Facilitation of Declarative Memory and Congruent Brain States by Applications of Weak, Patterned Magnetic Fields: The Future of Memory Access?

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Abstract

Modern communication and electronic technology have produced a complex secondary electromagnetic environment within which we are all immersed. Ultimately patterns will be generated that are intimately congruent with those generated by the human brain during memory consolidation. Their strategic patterning within educational contexts could facilitate learning and memory consolidation. Human volunteers exposed to a weak patterned magnetic field whose electrical equivalent produces long-term potentiation or memory enhancement in a variety of contexts, showed a significant increase in the retention of narrative details 20 min after the field was applied over the left temporal lobe but not the right temporal lobe; scores for the latter group did not differ from sham-field subjects. The effect size of the memory enhancement was sufficiently large, accommodating 60% of the variance, to have educational and practical applications. The changes required about 15 minutes to be apparent and were related to the expected quantitative changes in brain activity. These results, which replicate previous experiments, indicate there is a potential technology that could be developed to enhance memory capacity and to promote vocational advantages for the average person in the 21st century.

Keywords: episodic memory, applied magnetic field, Long-Term Potentiation, memory enhancement technologies, future education

1. Introduction

Memory is the representation of experiences within cerebral space. Classical approaches to the taxonomy of human memory have differentiated between types of memory that involve non-awareness and awareness (Squire, 1986; Tulving, 1992). The latter is dependent in large part upon language processing. Declarative memory has been dichotomized further into semantic and episodic forms. For most human experiences declarative memory is the form that defines the individual's memories concerning knowledge in general (semantic) and with whom, where, and when (episodic) this knowledge was acquired. Autobiographical memory is considered a subset of episodic memory. Both episodic and autobiographical memories are "reconstructions" of experience rather than isomorphic reiterations and primarily involve the integrity of the right prefrontal regions of the cerebrum (Buckner and Petersen, 1996).

Although there are pharmacological enhancements for some populations who exhibit deficiencies in memory, particularly the elderly, facilitation of retrieval accuracy for normal individuals with average memory has been more variable. However within an expanding age of information processing and successful access to vocational opportunities that are contingent upon "how much" one knows, even small increases in retention rates can be advantageous. Within the near future one would expect a technology to emerge that would enhance memory capacity in order to adapt to the greater demands and challenges of competition.

One promising non-pharmacological technology involves applying weak, physiologically-patterned magnetic fields while the person is engaging in acquisition of information. They can be both programmed and generated by contemporary computer software and stylized for individual differences.

2. Technical Rationale and Development

By "weak" magnetic field intensities we refer to those within the 1 microTesla (10 mG) range. These intensities are easily generated from computers and other electronic devices. "Physiologically-patterned" indicates the temporal configurations of the applied fields are similar to and have the potential to overlap with the intrinsic complex changes occurring within specific regions of the cerebrum. The operational assumption is these regions could be accessed through the appropriately patterned magnetic field applied through the cerebrum. Continuous, presumably "random", penetrations of ambient fields occur naturally from the plethora of electronic equipment and communication systems in the modern environment and from small changes in the earth's magnetic field. In the balance of possibilities these "spontaneous" patterns likely cancel through mass action.

Any complexity of physiologically-compatible magnetic field can now be generated by computer software. This can be completed by employing analog to digital converters. Here a column of numbers between 1 and 256 is converted to voltages between -5 V and +5 V. They are then applied through arrays of solenoids that generate the magnetic fields. Where the arrays of small solenoids are placed as well as the rates of change (derivatives) of their activation over brain space influences their effectiveness. Alternatively programming wave files by more routine computer software can simulate the complexity of brain function.

"Focusing" of the field is not required. The operation is similar to that of hormonal action. For example when thyroid stimulating hormone (TSH) is released from the pituitary the compound is distributed through the blood proximally to every cell in the body. However this compound is sequestered specifically to the thyroid because of the compatibility between the chemical structure and the receptors on this organ.

Electromagnetic patterns that penetrate the brain work in an analogous manner. The congruence involves temporal patterns rather than spatial (molecular) structures. There is experimental evidence for this effect. Lagace et al (2009) showed that whole body application of specific patterns of magnetic fields patterned to simulate LTP (long-term potentiation) in different regions of the rat brain selectively preserved neurons rendered vulnerable by excessive electrical activity. LTP phenomena are considered to be the primary substrates or correlates that contribute to structural and stable representation of experience within cerebral micro-space. The Lagace research was based upon the electrophysiological data from Yung et al (2002) who found that different structures associated with memory each displayed relatively specific and distinguishable electrical patterns to produce optimal LTP in that region.

