

**The Improvement/Rehabilitation of Memory Functioning with
Electrophysiological Interventions**

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Abstract

Five clinical case studies are presented which addressed the effectiveness of EEG biofeedback with individuals impaired in auditory memory ability. A normative QEEG activation database of 59 right-handed subjects was developed, which delineated the QEEG variables which were positively related to auditory memory performance (paragraphs). Subjects who had experienced a brain injury underwent the same procedure employed in the development of the database. The subject's values on the effective parameters of memory functioning were determined. Neurotherapy (EEG biofeedback) interventions were determined by the subject's deviation from the normative reference group in terms of the relevant QEEG parameters of effective auditory memory (paragraph recall). Five subjects (1 normal, 3 brain injured and 1 subject who had a left frontal hematoma) underwent interventions directed towards the electrophysiological dysfunction, which is specifically involved in memory. The subject's improvements ranged from 39% to 134% as a result of the interventions and either maintained or improved in all of the subjects who had a follow up assessment that occurred from one month to one year following termination of treatment.

Introduction

The literature on memory improvement has focused on different groups (normal, elderly, individuals with brain damaged, depressed) with different interventions (repetitive practice, strategies, visualization, PQRS, etc.) and have found generally minimal to mixed results. The broad issues in the area concern approaches, effectiveness, generalization (to other tasks and everyday life), long term maintenance of improvement and the subject's self report of changes. Due to the general lack of impressive results, researchers in the area generally do not discuss the issue of returning to normal levels (in individuals with brain damage). More specific issues focus on how the improvement is reported (percentage change, raw score changes, etc.), length of treatment required to obtain results, control groups, spontaneous recovery (in the case of individuals with brain damage), relationships between neuropsychological measures of memory and everyday memory, types of memory addressed (visual, verbal, etc.) and effects of attention training on memory. As the present case studies involve auditory memory for paragraphs, this discussion will focus on only the articles which address the area of auditory memory of prose passages.

One of the initial reviews in this area [1] concluded, "findings regarding the effectiveness of memory remediation interventions have been inconsistent", adding that methodological inadequacies have hindered the identification of specific treatment effects. A more recent review [34] was more positive regarding the improvements in memory rehabilitation approaches and described research in the areas of restoration, reorganization and behavioral compensation. The

enthusiasm was predominantly based upon research with the method of vanishing cues [12], which involved learning of specific information. Another review [9] review focused on methodological problems, the lack of relating present knowledge about brain function to interventions and concluded that it may be possible to constructively intervene but our confidence in such a statement should be tempered with caution.

The literature is clear that simple repetitive practice is of minimal or no aid in improving memory for recall exercises [13]. Specific techniques such as visualization, method of loci and cognitive strategies have shown different degrees of effectiveness. However, researchers in the field generally agree that these approaches face the problem that the subject does not continue the use of the strategy [11]. Significant improvements from repetitive recall drills have not been found [22] and internal memory aids such as imagery instructions are employed less than external memory aids, but patients generally employ neither. Some approaches (vanishing cues, errorless learning) focus on the learning of specific information.

Various cognitive strategy approaches with different clinical populations have resulted in different success rates. Imagery and use of categories has been shown to produce no significant results with elderly [38], strategy (visualizing, mnemonics) training has resulted in a 38% improvement in one group of elderly [6] (visual imagery and semantic elaboration) while an 8% average memory improvement with memory tapes, lectures and computer based program with the elderly [28] has been obtained in another study. A memory and attention training program with recovering alcoholics obtained a 40% increase in logical memory scores [32].

In individuals with brain damage, one study has shown a 53% improvement on short term paragraph recall and 15% long term recall [18] (single case design), employing visualization and semantic elaboration. With a questioning technique, almost no improvement on a 9-month follow up was obtained [8]. Individuals with mild brain injury have shown increases of 22% on short term recall (logical memory) and 86% delayed recall with treatment addressing both psychosocial issues and cognitive approaches [29] with no difference obtained between the type of treatment. When compensatory and executive skills training program was employed [11], individuals with brain injuries obtained 100% improvement immediately after the end of the program. However, some scoring issues may have inflated the results. Employing the PQRSST (Preview, Question, Read, State, Test) [2] with individuals who were brain injured resulted in only marginal results in one subject, while another study [14] obtain improvement in 40% of individuals with brain injuries on 50% of the memory tests employed. A memory notebook treatment [31] program obtained no improvement in logical memory scores.

