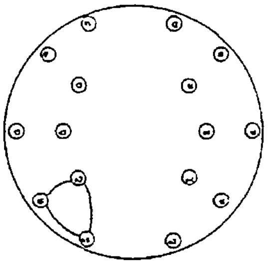

Posterior Parallel Beams

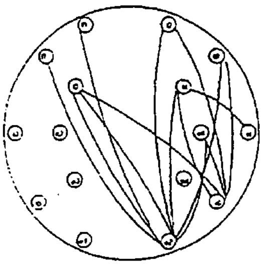

Anterior Mirror Beams

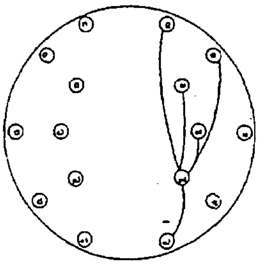

Matched Anterior Beams

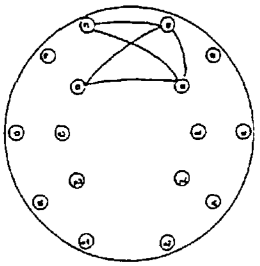

P3-Starburst Beam

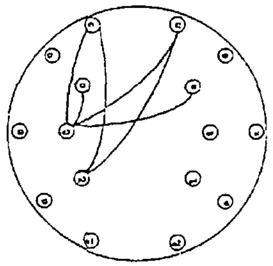

F3-Curly Beam


Left Posterior Circle Beam


Complex Crossing Beams


P4-See Saw Uncrossed Simple Beam


Anterior X Beam


Complex Matched Band Beam

There were several differences in the task and the subjects' approaches to the task which need to be stated. For ON the task was somewhat different than the other two, as the words were presented in the category groups and sometimes presented in a more rapid fire manner without a one-second intervening period. This subject was quite consciously employing a visualization technique in which the objects were placed mentally in separate visual spaces. This presentation style and strategy may have had an effect on the subjectís brain response in terms of the parameters under consideration. YN was consciously attempting to recall by sequence, as the serial order score of the CVLT indicated, a Z score of +5. TBI also employed somewhat of a sequential approach as indicated by his serial order score of +2.

The respective memory performances were: TBI: 44 of 80 (Raw Score, T score of 26, percentage score of 55%), YN: 63 of 80 (Raw Score and 48 T score, percentage score of 79%), and ON: 73 (Raw Score, percentage score of 87%) out of a possible 84.

Results

Activation During Presentation

T-test comparison of all the variables between eyes closed, resting condition and the activation condition in which the subject is attending to the word lists is presented in Figure 2. This data includes all five presentations; artifact epochs were not included in the analysis. The epochs analyzed included both the periods when the subject was listening to the words and the intervening one second of processing time. An additional analysis employed the factor activation patterns. Factor loadings were generated for all the factors and t tests were conducted on the factor loadings in the different comparisons.

One of the possible criticisms of the t-test approach involves the statistical probability of effects being due to chance. Given the 16 positions and 8 bandwidths which are analyzed in terms of the phase and coherence concepts, there are 960 connection figures. At a .03 level of significance, there are about 29 significant correlations expected by chance. Given one significant difference occurring at one location in a particular bandwidth, the probability of another significant difference occurring at the same location and same bandwidth is .0625*.125 or .0078. The probability of a third at the same location and same band would be .0078 x .0078 or .00006104. Thus, although there is an issue regarding significance by chance alone, a pattern generation analysis attenuates some of these concerns.

In terms of the differences between the three subjects, it appears that the phase figure offers one of the most powerful discriminators of successful memory performance, under the assumption that the differences observed relate to memory performance. The memory performance increases from TBI to ON as the dominance of the phase activity increases. This is evident in Figure 2. The heavy reliance of the FP1—simple uncrossed and wide crossed posterior beams (coherence Beta4) by TBI to accomplish the memory task is clear in Figures 1 and 2. In addition, both YN and ON activated the left posterior (T5,O1) phase generators as well as the F8 phase generator to a larger degree than TBI, who did not appear to engage them at all. It is evident also in these figures that memory encoding involves the entire cortex and cannot be conceptualized as involving only the temporal regions. What is unclear in these figures is the differences between processing the words and the encoding of those words into memory. The dominance of the long distance connections versus short distance connections is another pattern evident in the figures. ON also appears to be employing higher frequencies to obtain a better memory performance.

