Improvement/Rehabilitation of Memory Functioning with Neurotherapy/QEEG Biofeedback

This article presents a new approach to the remediation of memory deficits by studying the electrophysiological functioning involved in memory and applying biofeedback techniques. A Quantitative EEG (QEEG) activation database was obtained with 59 right-handed subjects during two auditory memory tasks (prose passages and word lists). Memory performance was correlated with the QEEG variables. Clinical cases were administered the same QEEG activation study to determine their deviations from the values that predicted success for the reference group. EEG biofeedback interventions were designed to increase the value (to normal levels) of the specific electrophysiological variable, which was related to successful memory function and deviant in the subject. Case examples are presented that indicate the successful use of this intervention style in normal subjects and in subjects with brain injury; improvement cannot be fully explained by spontaneous recovery, given the time postinjury. Five cases (two normal, two subjects with brain injury, and one subject who had stereotactic surgery of the hippocampus for seizure control) are presented. Improvements ranged from 68% to 181% in the group of patients with brain injury, as a result of the interventions. Key words: *auditory memory rehabilitation, EEG biofeedback, memory improvement, neurotherapy, QEEG biofeedback*

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INTRODUCTION

Cognitive rehabilitation for memory disorders has focused on different groups of patients with different methods of interventions; results have been variable. Specific techniques, such as visualization, method of loci, and cognitive strategies, have shown different degrees of effectiveness but these approaches face the problem of continuation of the approach by the subject, who usually does not continue employment of the strategy.[1] McKinlay[2] failed to find significant improvements from repetitive recall drills and found that internal memory aids, such as imagery instructions, were employed less than were external memory aids, but that neither are generally employed by patients. Schmitter-Edgecombe et al[3] employed a 9-week memory notebook treatment with subjects more than 2 years postinjury. A 6-month follow-up indicated that the treated group had fewer everyday memory failures (assessed with a questionnaire provided to subjects and significant others) but that there were no significant

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effects on laboratory measures (logical memory, visual reproduction).

Benedict reviewed the memory improvement literature and concluded that "findings regarding the effectiveness of memory remediation interventions have been inconsistent,"[4(p.)] adding that methodological inadequacies have hindered the identification of specific treatment effects. Tate[5] was more positive regarding the improvements in memory rehabilitation approaches and described research in the areas of restoration, reorganization, and behavioral compensation. Franzen and Haut's[6] review focused on methodological problems in the research literature and concluded that it may be possible to intervene positively, but confidence in such a statement should be tempered with caution.

<AQ1>

The more successful interventions have employed strategies to obtain their results. Best et al[7] demonstrated, with a group of elderly subjects, the effect of strategy training (visualizing, mnemonics) (N = 55, mean age 82) and found increases on higher prose and phone numbers. Paragraph recall (Logical Memory of Wechsler) increased from 6.08 to 8.38 (38% increase) with a delayed posttest score of 10.77 (77%). Benedict and Wechsler[8] employed a PQRST (Preview, Question, Read, State, Test) with two subjects with brain injury and were able to obtain marginal results in one subject. With an elaborative encoding approach, they obtained better results with word lists. Grafman[9] employed the PQRST technique with subjects with brain injury and was able to obtain improvement in 40% of the patients on 50% of the 14 memory tests employed. Crosson and Buenning[10] analyzed story recall in a single case study employing different intervention strategies. Significant increases in performance were obtained, most notably with the questioning technique (an increase in recall from approximately 30% of the material to approximately 75%). However, follow-up at 9 months indicated that performance had dropped to near the pretreatment level.