Effects on memory with attention training [23] but not with memory training have been reported. This effect has been found in other studies: [21], [19], [20]. Interventions directed towards alleviating depression in the elderly [38] were as effective in improving memory as cognitive skill training (imagery, organizational strategies). The categorization and visual mediation training significantly improved performance for list recall, but no improvement for paragraph recall.

Long term follow up studies are few. Strategy training, drill and practice and a no treatment condition (18 sessions) [4] indicated positive effect on objective memory measures (especially at 4 month follow up), but no effect after 4 years. In about 30% of the severe memory impaired participants [37] showed an improvement in memory as assessed by a standardized measure, a small number had deteriorated and 60% showed little or no change since leaving the rehabilitation clinic some 5-10 years before. About 88% of the participants admitted to still having memory problems. Although this short review is not exhaustive of all remediation efforts

in terms of memory functioning it presents the problems inherent in this area, i.e. consistency of results across studies, maintenance of gains and influence of other factors.

An alternate approach to improving cognitive function has employed biofeedback techniques. The biofeedback methodology is a procedure for 1) measuring a physiologic process/parameter; 2) converting the output to an understandable (unit of measure) form; and 3) feeding back the information in a sensory form (visual and/or auditory) to increase awareness of the physiological process. Employment of this procedure allows the person to learn self-control of physiological process in an operant conditioning modality, whereby the person receives a reward when the desired behavior is obtained and/or an inhibition signal when an alternate, undesirable physiological response occurs.

EEG biofeedback (Neurotherapy) employs the standard methodology of biofeedback with an electrode placed on the head which records the electrical activity generated by the brain and provides that information to the person for the purposes of changing the electrophysiological signal. These electrophysiological signals relate to different functional and mental states.

EEG biofeedback has been impressively employed with children to improve cognitive functioning. These electrophysiological interventions have been shown to result in improvements on scores on standardized IQ tests from 10 to 25 points: [33], [24], [16], [35]. The behavioral and cognitive remediation effects have also been demonstrated with Attention Deficit Disorder children [17]. Although the use of standardized intelligence testing indicates improvements on scales in which memory is involved (Digit Span, Coding, etc.), there has been no specific measures of memory for prose under immediate and delayed recall conditions. The interventions employed in these approaches have generally focused on the Cz location (superior central position) in terms of increasing Beta frequency activity (13-22 Hertz) and inhibiting Theta activity (4-8 Hz). Due to the lack of information regarding what are the specific electrophysiological parameters of effective cognitive functioning, specific interventions have not focused on those parameters. There is no published research focusing on employment of EEG biofeedback in individuals who have a brain injury and are memory impaired. The goal of this research was to address the problem of memory improvement from a new perspective (EEG biofeedback) with the hope of defining a new, more effective approach to a consistent and substantial problem in human functioning.

Method

To address the problem of memory rehabilitation from a different perspective, a Quantitative EEG (QEEG) activation database was collected for a 18 different tasks, most of which addressed memory functioning (auditory, visual, reading, names of faces and autobiographical) in terms of the input, immediate and delayed recall (30-45 minutes after initial presentation) conditions. The QEEG variables were correlated with the memory performance of 59 normal right-handed participants to determine the cortically based electrophysiological correlates of effective cognitive functioning. Normality was determined by the lack of neurological disorder, history of brain injury or learning problems.

Person with brain injury underwent the same QEEG activation procedure as the normative reference group to determine the nature and extent of their electrophysiological dysfunction under different task conditions. The subject's electrophysiological response pattern and task scores were compared to the normative database with respect to the variables, which were positively correlated with auditory memory recall. The specific parameters that were below normal (1-2 Standard Deviations) were chosen as the focus of the EEG biofeedback interventions, with the greatest difference being the initial focus. The goal of the treatments was

to normalize the QEEG variables. There was no attempt to teach the participants cognitive strategies to improve memory functioning. A post QEEG was not administered, as the values during the treatment session were employed as the electrophysiological criteria for improvement.

As part of the treatment, participants were read novel stories prior the onset of the session, asked to immediately recall the information and then asked for their recall of the paragraph after the session was completed (33 minutes). Generally the participants would lose only 2-4 pieces of information by the time of the delayed recall. During the sessions the participants were asked to listen to an audiotape and attempt to raise the visual image (airplane, etc.) used to depict the electrophysiological variable as well as pay attention to a sound that indicated when the variable was above a pre-selected threshold.

An example of one of the stories is included below. The slash marks represent the scoring units.