A further understanding of these processes can also be obtained by an examination of the nature of the differences, that is the highest level of significance. In terms of the factor activation patterns, TBI had the highest loadings on the F4-P4 coherence

Figure 2

T-Test Significant Differences of Variables: Eyes Closed vs. Task

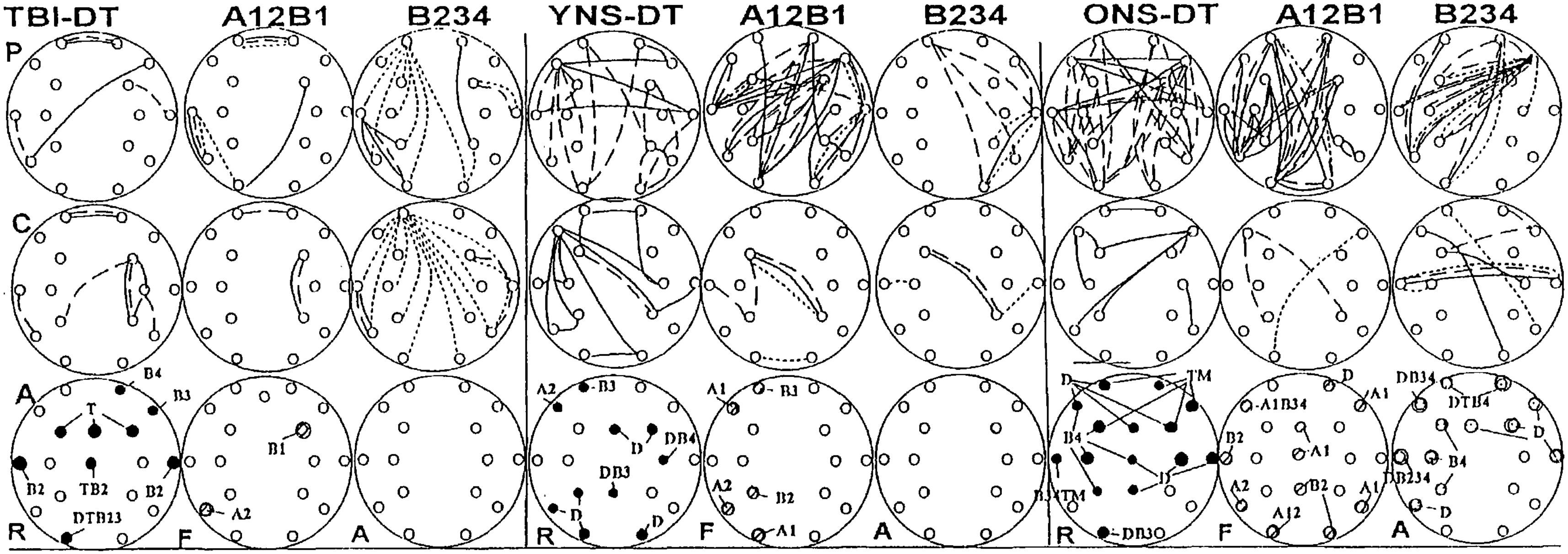


Figure 2: First three columns represent TBI subject, second three columns YNS, and last three columns ONS. First row represents phase figures (P), second row represents coherence figure (C), and last row the activation patterns (A). First column of each subject represents the Delta and Theta bands; the second column the Alpha1, Alpha2, and Beta2 bands; the third column the Beta2, Beta3, and Beta4 bands. Each head figure depicts the respective bands it represents by the nature of the line drawn. Within each figure, the lowest band represented is drawn as a solid line. The next higher band is presented as a dashed line, and the third by a dotted line. The activation patterns are presented in the respective middle figures with diagonally filled circles or ellipses. The peak amplitude figures are presented in the third figures in terms of dotted enclosed circles or ellipses. Each activation figure has its appropriate label (R=relative power, F=frequency, A=amplitude) in the lower left quadrant of that figure. The bandwidths are indicated by the following letters: D=Delta, T=Theta, A1=Alpha1, A2=Alpha2, B1=Beta1, B2=Beta2, B3=Beta3, B4=Beta4, Total Microvolts=TM.