Berg et al,[11] in a long-term follow-up study, employed a strategy training, drill, and practice and obtained a positive effect on objective memory measures at 4-month follow-up, although there was no sustained effect at 4 years. Wilson[12] (N = 43) studied the long-term improvement of memory in severe memory disorders. About 30% of the subjects showed an improvement in memory, as assessed by a standardized measure. A small number had deteriorated, and 60% showed little or no change after leaving the rehabilitation clinic at 5–10 years. The mean improvement on the Rivermead was 4.69 points (SD = −.99) for the 13 subjects who showed improvement. About 88% of the subjects admitted still having memory problems. <AQ2>

In terms of prose passages, Zarit et al[13] were unable to obtain any improvement with a group of elderly patients employing an instruction to use categories and imagery when reading long prose paragraphs. They were, however, able to obtain significant improvements in terms of names of faces (approximately 75% improvement).

Malec and Questad[14] reported in a single case study the improvement of Prose Memory (Logical Memory of Wechsler Memory Scale) in an individual with brain injury. The subjects underwent approximately 50 sessions of training in visual imagery and semantic elaboration in a word recall task. Generalization to the Logical Memory task indicated a 53% improvement on short-term recall and 15% improvement on long-term recall. Prigatano et al[15] addressed the cognitive problems of a subject with brain injury who had been in a coma longer than 24 hours. Intensive (4 days a week, 6 months) remediation resulted in raising the scores on the Logical Memory subtest of the Wechsler from 6.9 to 8, an approximately 16% improvement.

Techniques such as visualization, executive, and attention training have also been employed. Van Dam et al[16] employed a visual and verbal embellishment technique (N = 108) to ascertain whether memory in a free-recall paradigm could be enhanced. They found no significant effect. Ryan and Ruff[17] obtained (across three memory measures) a nonspecific treatment effect, **<AQ3>** with an average improvement of 2–5% after treatment. However, the control group, which had received treatment focusing on psychosocial issues, improved equally. The injured group (control and experimental) was subdivided into mild and moderate impairment on the basis of neuropsychological measures. On the Wechsler Logical Memory test, the group with mild brain injuries increased 22% on immediate recall and 86% on delayed recall, whereas the moderate group increased 38% on immediate and 41% on delayed recall. The remainder of the comparisons reflected a greater improvement for the mildly injured group, compared with the moderately injured participants.

Freeman et al[18] addressed the problem of memory for prose passages by employing a compensatory and executive training skills approach on patients with brain injuries, based on Ben-Yishay's program. With 16 sessions (N = 6) and an average time since injury of 33 months, the program was able to obtain a 100% improvement in paragraph recall with the posttesting conducted immediately after the training period. The paragraphs had 10 pieces of information in each. However, the scoring method may have inadvertently capitalized on the serial position effect, in that recalling the first and last piece of information would result in a 60% recall. Thus, a subject could have doubled his or her memory score by merely recalling one more piece of information.

Steingass et al[19] employed an 18-session memory and attention program to improve memory functioning in recovering alcoholics. The subject's logical memory scores increased from 5.3 to 7.2 (40%), whereas the control group scores went from 5.4 to 6.4 (18%) (norm is 10–12, depending on age). There were no significant differences between the improvement of the control group and the treatment group. Nieman et al[20] trained subjects on attentional ability and obtained effects on memory. When subjects were trained on memory, there were no effects. Other studies have demonstrated the effect of attention training on memory.[21–23]

Zarit et al[24] identified the effect of depression on memory function in a group of elderly subjects. The interventions directed toward alleviating depression 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. However, neither treatment resulted in improvement in paragraph recall.

QEEG BIOFEEDBACK

An alternate approach to improving cognitive function has employed biofeedback techniques. The biofeedback methodology employs a procedure during which a device that measures a physiological variable is placed on the subject. The device/software converts the information to a quantitative measure, which can then be presented to the subject in an audio/visual form to increase awareness of the physiological process under investigation. Neurotherapy (quantitative EEG [QEEG] biofeedback) employs the standard operant conditioning methodology of biofeedback with an electrode placed on the head that records the electrical activity generated by the brain.