John Smith /lived on an old dirty barge/ in New York harbor/. One day he left the boat/ to go shopping/ for some milk,/ potatoes/ and hamburger/. He entered an alley/ to save time/, but as he began to exit the alley/ a tall, large man/ came over to him/ and demanded his money/. John gave the man/ the \$10 that he had/, as he was afraid/. The man left/. John continued to the store/ in the hope of getting credit/. He found a \$20 bill/ on the ground/ near a fire hydrant/ as he approached the store/. N=24

In the quasi-experimental design [7] the experimenter does not have full control over all the variables which could be operational. The design employed in this research is similar to the multiple time series design, in which a different group of subjects undergoes the assessment (the control group data obtained) over time. The experimental value resides in the effect being demonstrated twice, once with the controls and again in reference to the subject's own pre-treatment condition. This methodology provides for a maturation control in both the experimental and control group. Instrumentation or regression effects are ruled out, although interaction of the selection difference with history remains a possibility. It is considered [7] to be an "excellent quasi-experimental design, perhaps the best of the more feasible designs." (p. 57). This study does not follow the exact guidelines for consideration as the control group was tested over a shorter period of time, thus allowing maturation in the experimental group to be a factor (though unlikely). Difficulty level of the paragraphs is controlled for as both the experimental and control group are receiving the same paragraph.

Apparatus

The EEG recording equipment of Lexicor Medical Technology, Inc. was employed. 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 sampling rate was set to 256 to allow for examination of up to the 64-Hertz range with a 60-Hertz notch filter. The bandwidths were divided according to the following division: Delta: .5–3.5 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 measurements available through the software provided by Lexicor Medical Technology were employed. These included the following for each bandwidth and employed the peak-to-peak measurement approach.

Measures

Activation Measures

Absolute Magnitude-the average absolute magnitude (as defined in microvolt) 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 microvolt 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 $(A-B)/(A+B)$

Connection Measures

Coherence-the average similarity between the waveforms of a particular band in two locations over the one-second period of time. The measure has been 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. The algorithms employed by Lexicor Medical Technologies, Inc. to calculate these parameters are proprietary information and are not available for specific analysis.

PROCEDURE

Description of Figures

The figures present the results of the interventions. The session number is noted on the X-axis and the total recall (short and delayed) on the Y-axis. The breaks in data points on the X-axis indicate no assessment was conducted and the times (on the X-axis) indicate breaks in treatments. The curve is a polynomial best fitting trend line. The session marked 0 on the X-axis is the initial evaluation. In the upper right of the figure is a head figure indicating the 10-20 locations and the focus of the interventions. The change in the value of the electrophysiological variable during treatment is presented in the graph underneath. As the interventions varied in terms of locations and focus, the figure presents one of the more persistent focuses of the interventions. For subject number 1 the session number indicated on the two figures do not indicate the same session, as the numbers would appear to indicate. The title presents the overall improvement in short-term memory. The norms available are presented in the figures as a broken line. The following labels are presented and defined as follows: PA-Phase Alpha, CB2-Coherence Beta2, PB2-Phase Beta2.

RESULTS

The results in the Figures are presented in terms of the total memory score (short and delayed delay) of the subject during the treatment. The subject is read the passage prior to treatment, asked for immediate recall and then 30-45 minutes later is requested for delayed recall. The participants were assessed on a weekly basis with short paragraphs written by the author. Each story averaged between 20-25 pieces of information. The norms which were obtained for the first 15 stories (N=7) are presented in the Figures. Participants for the norming procedure were obtained by advertising in the local paper. Participants were read the stories over the phone, asked for immediate recall and then called 30 minutes later for their delayed recall.

The improvement scores indicated in the figures employed a method of averaging the first two short-term (immediate) memory measurements compared to an average of the last two short-term memory measurements. The reason for this approach is that because the initial testing involves considerable distractions between the original input and the delayed recall, many of the individuals with brain injury were unable to recall any of the information in the delayed recall situation. In the treatment situation, the subject listens to an audiotape, which proved to be less interfering in terms of the memory performance than the multiple tasks involved in the original evaluation. To employ the long-term memory score as a measure in the baseline would not represent a valid comparison. To employ the short-term memory scores during the first several sessions would also not be valid as the treatment was underway. Therefore, the memory score from the initial evaluation and the start of the first treatment was deemed the best measure of the preexisting memory ability. Control group and practice effect issues were addressed by the obtaining of norms, which indicated minimal effects of practice on memory performance. The control group data also controlled for possibility of varying degree of difficulty in the paragraphs. Previous research [3] noted that verbal memory testing (word lists) is resistant to practice effects when alternate forms are employed.