Delta and Theta factor (.77). This was manifested again in t-test comparisons of the individual variables in terms of the highest t values (9.3 and 10.1 for Theta and Delta, respectively). For YN, the highest individual variable and factor loadings were on the F3-P4 coherence Delta and Theta figures (.85). For ON the highest factor activations were for the left hemisphere phase Alpha1&2, relative power of Beta4 at F7, F3, and Fz, and phase Theta relationships between the right posterior and bilateral frontal areas. In terms of the t test comparisons, it was the relative power of Beta4 at F7 (t value of 10), the FP1-T6 connection in terms of the phase figures between Delta and Beta1 (t values of 4 -7), peak amplitude at F7 of Beta4 (t value of 15), peak amplitude at F3 of Alpha1 to Beta1 (t values around 7), and peak amplitude at T3 of Beta3 and Beta4 (t values of 12-17).

How these differential activation and connection patterns relate to the memory performance, individual strategies for recall, and brain organization can only be pointed to as existent in this research. It appears, however, that the concept of dominant connections and activation patterns which can be differentiated from the background activated patterns may be useful in this type of research.

In terms of the more global Theta/Beta comparisons, TBI did not show a significant change from eyes closed to the listening task in terms of either the Theta/Beta low or high comparisons, yet had the lowest figures (indicative of highest relative activation of the Beta bands) of the three subjects. YN showed a decreased ratio on all variables (indicating greater activation of the higher bands) in both the left and right frontal areas, but the Theta/Beta high ratio was a more significant and larger shift. ON showed significant changes in the left frontal Theta/Beta high ratio and right frontal Theta/Beta low (toward greater activation of the Beta bands). Thus the higher ranges of the Beta bands in the frontal regions appear to be more important than the lower bands during the listening condition. An analysis of the individual frontal variables indicated that ON activated the F7 Beta4 relative power, while YN activated FP1/F7/F8 Beta3 and TBI activated the F7/F8 Beta3 relative power. Thus for all three subjects the F7 position represented the common activation region. For ON the absolute values were higher for the Beta4 (as well as Beta3) than the other two subjects, who were roughly equal for level of activation of Beta3. Thus activation of the F7 position by TBI does not appear to be the critical issue for recall ability as TBI and YN showed equal levels of activation. The differences resided in the coherence and phase relationships.

In terms of the global variables, TBI increased the relative power of Theta and Beta2&3, increased peak frequencies of Beta1, increased homologous Theta coherences, left hemisphere Beta4 coherences, and right hemisphere coherence Theta under the activation condition, while decreasing all peak amplitudes.

YN increased the relative power of Delta, decreased relative power of Theta, increased Alpha1 peak frequency, decreased peak amplitudes of Theta to Beta2, increased phase relationships in the left hemisphere (Theta to Beta4), increased right hemisphere phase Beta4, left hemisphere coherence Delta, and decreased right hemisphere coherences in Beta2 and Beta4.

ON increased the relative power of Delta and Beta4, increased peak frequencies of Alpha1 and Beta2, increased peak amplitudes of Delta and decreased all other peak amplitudes, increased phase relationships in the left hemisphere for Theta, Alpha1&2, increased homologous coherence Beta2 activity and phase Delta and Theta, and increased right hemisphere coherence Beta2 and phase Theta activity.

All subjects decreased peak amplitudes generally. Better memory performance was accomplished with use of the higher Beta bands (ON only), increases in phase relationships in the left hemisphere and right hemisphere, and homologous relationships. TBI did not activate the phase relationships.