QEEG biofeedback has been 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.[25–28] The remediation effects have also been demonstrated in children with attention deficit disorder.[29] Although the use of standardized intelligence testing indicates improvements on scales in which memory is involved (digit span, coding, etc.), there have 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 Hz) 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 been focused on those parameters. Neither has there been any published research evaluating memory functioning and focusing on employment of this intervention in cases with brain injury.

The employment of QEEG biofeedback has been demonstrated to be effective in a number of other clinical conditions, such as alcoholism,[30] posttraumatic stress syndrome,[31] anxiety,[32] and seizure disorders.[33]

METHOD

To address the problem of memory rehabilitation from a different perspective, a QEEG activation database (employing all 19 locations of the 10–20 system) was collected for 18 different tasks, most of which addressed memory functioning (auditory, visual, reading, names of faces, and autobiographical) in terms of the input and immediate and delayed-recall (30–45 minutes) conditions. The QEEG variables were correlated with the memory performance of normal subjects to determine the cortically based electrophysiological correlates of effective cognitive functioning. The results of the auditory memory for paragraphs study have been accepted for publication.[34]

The subjects with brain injury underwent a full QEEG activation study 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 relevant to success on the particular task under consideration. The main focus was on the recall of audibly presented paragraphs. Interventions focused on QEEG variables, which were below normal (less than -1 SD) and (1) were correlated in the completed research with auditory memory or (2) were correlated with auditory memory during the collection of the research data. There was no attempt to teach the subjects cognitive strategies to improve memory functioning.

The interventions were preceded by the researcher (or assistant) reading a novel paragraph to the subject and asking for immediate recall. The intervention would constitute a standard operant conditioning biofeedback session, with the protocols designed as indicated in the previous paragraph. At the end of the session (33 minutes), the subject was asked for recall of the paragraph read at the beginning of the intervention. The subjects were instructed that the variable they were attempting to increase was related to memory. The subjects listened to audiotapes of novels and lectures during the treatment session. The software provided feedback in an audio (tones) or visual (airplane, bar graph, etc.) format. The specific protocol was written to increase the deviant QEEG variable. The subjects were instructed to listen to the audiotapes and simultaneously to attempt to keep the audio tone on and the airplane as high as it could go. This operant conditioning approach was taken to ensure that the relevant

QEEG variable was being conditioned in the auditory memory task. The interventions generally involved two locations (as is required to generate a phase or coherence measure) or one or more locations to increase beta activity and decrease theta or delta activity.

The methodology employed is a quasi-experimental design, as outlined by Campbell and Stanley,[35] in that the experimenter does not have full control over all of the variables that could be operational. In the Campbell and Stanley[35] classification scheme, this design 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 value resides in the experimental effect being demonstrated twice; once again the controls and again in reference to the subject's own pretreatment condition. <AQ4> This methodology (in principal) controls for maturation 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. Stanley and Campbell consider this design to be an "excellent quasi-experimental design, perhaps the best of the more feasible designs."[35(p. 57)] This study, however, does not follow the exact guidelines for consideration because the control group was tested over a shorter period of time, thus allowing maturation to be a factor (although unlikely). Difficulty level of the paragraphs is controlled for, however, because both the experimental and control groups receive the same paragraph. Potential practice effect problems were addressed by obtaining a control group. However, a weakness in the design is that the means for the control group were available for only the first 15 stories.

Equipment

While the subjects underwent the procedure, they were videotaped and recorded. The recording device combines a computer and video audio recording equipment, and allows an experimental recording session to be saved to a high fidelity 8-mm tape with all pertinent information. The videotape, which is saved, is a split-screen videotape, with the left side reflecting the EEG recording with the appropriate epoch number and the right side of the screen showing the subject during the experiment. The epoch number refers to a 1-second period of time. Thus, epoch number 1 is the first 1-second period of the recording, and epoch number 60 is the 60th second of the recording. This device enables the experimenter to review the tape to check and confirm the scoring of the subject's responses during the experiment.