If individual memory is "experience" represented within brain space, then stimuli that have the capacity to penetrate this volume could potentially enhance, diminish or even alter (Healy and Persinger, 2001) the details or themes of memories. The 21st century environment is replete with myriad weak electromagnetic fields from electronic equipment and communication technology that have the capacity to interact with the microstructure of brain tissue. Effectively most human beings are now exposed to a complex matrix or "secondary" field of electromagnetic signals that have the potential to contain rich information capable of modifying the chemistry that is strongly correlated with memory consolidation (Whissell and Persinger, 2007).

The arguments against the influence of weak, physiologically-patterned magnetic fields because of their limited penetrability were based upon beliefs rather than upon data. Persinger and Saroka (2013a) showed conclusively that the patterns and intensities of the magnetic fields employed in the present study exhibited no statistically significant attenuation when applied across and through densities and thickness about twice that of the human skull. In addition, source localization algorithms indicated that different patterns of magnetic fields influenced different frequency bands and regions of the cerebrum as demonstrated by s_LORETA or Low Resolution Electromagnetic Tomography of quantitative electroencephalographic measurements (Saroka and Persinger, 2013). The subjective experiences associated with the specific patterns of the transcerebral exposures (across the temporal lobes) were predicted by the regions of the cerebrum that were activated. Finally, the quantitative electroencephalographic changes and intracerebral indicators required about 10 to 15 min to emerge, thus eliminating the explanation that the EEG changes were "induction" artifacts.

Weak (1 microTesla) complex (physiologically) patterned applied electromagnetic fields may not necessarily be deleterious. Arendash et al (2010) found that long-term exposure of mice to cell-phone fields reduced the chemical markers associated with Alzheimer's disease. Baker-Price and Persinger (1996, 2003) found that patients who had sustained closed head injuries and who displayed persistent complaints of "poor memory" and depressed mood years after the injury, usually in conjunction with mild to moderate neuropsychological impairment, showed marked improvements after six, weekly (1.5 hr per week) treatments with a specific field pattern. It was composed of repeated sequences of pulses in a brief (about 1 s) packet followed 4 s with no activation before the packet occurred again. The improvements were psychometrically conspicuous, were evident in even strip-chart electroencephalographic recordings, and exhibited effect sizes (the amount of variance explained) that were comparable to that reported for TMS or Transcranial Magnetic Stimulation (Dell'Osso, et al, 2011). However, TMS technology requires special equipment, is regulated, and involves field strengths a million times more intense than that available from electronic backgrounds. The mechanism has been attributed to the induction of electric currents within the brain regions in which the field was focused.

Our theoretical and experimental data strongly suggest that the weak, physiologically-patterned magnetic fields produce their effects because of the magnetic energy, rather than the direct current induction, associated with penetration through the brain's volume. As shown by Cifras et al (2011) the traditional arguments by classical physics that the energies are too low to compete with that associated with the molecular energies coupled to brain temperature are not valid. In fact the energy within the cerebral volume ($\sim 10^{-3}$ m^3) available from 1 μT magnetic fields would be sufficient to influence the energy from action potentials of hundreds of millions of neurons per second. This calculation, which has been verified experimentally by photon emissions from cells (Dotta et al, 2011; a,b) indicates that each action potential is associated with 10^{-20} Joules of energy. That the global energy from the applied field is physiologically relevant and produces effects comparable to that from direct current induction has recently been shown through comparison of clinical data collected from both protocols by Persinger and Saroka (2013b).

For the last two decades we have been investigating the facilitation effects of physiologically-patterned magnetic fields upon human volunteers (Michaud and Persinger, 1985; Richards et al, 1996). Several experiments have shown enhancement of the details of brief (a few minutes) complex narratives if biofrequency weak magnetic fields were applied across the brain at the level of the temporal lobes (Richards, et al, 1996). The enhancement was usually in the range of 20 to 40% compared to control or reference conditions. There is also evidence that strategic application of very weak, patterned magnetic fields over the left prefrontal region will increase the person's likelihood of accepting a false statement as true (Ross and Persinger, 2008). The left prefrontal region is involved with decision-making and the perception of "choice".