Thus, the registration phase of learning a word list can involve activation of connections in both hemispheres and homologous connections in different bandwidths. Under the assumption that TBI's approach to the task is ineffective, then his failure to activate the left hemisphere phase relationships in the higher bands appears to be a cause of his memory failure.

The use of the high frequency range (Beta4) by ON in the frontal (Fz/F3/F7) area is consistent with PET scans and fMRI studies of working memory. An examination of the relative power figures (F7-Beta4) for TBI, YN, and ON revealed respective relative power figures of Beta4 of 6.2 (ns), 5 (ns), and 10.3 (sig. at .05). However, TBI and YN had respective significant Beta3 relative power figures of 10.9 and 1 1.2. Thus all three subjects activated the F7 position in terms of the high Beta bands. To examine the phonological loop hypothesis, presumably there should be positive and significant differences related to the F7 position (closest to Broca's area) in terms of its relationship to the other positions (under the assumption of a cortical representation of the loop). For ON an examination of the relationships between the F7 relative power of Beta4 and all the other possible relationships revealed only one significant positive relationship of .31 in terms of F7-C3 coherence Beta4. Most of the other relationships were negative or significantly negative. It appears that when the brain activates an area for processing it generally disengages that area from the rest of the cortical areas in terms of the band width that it is activating. The fact that the C3 position is activated could, however, argue for the phonological loop as the C3 is the area close to the mouth representation. However, this is contrary to the current hypothesis which links Broca's area with the superior temporal gyrus as the subcortical looping connection. For YN there were small but significant relationships (.16-.19) between the relative power of Beta3 at the F7 position during the listening condition and C3 phase Beta3 as well as coherence Beta3 to the P4 and T6 position, and positive relationships to the T6 position in terms of phase Alpha1 and Alpha2.

For TBI there were only two positive relationships between the relative power of Beta3 activation at F7 during the activated condition and coherence Beta1 to T3 (.18), which is closer to the superior temporal gyrus, and T6 coherence Delta (.17).

It is also of some interest to note that for TBI, the normative database comparison indicated excessive Beta in the posterior regions, asymmetry problems in terms of excessive Delta, Theta, and alpha emanating from the FP1-FP2 sites, low Beta activity at T4, high coherence Beta measures emanating from the FP2, F8, and F4 positions, and elevated phase figures in the alpha and Beta ranges in both hemispheres emanating from the F7/F3 and C3, and FP2/F8/F4/T4 and C4 positions. Thus, a frontally originating phase and coherence generator problem. There is an inherent theoretical problem implicit in these figures. On the surface the question might be how is it that a subject who shows increased phase and coherence figures in an eyes-closed condition is unable to activate or increase these figures when required by tasks? In examination of the raw figures, it is clear that the activation condition raises all values and therefore is a state that is qualitatively and quantitatively different from the eyes-closed condition. Inference from one to the other is not possible at this point in the state of our knowledge of these figures.

Results of Other Comparisons

A comparison of the listening to the immediate free recall condition indicated that for TBI and YN there were greater activations of the higher frequencies (Alpha1 to Beta4) in terms of phase bilaterally and coherences (Beta2 to Beta4) in the immediate free recall condition. Interestingly, TBI did not activate the frontal coherence and phase activity as much as YN did. For ON there were not many significant changes in the phase and coherence relationships, probably due to the significant increases observed during the listening condition. All subjects showed increased relative power and increased peak amplitudes in the higher ranges (for the immediate recall condition), while for two subjects there were increased use of elevated peak frequencies in the higher ranges (TBI and ON).

Inaccuracy of subsequent recall could be determined for TBI and YN by their use of the FP1 coherence generator during the presentation, a right hemisphere processing approach or lack of left hemisphere activation connection patterns for all three subjects. For TBI, intrusions (words not on original list) and perseverations (repetition of previously stated words) showed a pattern of the FP1 coherence generator or right hemisphere activity as dominant during the errors (while stating his response).