The EEG recording equipment of Lexicor Medical Technology, Inc. was employed. In the system employed in this study, filtering is accomplished in the software. The signals passed are between .5 and 64 Hz (3 dB points). The signals that 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-Hz range with a 60-Hz notch filter. The bandwidths were divided according to the following division: Delta: .00–3.5 Hz, Theta: 4–7.5 Hz, Alpha: 8–12.5 Hz, Beta1: 13–31.5 Hz, Beta2: 32–63.5 Hz. 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 Kohm (and <AQ5> within 1.5 Kohm 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. <AQ6>

The measurements available through the software provided by Lexicor Medical Technology were employed. These included the following for each bandwidth:

Measures

Measures employed the peak-to-peak measurement approach.

Activation measures

Absolute magnitude: the average absolute magnitude (as defined in microvolts) of a band over the entire epoch (1 second)

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

Peak amplitude: the peak amplitude of a band during an epoch (defined in microvolts)

Peak frequency: the peak frequency of a band during an epoch (defined in frequency)

Symmetry: the peak amplitude symmetry between two locations in a particular bandwidth- ie, defined as $(A - B)/(A + B)$. The average symmetry measure was calculated by summing the symmetry measure between one location and all other locations.

Connection measures

Coherence: the average similarity between the wave forms of a particular band in two locations over the 1-second period of time. Conceptualized as the strength/number of connections between two positions.

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

Roland[36] discusses the issues of connectivity of the brain in terms of the anatomical organization of the neocortex, which contains six layers (with layer I being closest to the scalp) and is approximately 3 mm thick. The pyramidal cells (excitatory) in layer II and the upper part of layer III send their axons to the cortex in the same hemisphere while the pyramidal neurons in the lower part of layer III send their axons to the other hemisphere or over longer distances intercortically. Thus, apart from other subcortical considerations, these are the physiological foundations of the coherence and phase figures.

Procedure

Description of figures

The circles represent the locations of the 10–20 electrodes. Each head figure is labeled on top with the parameter that was the focus of the treatment, according to the following nomenclature. Only one parameter, phase alpha (PA), is addressed in the graphs. This parameter was significantly correlated with auditory memory functioning in the development of the norms.

RESULTS

The results in the figures are presented in terms of the total memory score (short and 30-minute delay) of the subject during the treatment. The subject is read the passage prior to treatment, asked for immediate recall, then, 30 minutes later, is requested for whatever can be recalled of the story. The subjects were assessed on an almost weekly basis with short paragraphs written by the author. Each story averaged between 20 and 25 pieces of information. Norms were obtained for the first 15 stories ($N = 7$) and are presented in the figures. The improvement scores indicated in the figures employed a method of averaging the first two short-term memory measurements, compared with an average of the last two 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 subjects with brain injury were unable to recall any of the information on the delayed testing. In the treatment situation, the subject listens to an audiotape, which proved to be less interfering than the multiple tasks involved in the initial evaluation (in terms of the memory performance). 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. There were no measures taken of depression or anxiety during or after the treatment period.

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) for that session is indicated on the Y-axis. The breaks in data points indicate that no assessment was conducted, and the times indicate breaks in treatments. The undulating curve is a best-fit polynomial trend line to the sixth order. The session marked "0" is the initial evaluation for all subjects. In the upper right corner of Figure 4 s a head figure with the 10–20 locations and indicates the focus of the interventions. The changes in the electrophysiological values are presented in the graph underneath. Because the interventions varied in terms of locations and focus, the figures presents one of the more persistent foci of the interventions. Interventions varied by subject and were determined by the subject's deviation from the norm on the variables, which were demonstrated to be important for auditory memory. The critical variables for auditory memory are reported by Thornton,[34] who indicated that the critical variables for auditory memory during the input and immediate recall condition involve the phase and coherence Alpha projections from the left temporal position (T3) to all frontal locations. Long-term delayed recall is determined by these temporal projections, as well as left frontal projection activity to posterior locations. The interventions would vary by subject because their deviations were different. The title presents the overall improvement in short-term memory, as discussed in the results section. The norms available are presented in the figures as a broken line. Some of the subjects underwent double treatment sessions, with a story presented prior to the beginning of the first session and recall assessed immediately and after the first session was over. Case #5 is an exception to this testing procedure. When the double sessions were conducted with case #5, stories were administered and recall assessed at the beginning and end of each session.