Several of the participants were experiencing emotional problems, as evidenced on psychological testing (MMPI2). A recent review of the QEEG literature [15] noted that depression (unipolar) is marked by increases in alpha and theta, asymmetry and hypocoherence in anterior regions. Bipolar depressed patients are marked by decreased alpha and increased beta activity. The authors also noted [15] that consistent patterns in other psychiatric disorders (anxiety, obsessive compulsive and eating disorders) have not been discerned by the research at this point in time. The interventions employed in this research did not involve the electrophysiological activity associated with these psychological problems.

Neither did the interventions address auditory attention. The temporal lobes have been established as the initial cortical recipient of auditorily presented verbal information. In one positron emission tomography study (PET) it has been demonstrated [39] that 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 (Brodmann's Areas (BA) 45/47) when subjects were asked to make judgements regarding syllable pairs. These results have been replicated and elaborated on by others: [5], [27], [25]. In a functional Magnetic Resonance Imaging (fMRI) study (N=14) [30] it was 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.

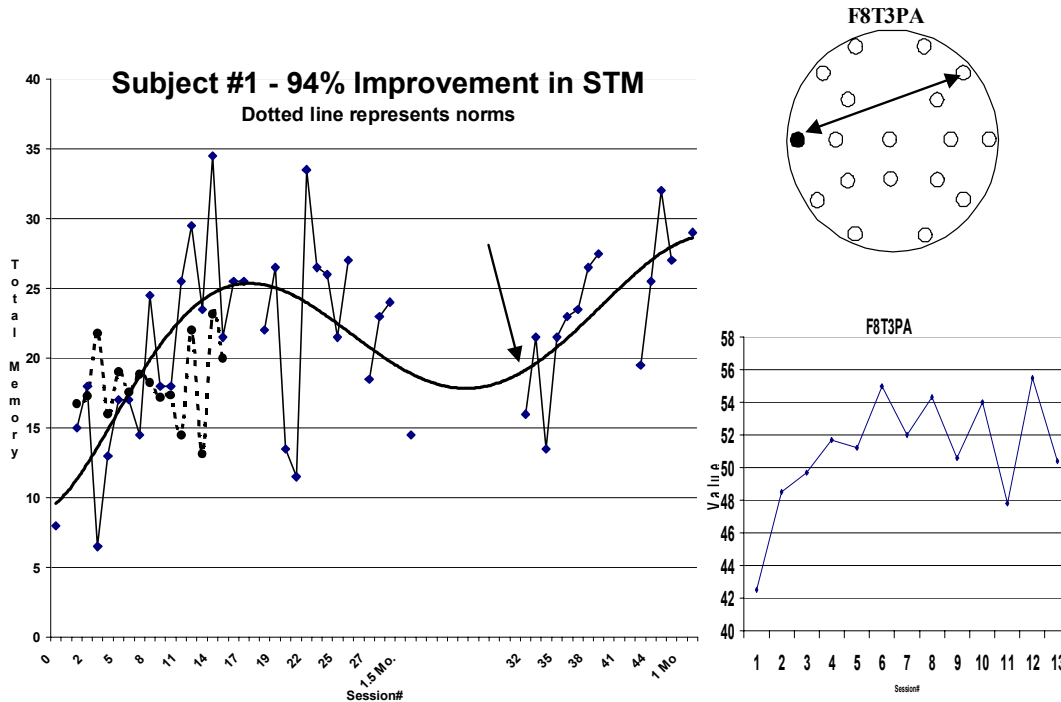
The original normative data collected by the author included an auditory and visual attention condition, to understand and separate out the attention component from memory processing. The auditory attention task required the individual (eyes closed) to raise their right index finger slightly whenever they heard the sound of the experimenter's pen tapping on the table (approximately once every second). One-hundred seconds of data was collected and a comparison to the eyes closed condition was conducted. The comparison of eyes closed to the auditory attention condition (N=40) indicated significant increases (averaged t-values which were greater than 2.02 (significant at .05 level with df=40 as indicated in a standard statistics book [10] in the auditory attention condition in terms of T3 and T4 (relative power of Beta2,

peak amplitudes of Beta2, magnitudes of Beta1, magnitudes of Beta2, and symmetry measures of Beta1 and Beta2). The results indicated that the distinguishing response of the brain to this situation is an increase in beta activity at the temporal locations (T3 and T4). There were also significant increases in frontal beta activity. There was no strong pattern of increases in phase or coherence values. Therefore, the act of paying auditory attention, although increasing beta activity in temporal locations does not affect the phase and coherence values emanating from the temporal locations or from any location. The comparison across these results (PET studies and results of the comparison of eyes closed to auditory attention) would indicate that increased blood flow is related to increased beta activity and not to increases in connectivity patterns. However, inferences drawn across studies should be rendered tentatively.