Successful immediate free recall (vs. unsuccessful search) was reflected in decreased use of the phase relationships during unsuccessful free recall for all subjects, decreased use of the higher bands in terms of peak amplitudes, and differing patterns for the relative power and frequency parameters.

Hearing and processing the words reflected individual differences in processing. The comparison between free recall and cued recall also revealed individual patterns in responding. A comparison between immediate free recall and delayed recognition indicated increased use of the connections (phase and coherences) in the higher frequencies (bilaterally) for TBI under the recognition condition and decreased use of phase and coherence relationships for YN and ON.

A comparison of the immediate free recall vs. long-delayed free recall indicated a right frontal activation connection pattern in the delayed free recall condition, consistent with other current research implicating the right frontal lobe's involvement in delayed recall and recall from long term memory.

A countdown to recall analysis was conducted to examine how the mind is functioning just prior to the verbalization of the response. There was a strong indication that the frontal lobes are bombarded with connection activity from the posterior sections and within the frontal lobes just prior to the verbalization of the response for all three subjects.

There were indications throughout the comparisons that the three individuals had particular connections that they employed to a greater extant than other connections. How these patterns relate to memory and/or personality functioning is unclear at this point.

Discussion

The Andreasen et al. (1995) PET study had indicated cortical activations in the frontal, parietal, and temporal regions. This analysis reflected relative power activations at F7 (across all subjects at .05 level of significance), a more varied and diffuse activation (in terms of relative power, peak frequency, and amplitudes) across the hemispheres, and a strong pattern of interconnections evident. Activations were also observed in the areas indicated by the Andreasen study.

The neural network model of distributed parallel processing appears evident in these results. Tulving's concept of serial encoding is not necessarily negated by this evidence as the serial encoding could occur at a much more rapid rate than the one-second period of time under consideration. However, the evidence also certainly points to a greater probability that encoding is occurring in parallel operations rapidly. There have been numerous reports in the literature regarding the involvement of the right parietal lobe in attentional functioning. For both TBI and YN there was activation (in terms of the factors) of this region in terms of Alpha1 relative power as well as peak amplitudes for

YN. In addition, both TBI and YN had powerful activations of connections to the P4 position. However, this was not evident in ON, who presumably was paying attention as the recall score was the highest for this subject. An examination of the absolute values did not indicate that ON was activating this region on a lower level of significance, but did indicate lower levels of Alpha1&2 relative power and higher levels of Beta3 activity. This finding poses a problem for the formulation of necessary activation of the right parietal lobe for adequate attentional allocation.

The F7 relative power activation and the factor activation patterns for TBI and ON substantiated the PET studies indicating frontal lobe location of working memory, if activation is considered the criteria. The modular theory of Roland is substantiated in part, but the modules appear to have a greater area of size when analyzing the factor patterns, and thus could represent combinations of the modules into larger activation units, a possibility not precluded by Roland's theory.

Luria's analysis of syndromes has in its formulation a location orientation. It is also a hierarchical, modular, connectionist model. It is evident that Luria's formulation of activation of multiple modules is substantiated by this data. Subcortical issues cannot be examined in this type of design, but have been clearly implicated in memory functioning (Crosson, 1992).

Pribram's holonomic theory receives support as the basic units of communication appear to be projections from one location to a diverse set of receiving locations. This could be accomplished by a projecting source with inhibitory influences affecting the direction and expanse of projection. It should be kept in mind, however, that the projecting source is not necessarily the location of the particular electrode. The electrode is picking up a signal from a mass of underlying activity. To define the exact nature of the source would require more electrodes.

There is a well-known theoretical position in cognitive psychology which argues the importance of the distinction between top-down and bottom-up processing. Employing the generators as indicators of these types of activities, it appears that TBI is relying heavily on top-down processing while the other two subjects are combining the two modes of processing.