Subjects with brain injury

Subject #1

Subject #1 (Fig 1) is a 31-year-old man who was involved in a car accident 6 months before the onset of treatment. He was hospitalized for two days following the accident. During the accident, he hit the right frontal area of his head. His memory was poor for the days preceding the accident and for the events in the hospital. His native language was Spanish. He had studied and learned English during the nine years he was in the United States. The original evaluation was conducted in Spanish. He requested to change to English stories within a month after the onset of treatment. His initial recall of the stories was characterized by confabulatory and tangential thought processes. At the end of treatment, there was no evidence of confabulation or tangential thought, although he was slow in recalling the information. There were a total of 36 treatments. He demonstrated an overall improvement of 168% in memory functioning. A 1-month follow-up memory assessment demonstrated maintenance of improvement in memory functioning. Fig 1

Subject #2

Subject #2 (Fig 2) is a 50-year-old female who was involved in a car accident 34 months prior the onset of treatment. She struck her head during the accident but was not rendered unconscious. Anterograde memory was affected. She experienced depression and post-traumatic stress disorder following the accident. There were several breaks in the treatment period, due to her difficulty with headaches, as well as several lower per- Fig 2 formances, due to the headaches (including the one at the 6-month follow-up). She demonstrated an overall 83% improvement in memory functioning after 17 treatment sessions.

Subject with history of hippocampal surgery for seizure control

Subject #3

Fig 3 Subject #3 (Fig 3) is a 33-year-old male who underwent stereotactic surgery for seizure control. The surgeon removed 3–4 cm of the anterior temporal cortex and amygdala and 2–3 cm of the hippocampus. Treatment began approximately one year following surgery. After 11 sessions, he had demonstrated a 68% improvement in memory functioning. Improvement in this case was calculated using both short and delayed measures for the first two sessions and the last two sessions. The reasoning for the different approach was that the first session did not result in significant improvement. Fig 3 presents the improvement in memory score, as well as the intervention sites (indicated in the head figure in the upper right) and the improvement in the value of the phase relationships (indicated in the graphs on the right) during the sessions, with the session number indicated on the X axis. An additional intervention site included F4-T3 (not presented in the figure). This relationship also showed significant gains. For this subject, all of the interventions focused on the relationship between the T3 location (left temporal) and frontal locations. The relationship between the left temporal position (T3) and all of the frontal locations (for coherence and phase values in the alpha range) had been demonstrated in the original research to be the critical variables for success in recall of auditory memory information (in the input, immediate, and delayed conditions). For this subject, it was these values (phase and coherence values of the alpha frequency between T3 and frontal locations) that were significantly affected (−1 to −3 standard deviations below the mean) during the three conditions (input, immediate, and delayed recall). The presumed effect of the surgery was predominantly in these relationships. The subject also reported a general improvement in clarity of thinking.

Normal subjects

Subject #4

Fig 4 Subject #4 (Fig 4) is a 15-year-old male. He was asked to participate in an experiment to determine whether a normal subject's memory could be improved. Parental permission was obtained. He demonstrated a 138% improvement in memory as a result of the 13 interventions. The intervention focused on the Fp1–Fp2 phase Alpha relationship, which (for this subject) was significantly below the norm and related to recall ability, according to the available data at the time of the interventions. There were no indications of significant emotional dysfunction.