If weak magnetic fields can affect human cognition they should produce, under optimal conditions, effects similar to that of well known pharmacological agents. However unlike pharmacological agents the representation of the magnetic field patterns and the information within them are not limited by blood flow or the capillary distribution and density. Unlike pharmacological agents whose effects can continue after they have been uncoupled from the receptor because of degradation into other structures (and compounds), when the magnetic field is stopped the "virtual field" that was generated within the cerebrum stops immediately. There are no "side effects" due to metabolites; they are chemicals transformed by intrinsic chemical activities into compounds that may or may not be beneficial.

The field pattern that was applied across the temporal lobes of the patients whose memory improved and mood was elevated after six weeks of weekly exposure was a "burst-firing" pattern; it was presented for about 1 s once every 4 s during a 60 min period. When this same field was applied to rats for 30 min an analgesia that was equivalent to 4 mg/kg of morphine was produced (Martin et al, 2004). Different patterns of these weak magnetic fields produced different magnitudes of analgesia. The most impressive effects were observed for rats in which brain damage had been induced by experimentally-induced protracted epileptic seizures. Their threshold for responding was permanently "normalized" after only three daily exposures to the field (Martin and Persinger, 2005).

Here we present results of an experiment that was modified from the procedure first reported by Richards et al (1996). Unlike other studies the shape of the applied magnetic field was designed after a specific pattern that was demonstrated to evoke LTP in slices of hippocampal tissue ("the gateway to memory") and to be associated with intrinsic processes coupled to the transition from short-term to intermediate and long term memory.

In the Richards study the numbers of accurate details recalled by the group who listened to a narrative while they were being exposed to this field applied over the left hemisphere but not the right hemisphere were twice that of the sham-field group approximately 10 days later. In the present study we expanded this procedure to include additional measurements of mood and subjective experience as well as the ongoing (real-time) quantitative electroencephalographic activity during the field exposure and consolidation period. We reasoned that if the treatment promised any practical or clinical effects, the effect size (eta^2 or the amount of variance explained) should be at least 40% and would therefore require a small sample size to be statistically significant. We also concluded that the subject as well as the person who interacted with the subject and who scored the results should be blind to the experimental condition.

3. *Methodology*

3.1 Subjects

A total of 12 university men and women volunteered to participate in the experiment. Their ages ranged from 20 to 27 (mean age of 22.5 years; standard deviation of 2.6 years). Eight of the participants were exposed to the magnetic field condition; 4 participants were exposed to the field over only the left hemisphere while another 4 participants were exposed to the field over only the right hemisphere. In addition, 3 subjects were exposed to the sham condition. In the sham field condition all procedures were identical but no magnetic field was applied. One individual was excluded from the analysis after the study was completed because a field not designated for this study had been applied.

3.2 Procedure

After approval by the university's Research Ethics Board, the protocol was initiated. Each participant was told that he or she may or may not receive a weak intensity magnetic field. The participant was seated in a comfortable chair in a darkened, shielded acoustic chamber to minimize extraneous sounds and visual stimuli. An ELECTRO-Cap international electrode system with 19 AgCl sensors was placed over the head and referenced to the ears for collecting monopolar EEG data. Impedance under 10 kOhms was verified and maintained for each sensor. The EEG cap was connected to a portable laptop outside the chamber employing a Mitsar 201 amplifier system. WinEEG version 2.84.44 working in Microsoft Windows XP was used to collect the EEG data.

A baseball cap was placed over the EEG cap. Over the surface of the hat there were 8 solenoids. The 8 solenoids were arranged with four over each temporal lobe in (Figure 1). The Shiva Neural Stimulation Software (Todd Murphy) was used to apply the magnetic field to the appropriate solenoids through USB audio devices. The software was custom-designed by Professor Todd Murphy to deliver weak-intensity (1 µT) magnetic fields to each of the solenoids at specific times. This intensity is comparable to that generated by some electronic sound sources that are placed within the ears.

The signals generated from the Shiva software were audio derivatives of patterns converted into magnetic fields. For this experiment the Shiva patterned "hippocampal field" was selected given that it is modeled after the LTP (long-term potentiation) field (see Figure 2). The purpose of the experiment was to discern the effects of the field on memory while concurrent QEEG measurements were recorded. To ensure specificity the field was not applied over both hemispheres concurrently. Participants were either exposed to a sham field condition (no field), left hemispheric field exposure only, or right hemispheric field exposure only. Within the treatment conditions the magnetic field would rotate to each solenoid individually (clockwise if the exposure was over the left hemisphere and counter-clockwise if the exposure was over the right hemisphere).