As the phase and coherence values were the sole focus of the treatment interventions, the treatment was not addressing attention issues, but memory processing relationships.

Head Injured Subjects

Figure #1

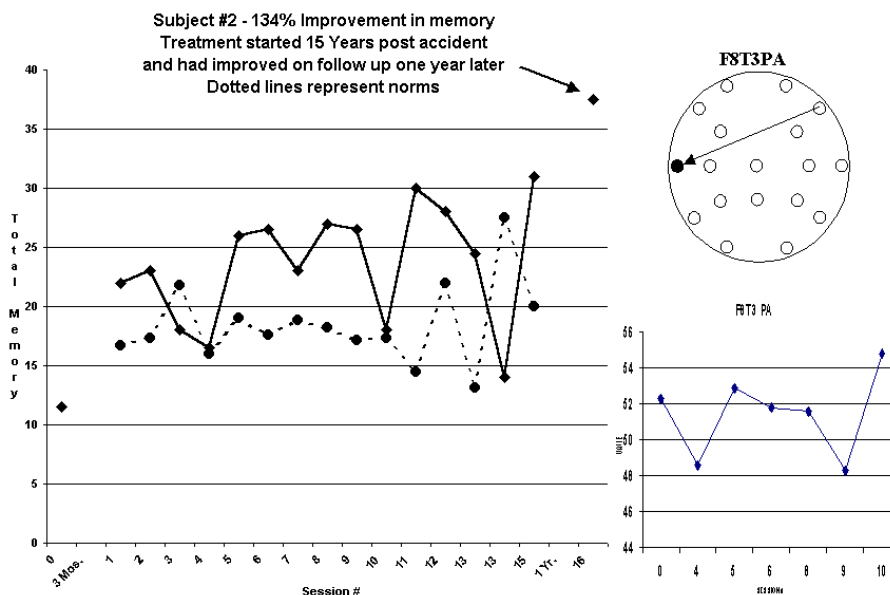


The results of interventions for five participants who were consistent in their attendance are presented. This sample is drawn from the group of participants with brain injury who underwent the original evaluation. These participants were selected out of a group of 10 participants and were chosen as they represent a sampling of three different conditions (brain injured with no documentation of physical damage, physical damage to the brain and normal). Case #4 is an example of documented physical damage (hematoma). Cases #1, #2 and #3 present individuals with brain injury who had different time periods before the onset of treatment and case #5 presents a subject with no history of brain injury.

Subject #1

Subject #1 is a 38-year-old female with a history of two brain traumas (one dating 13 years prior and the second one 6 months prior the onset of treatment. The subject hit the front part of her head during the recent accident and was unconscious for several minutes. Neuropsychological evaluation indicated significant problems in memory as well as other areas of cognitive functioning. The original evaluation (full QEEG study) indicated an average score of 8 (total of short and delayed recall) for four stories (five months post accident). Figure #1 presents the results of the subject's improvement. As can be discerned from the figure there was an initial improvement, which could reflect spontaneous cure as well as the effect of intervention. However, her memory functioning appeared to be deteriorating during the middle section (for unknown reasons) and interventions were selected to refocus on her auditory memory. The arrow presents the onset of those interventions (20 months post accident) and the focus of the interventions reflected in the adjacent figure and graph. This analysis presents a clear picture of improvement in memory correlating with interventions concerning the phase Alpha relationship between two locations (T3-F8). These values increased in value as her memory improved. The value indicated in session #1 denotes the value during the initial full QEEG study and the session marked #2 (bottom right figure) is session number 34 in the figure on the left. The phase Alpha relationship had been demonstrated in the research by the author to correlate with memory functioning and was at an impaired level in this subject during the initial evaluation. Follow up evaluation was conducted 6 weeks after cessation of treatment to ensure that the improvements were maintained. The follow up indicated that her memory ability had not deteriorated and the F8-T3 phase value was still within the improved range. Her overall improvement score was 94% as a result of 55 treatments (which were a combination of single and double sessions). The focus of the interventions was on a number of deviations from the normative database, which are not presented in the figure. Psychological testing (Minnesota Multiphasic Personality Inventory II) did not indicate a pattern of major depression, although emotional difficulties were present.