What this experiment can provide is a general appreciation of the complexity of the problem. While reduction of the variables (in terms of bandwidths, etc.) may have led to a more simple description of the differences, it would have lost the intricate and separate nature of the processes. The results do not confirm Bressler 's observation that the coherences for the different bands generally rise and fall together , as this research indicates that there are separate activations in different regions with different connection patterns.

In terms of all of the theories proposed in the introduction, the most compelling match to this type of data is the work of Pribram in terms of his holonomic theory. The patterning of the phase and coherence relationships appear to operate as holographic generators of projection beams. The primary functional structure at this level of analysis appears to be one of activation and send, and these processes appear to be by and large independent of one another, negating Roland's assumption that activation means communication. Pribram (in press) notes that "the circuits composing each of the posterior, central or frontal cortical systems can be divided into extrinsically connected (to receptors and effectors) projection systems and so called association systems intrinsically connected in large measure to other brain and brain stem structures."

The distinctions made in cognitive psychology between free recall, cued recall, etc. may have physiological counterparts, but the results indicate that the electrophysiological differences of these concepts reside as much in individual patterns of response as they do to similarities across individuals.

Cued recall, for example, does not engage the exact same process across all individuals.

What is evident is that more sophisticated designs need to be constructed to break apart these processes and to narrow down the most important underlying processes involved in memory. However, it must be kept in mind that the brain operates as a whole unit and one of the problems with research which attempts to focus only on one aspect of the problem is that the total response is lost, which defeats the goal. What can be gleaned as critical from this research is that no matter how simple the task may appear, there is a complex, individualized response to its solution. The individual and global nature of the response is not a problem to be avoided, but to be addressed. This research asked certain questions regarding the electrophysiological processing underlying psychological constructs. The answers to the questions have presented a set of data which is not conceptually easy to understand at this time. The results have resulted in more questions than answers.

Despite the findings obtained in this research, the small number of subjects must be kept in mind in terms of rendering broad generalizations of memory functioning. The processes represented in the figures and findings were chosen as the most dominant by the various methods. The assumptions that the highest figures reflect the dominant processing approach and that these are the critical processing variables for memory could be challenged from several positions. The most salient is the concept that the mind is actively engaged in the task on a number of different dimensions simultaneously and the highest number approach is not necessarily reflective of the most important process or indicative of the only possible meaningful breakdowns. For example, the ability of an airplane to fly is mainly dependent upon its engines and wings, but a small loose rivet in a certain location could totally disable the plane. Processes operating at less than the dominant mode could easily be essential for task completion.

The phase concept has been conceptualized as the activated linking relationship evidenced during a task. Degree of activation is reflected in the nature of the number generated. The coherence concept has been conceptualized as the strength of the connection between regions. This definition is a static definition and does not indicate the dynamic nature of the data obtained. It is also clear that coherence is task related. How to conceptualize these differences in processing and understand their nature is a theoretical task which requires linking to empirical data. The role of the higher band widths is evident in the data, as well as the involvement of peak frequencies, peak amplitudes, and nonhomologous connections. This research is limited in its lack of information regarding nonhomologous posterior connections and frontal nonhomologous connections for TBI and YN.

The modularity approach and the connectionism approach in neuroscience have been involved in a debate about the relative importance of each, although each does not deny the importance of the other. This methodology is the only one available which can simultaneously address both issues in clinical situations. Its limitation is the lack of direct information regarding subcortical involvement. One of the indications in this research is that activation does not imply connection to other regions. The assumption that activation of a bandwidth at a location automatically activates that band's phase and coherence relationships to other parts of the brain is incorrect. The activation of a region appears, if anything, to dissociate that region's connection to other regions. This fundamental fact, evident throughout the data in terms of correlational analysis, poses a basic problem in interpretation of PET data. Although it can be argued effectively, with the use of PET data, that the brain has a modular orientation, it cannot be assumed that the activation of that region automatically ensures that the information is being integrated with other information and is being presented to conscious awareness as a unified experience. Neither PET data nor this data can empirically and adequately at this point define the relationship between activation and connectedness at this level of analysis despite the compelling thought that there must be some relationship. What is being observed in this data is one level in the transfer of information from the neuronal and glial level to consciousness, with each level having its own set of dynamics and regulatory laws. Is what lies just below the level of conscious experience these electrophysiological correlates or is there an intervening step between these levels? Presumably through more refined research the functions of these pulsating beams of coherences and phase relationships, and macro activation patterns can be functionally delineated. However, the search for a function to an activation pattern may be doomed as the issue has not been conceptualized in its most appropriate terms.