Figure 1: Participant in the Acoustic Chamber Wearing the Magnetic Field Application Device

Prior to the experiment participants were administered the short form of Profile of Moods States as a pre-test as well as two memory tests. All memory tests were counterbalanced in their administration. The first memory test involved the immediate (within 15 s of completion of reading the stories or words) recollection of two stories from the Wide Range Assessment of Memory or WRAML2 as well as the Rey's (see Kolb and Whishaw, 2003) auditory verbal learning test (AVLT) which involves the recollection and recognition of lists of 15 words. Baseline EEG recordings consisting of 2 minutes of eyes open and 2 minutes of eyes closed EEG conditions before the experiment began. The participants were instructed to keep their eyes closed during the next portion of the experiment.
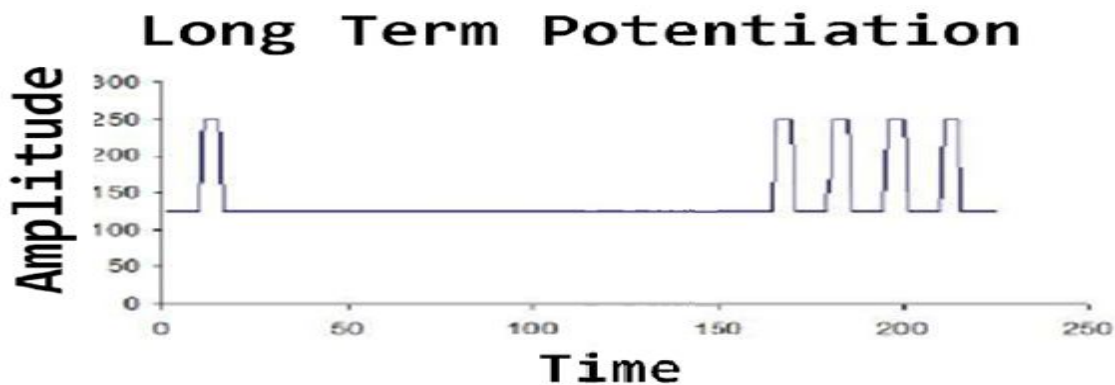

Figure 2. The pattern of LTP (Long Term Potentiation) that was applied as a weak magnetic field over either the right or left temporal lobe during the interval of memory consolidation. The x axis represents time in 1 ms intervals while the amplitude indicates values between 127 and 256 which were transformed to the magnetic field pattern. The time between the primer pulse and subsequent 4 pulses was 150 ms.

The participants were then exposed to one of the three magnetic field conditions for 20 minutes while QEEG activity was measured. After the treatment period a second set of baseline recordings were obtained. The participants were then asked to recall both stories from the WRAML2 as well as the wordlist from the AVLT. After the delayed recall participants were then asked to immediately recall two additional stories from the Wechsler memory scale (Wechsler, 1945) and the test of verbal learning (from the WRAML2) as analogues to the first two memory tests presented in counterbalanced order.

The information was reported by the subjects through the lapel microphone while they were still sitting comfortably within the chamber and recorded on standardized tests sheets.

Each subject was then administered the post-test POMS as well as an exit questionnaire for experiences within the chamber during the 20 min exposure period. This questionnaire listed items of common experiences reported by approximately 500 subjects exposed to variations of these weak magnetic fields over the last 15 years (Persinger and Saroka, 2013b). Each item was ranked according to the frequency of these experiences (0=no experience, 1=happened once, 2=occurred frequently). These experiences referred to visual, auditory, tactile, vestibular and spatial anomalies as well as the sensed presence, out-of-body experiences, and a variety of emotions including fear and sadness. The timeline of the experiment is presented in Table 1.

Two experimenters were responsible for the experimental procedure. One of the experimenter's was responsible for the control of the magnetic field equipment and the other for the administration and scoring of the psychological tests. Given that there is an element of subjectivity required for the scoring of the psychological tests the experimenter responsible for the administration and scoring was blind to the field conditions until all participants had completed the paradigm and the psychological data were scored and entered into an SPSS data file.