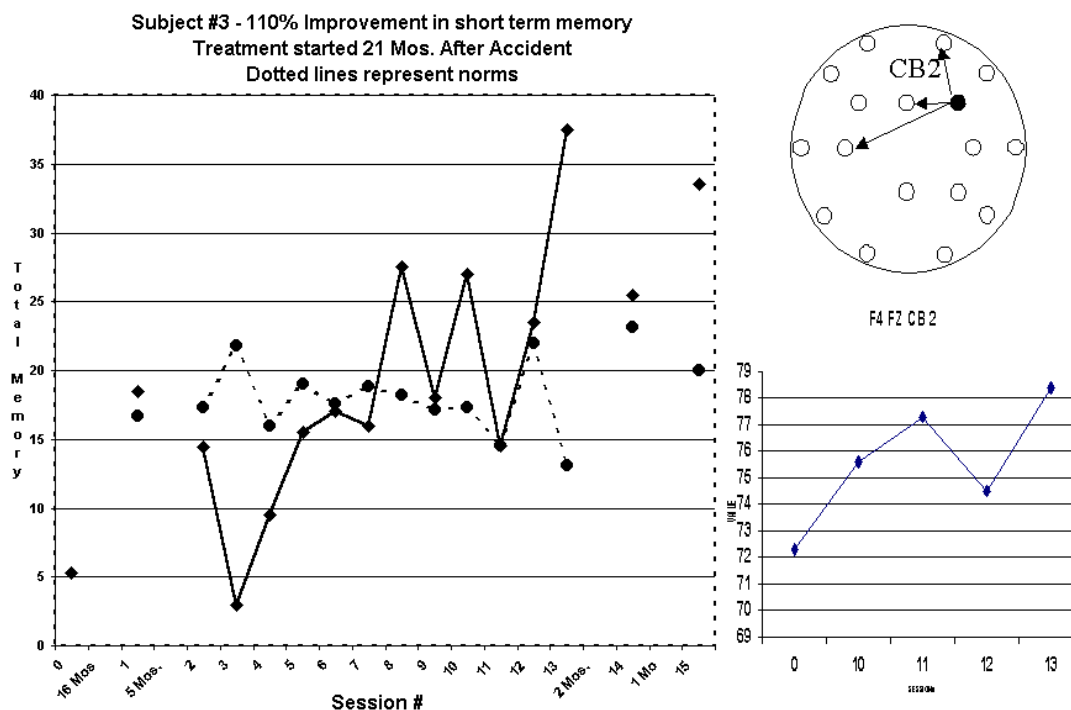
Figure #2



Subject #2

Subject #2 is a 48-year-old white male professional who was involved in an accident 15 years prior the onset of treatment. He hit his head on the windshield and was unconscious for 10-30 minutes. He demonstrated a 61% improvement in 16 sessions. Some of the initial interventions involved short right frontal lobe high Beta (32-64 Hertz) phase connections. He reported an increase in organizational skills in addition to memory following the treatment. There were no major symptoms of depression (although he was involved in psychiatric treatment). He was not administered any formal psychological testing to assess his emotional status. A one-year follow up of his auditory memory abilities indicated additional increases in memory ability, reflecting a 134% improvement. The session numbers indicated in the two figures refer to the same session.