Subject #5

Subject #5 (Fig 5) is an 11-year-old female who agreed to be part of the research with her parent's consent, to determine the effect of the treatment on a normal subject's memory ability. She demonstrated a 181% improvement after 19 sessions. This subject was intermittent in her attendance, with occasional breaks, as indicated in the figure. Stability of attendance began at session #8. The last four assessments were conducted on one day (similar to the original evaluation) and without any treatment sessions. Interventions were directed toward increasing Beta activity in the left posterior region and increasing phase Alpha values between the left temporal (T3) and frontal locations. Fig 5

DISCUSSION

Cognitive intervention models can employ a theoretical or en empirical framework. The guiding structure behind this research has been the empirically derived effective QEEG parameters of auditory memory. This research presents the first neurotherapy (QEEG biofeedback) attempt to employ this framework to improve a specific cognitive ability-auditory memory.

The results of these case studies suggest that a single posttest of memory functioning is not a sufficient measure of improvement. As the figures indicate, memory is not a fixed phenomenon and is dependent on a number of unmeasured variables. To rely on a single posttest of memory functioning can result in either over- or underestimations of a subject's progress. An additional potential source of misinterpretation of the data is the possibility of practice effects. The control group, however, did not demonstrate a practice effect, which is usually most evident in the first few trials. In addition, previous research by Benedict and Zgaljardic[37] noted that verbal memory testing (word lists) was resistant to practice effects when alternate forms are employed.

CONCLUSION

Neurotherapy (QEEG biofeedback) may be an effective tool in the rehabilitation of the subject with brain injury and may promote improvement of memory in normal subjects. There appears to be a meaningful relationship between the electrophysiological variables and memory functioning that can be studied effectively with QEEG biofeedback. The treatment approaches using QEEG may assist survivors of brain injury to achieve normal levels of functioning, as well as contribute to a normal subject's memory ability.

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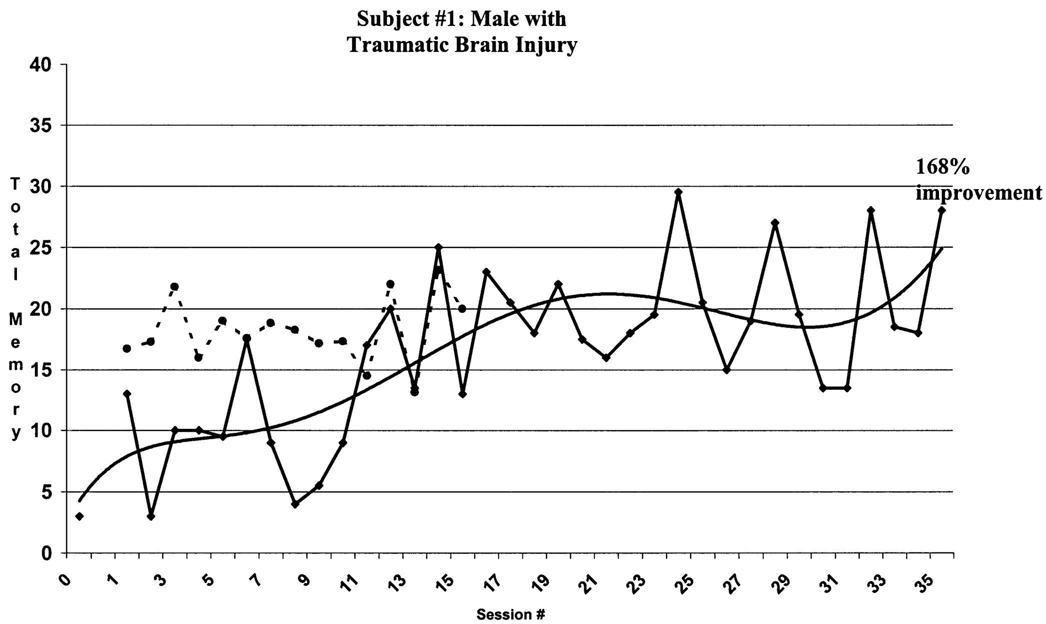

Fig 1. Undulating curve is a best-fit polynomial trend line to the 6th order. Dotted line = norms; Solid line = subject.