The complexity of the human mind is evident in this data, and differences in processing style, a fact long known and studied in psychological research, have potentially a psychophysiological correlate in these patterns. The analysis and neurotherapy treatment of psychopathology, brain injury, memory disorders, etc. in terms of this type of data is an area of potential rewarding research. Advancement in software development tied to theoretical and empirical developments can only help this area grow to its fullest potential. This research employs a method which is like a new microscope as there is a lot of information with un-known meaning.

Neurotherapy Considerations

The preceding analysis is only a beginning to understanding memory processing from the point of view of QEEG variables. In terms of the rehabilitation of memory functioning, the evidence points to the need to engage the phase relationships in the left hemisphere to the frontal lobes and to activate the F7 location. It is not clear whether the activation of F7 is a necessary but not sufficient condition as all subjects activated the area with the two normals activating connections from this position much more actively. However, it is clear from this research that there is no one set of relationships which is critical, as the effectiveness of memory depends upon the completeness and number of activated connections both in terms of inter and intrahemispheric connections, and nonhomologous connections also, as well as activation issues.

From these data, then, what is the prescription for the neurotherapy of memory functioning? Treatment prescriptions in the medical field are generally indicated in terms of type and amount. These recommendations must be tempered with the fact that although the data does not indicate a single direction of treatment, they do indicate in which process the problem resides—in the phase relationships and secondarily with some focus on left hemisphere phase relationships, but not necessarily to the temporal locations. The failure to recall may not be due to a break in the processing link which assumes a serial processing approach of the brain, but a breakdown in sections of the overall process, which are occurring simultaneously or in the lack of totality of response.

In addition, proposed psychological processes require physiological counterparts to be scientifically and practically useful. The right frontal activation of phase and coherence relationships during retrieval processes provide one such useful psychological distinction with anatomical correlates.

The problem in the application of these findings to the neurotherapy approach is a problem in the understanding of the results. Is the search failure pattern seen in these figures a result of the failure of the mind to find the words or is it that the pattern is the reason for the failure of the mind to find the information? If the latter is assumed, then it is a relatively simple matter to enhance the appropriate activity. However, if the results only indicate the reaction of the mind to the failure, then an approach based on the this explanation will be doomed, as we would be training a reaction.

There are problems in this area in terms of prescriptive treatment recommendations. One is tempted to mimic the response pattern of ON to enhance memory functioning. However, it must be kept in mind that the other subjects did recall many of the words employing a different approach. There was a strong indication that subjects favor certain connections in their approaches. Do we move them away from their dominant style of connection and activation or try to improve that approach within the style? Do these dominant patterns represent stronger or better connections or preferential use issues with no direct implication for memory rehabilitation?

Clinical Application of Research Results

The knowledge gained from this research was employed on a subject with a history of a recent head injury. On a test of working memory (Michigan Serial Recall test) conducted three months after the accident (to allow for spontaneous recovery) the subject performed in the 1st percentile on the visual and verbal tasks (Michigan Serial Recall Assessment Test). Six months later, following neurotherapy interventions based upon the above research, he undertook the same task and performed in the 99th percentile on both tasks. Additional Neuropsychological measures (CVLT, Category, Wisconsin, CPT, etc.) all showed significant improvements in functioning. A fuller explanation of these changes and interventions will be presented in future articles as more subjects become available. The subject had also undergone several months of Amantadine, a medication useful in head injury cases. However, he had ceased the use of this drug several weeks prior to the readministration of the testing, but was on an antidepressant (Paxil) during both testings. This result is extremely encouraging for this group of patients.

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