Figure #3

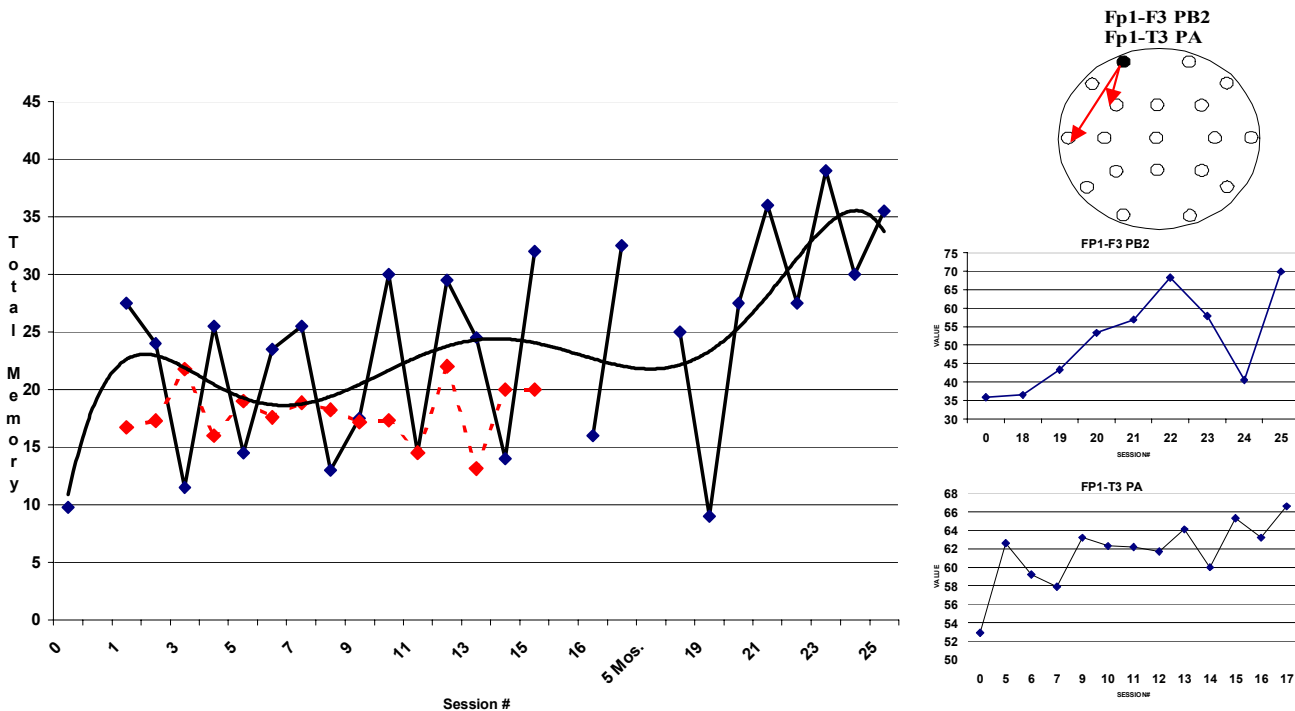


Subject #3

Subject #3 is a 43-year old female who was involved in a car accident 21 months prior the onset of treatment. There was no reported impact of her head on any object, no period of unconsciousness and no anterograde memory deficit. However, both herself and her husband noted memory problems. Neuropsychological evaluation confirmed the presence of these problems. There was evidence of mild PTSD and depression symptoms (MMPI-2), although the subject denied being depressed. The initial evaluation had indicated decreased connectivity values emanating from the F4 (right frontal) position in the upper Beta frequency (32-64 Hz). These relationships were related to the ability to recall reading material in the original research by the author. The treatment consisted of reading magazines while attempting to increase the values of the connectivity patterns between the F4 position and the two neighboring locations (as indicated on the head figure in the upper right). There were several periods of lapses in the

treatment. Follow up one month after termination of treatment indicated the improvements had been retained (as indicated on the figure). There was 110% improvement in memory functioning with a total of 15 treatments. Of particular interest in this case is that the subject was addressing the electrophysiology of reading and her auditory memory improved. This result indicates that generalization effects can be obtained. The session numbers in these two figures refer to the same session.

Figure #4
69 Yr. Old Female subject with Brain Trauma - Treatment started 24 Months after accident - 58% improvement in STM