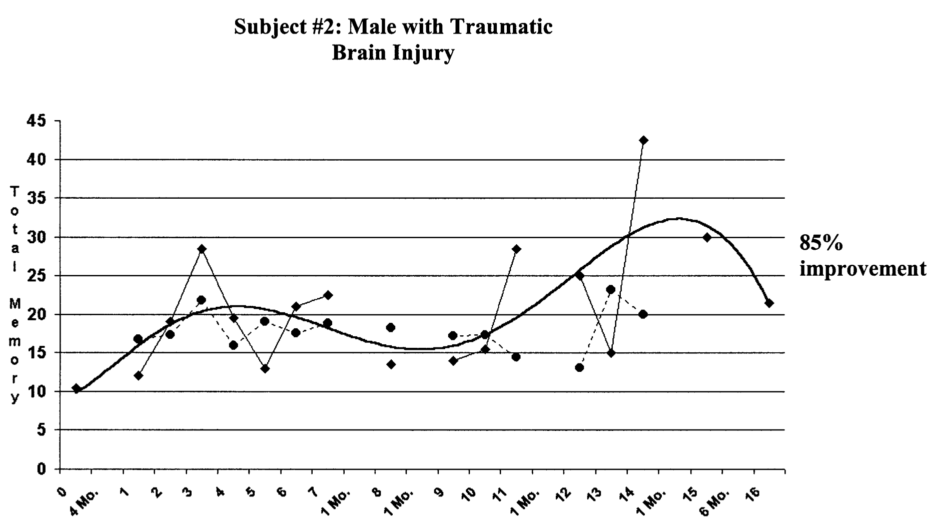

Fig 2. Undulating curve is a best-fit polynomial trend line to the 6th order. Dotted line = norms; Solid line = subject.

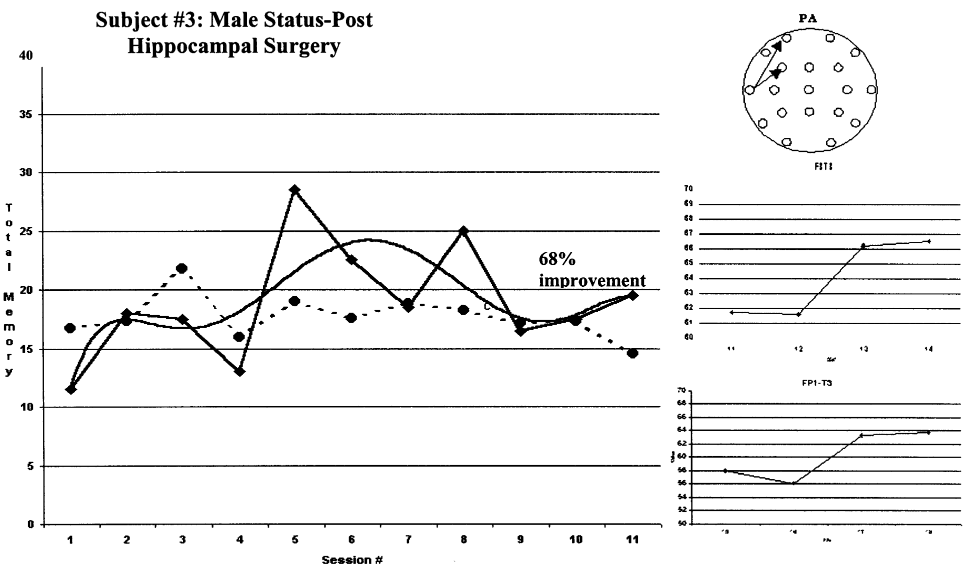

Fig 3. Undulating curve is a best-fit polynomial trend line to the 6th order. Dotted line = norms; Solid line = subject; PA = phase alpha.

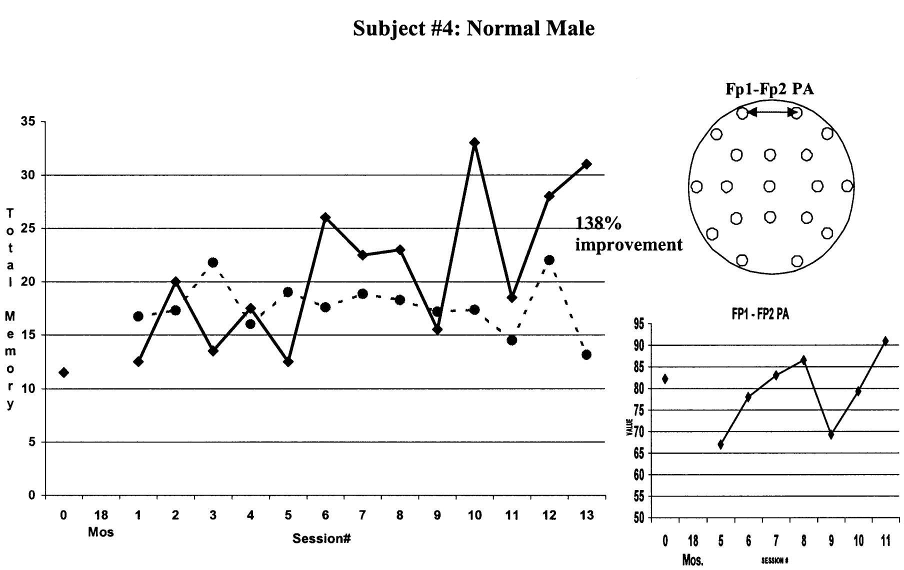

Fig 4. Undulating curve is a best-fit polynomial trend line to the 6th order. Dotted line = norms; Solid line = subject; PA = phase alpha.

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Subject #5: Normal Female

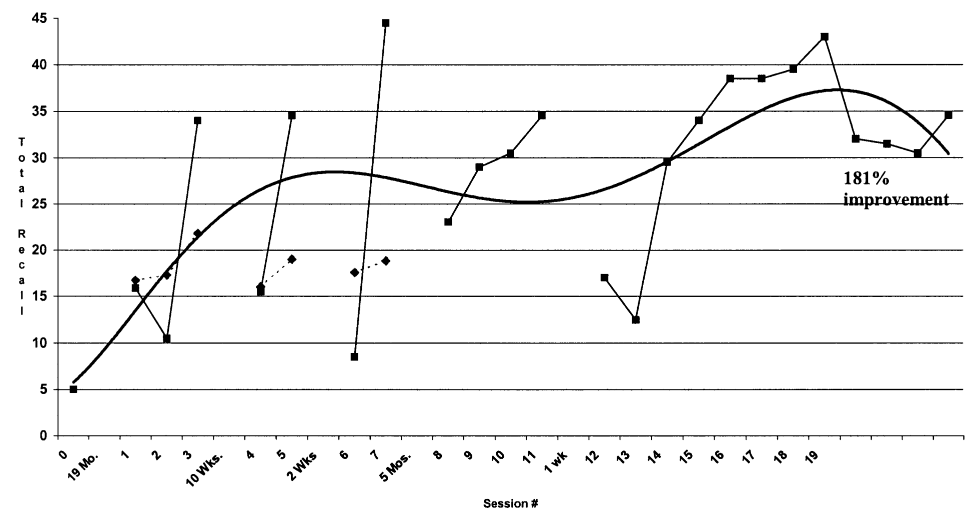

Fig 5. Undulating curve is a best-fit polynomial trend line to the 6th order. Dotted line = norms; Solid line = subject.