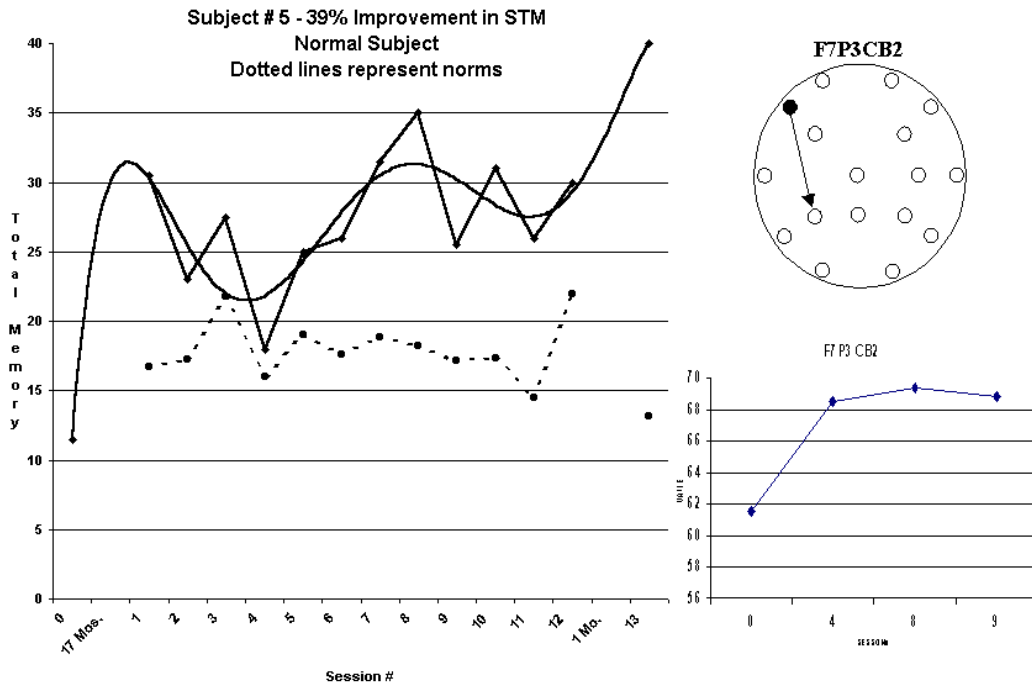


Subject with left frontal hematoma
Subject #4

Subject #4 is a 69-year-old female who was a pedestrian in a shopping mall when she was hit by a car. Her next memory after the accident is two weeks later of being in the hospital. She has no recall of the accident. The treatment started 2 years after the accident. There was an MRI report of a left frontal hematoma. There was a 28% improvement in memory after 21 double sessions. Of particular interest to note in this case is that the interventions spanned the left frontal area and demonstrated her ability to improve these values in terms of the phase relationships. Memory was not the predominant focus of the improvement, as her memory was close to normal at the start of the treatment (due to previous cognitive rehabilitation interventions). The focus of the interventions was the connections, which had been significantly affected by the accident. There was no significant emotional symptomatology (as determined by

the Minnesota Multiphasic Personality Inventory II). In these figures the session numbers indicated in both the figures reflect the corresponding session number.

Figure #5



Normal Participants

Subject #5

Subject #5 is a 29-year-old female subject who was part of the original database. She was asked to participate in an experiment to see if a normal subject’s memory could be improved. She had been experiencing problems in memory and was willing to be a subject. She demonstrated a 41% improvement in memory functioning after 13 sessions. The last session followed a one-month break in treatment to ascertain if the treatment effects were maintained. Her best performance to date was on this follow up session. She reported that there were indications in her normal life that her memory had improved, as she was no longer locking her car keys and two-year-old in the car. There were no indications of emotional dysfunctions. The session numbers noted in the two figures reflect corresponding sessions.

DISCUSSION

The progress in memory rehabilitation/improvement has traditionally progressed along lines of psychological interventions based upon common sense, intuition and psychological literature and theory. However, some authors [9] would argue that very little theory guides the interventions. What is presented in this report are the first interventions in the field which have been based entirely upon empirically derived electrophysiological parameters of effective memory functioning in a biofeedback type situation. The role of attention in auditory memory was addressed as part of the original research with the results indicating that auditory attention is predominantly an issue of temporal lobe beta activations. The interventions employed in this

research did not attempt to change the QEEG correlates of auditory attention, but addressed the QEEG empirical correlates of auditory memory [36] which involve the projection activity from the left temporal location to frontal locations in the alpha frequency (coherence and phase).

What is evident in these results is that a single posttest of memory functioning is not a sufficient measure of improvement. As the figures indicate, memory is a vacillating phenomenon, which is dependent upon a number of variables, which are not being measured. To rely upon a single post test of memory functioning does not accept this problem and can either over or under estimate the progress, in terms of a single individual's change. The author attempted to address this problem by averaging the last two measures.

The previous research in this area has demonstrated improvements in auditory memory of paragraphs ranging from 0% [38] to 100% [11] with most results in the 16% [26] to 53% [18] range. The results of the EEG biofeedback approached averaged 99% for these 4 individuals with brain injuries with follow up maintenance of gains of one month to one year.

These single case study results provide preliminary evidence that 1-electrophysiological variables can be changed through EEG biofeedback; 2- EEG biofeedback can be an effective tool in the rehabilitation of the auditory memory in individuals with brain damaged and normal participants, 3-spontaneous cure may underlie/contribute to some of the improvements, but is not applicable in several of the cases presented; 4-there is a meaningful relationship between the electrophysiological variables and memory functioning which can be addressed effectively with EEG biofeedback; 5- the treatment can possibly return participants who have brain injuries to normal levels of functioning. While there is no present standard for when a treatment effect remains stable, the one-month and one year follow up available with four of these participants is an encouraging result. All the participants reported that they felt their memory and general cognitive abilities had improved.

These case study results provided encouragement to further the research in this area with larger sample sizes and appropriate controls. If we can change one cognitive ability with an empirically derived set of EEG biofeedback protocol recommendations, then it becomes possible, in theory, to address any cognitive ability, if we know what are the relevant parameters.

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