Table 1: Procedure Timeline

Timeline
POMS(sf) Pre-Test
Stories 1 & 2 and AVLT in counterbalanced order (administration and recall)
Baseline Recordings
Field Exposure
Baseline Recordings
Stories 1 & 2 and AVLT in counterbalanced order (delayed recall)
Stories 3 & 4 and Verbal Learning in counterbalanced order
POMS(sf) Post-Test & Experiences Questionnaire

3.3 Electroencephalographic Recordings

Brain activity was measured by a Mitsar-201 portable QEEG system that was connected to a 19-channel electrode cap (Electrode-Cap International) that contained the 10-20 Standard Electrode Placement. Electrode site include Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, T6, O1, and O2 that were linked to the ears (A1 and A2) for monopolar recordings. Impedance of all channels was less than 10 kOhm. Data were acquired using WinEEG v2.84.44 software with a sampling rate of 250 Hz. A 50 Hz to 70 Hz notch filter was used in the WinEEG software for all subjects in order to filter high frequency noise during recording. The EEG record was inspected for movement artifacts; the principal component analyses (PCA) method of artifact correction within WinEEG software was employed where appropriate.

3.4 Statistical Analyses

Raw spectral power was extracted from the EEG data within the WinEEG software. Two, 30 second, artifact-free sample were extracted for each individual during a pre- and post-baseline, during all memory tasks (both pre- and post-field exposure), and at 5, 10, 15, and 20 minutes after the start of the treatment or sham field procedure. The spectral analyses partitioned the EEG data into delta (1.5-4 Hz), theta (4-7 Hz), alpha (7-14 Hz), beta 1 (14-20 Hz), beta 2 (20-30 Hz), and gamma (30+ Hz) bands. All statistical analyses involved SPSS 19.0 operating using Windows 7.

4. Results

4.1 Quantitative Memory Increase but No Mood Changes

The means of the z-scores for the immediate recall of the two stories were between 0.1 and 4 (SD=0.8) for all three groups combined indicating that the population was representative of the average person. Because persistent rather than brief memory enhancement was the focus of the study, the differences in z-scores 20 min after the stories (average of the two) were first recalled and after 20 min of treatment were subtracted from the immediate z-scores for the stories. Analysis of variance revealed strong and statistically significant differences between the three treatment conditions (sham or no field, left hemisphere application, right hemisphere application).

As shown in Figure 3 the z-scores for the stories (delay recall – immediate recall) was significantly [$F_{(2,10)}$=6.02, p<.05, eta^2=0.60] higher for the group exposed to the left hemispheric field application compared to the right hemispheric application or no field condition that did not differ significantly from each other.
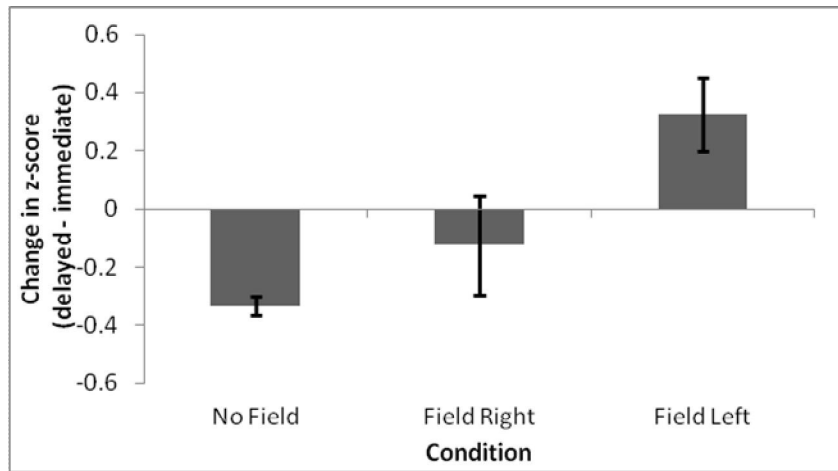

Figure 3: Change in z-Scores between Delayed and Immediate Recall of the Narratives (Stories) for Groups Exposed to No Field or to the Field Applied Over the Right or Left Temporal Lobe Region. Vertical Bars Indicate SEMs (Standard Errors of the Mean).

As shown in Figure 4 a general magnetic field effect was evident for the test that required the participants to recall a list of un-related words (AVLT). The change in total z-score for the pre-treatment first word list test (AVLT) to the post-treatment verbal learning test showed that the change in z-score (post-treatment word total – pre-treatment word total) was significantly improved for the group of participants exposed to a field (regardless of exposure hemisphere) compared to controls [$F_{(1,10)}$=5.28, p<.05, eta^2=0.37]. Analyses of variance demonstrated no significant difference in mood scores for any of the six domains for the groups. The grand means and standard deviations for each domain were: tension (2.0, 3.7), depression (1.9, 1.8), anger (0.5, 0.9), vigor (6.6, 4.8), fatigue (5.2, 3.5), and confusion (0, 1.7, negative scores are possible for this scale).
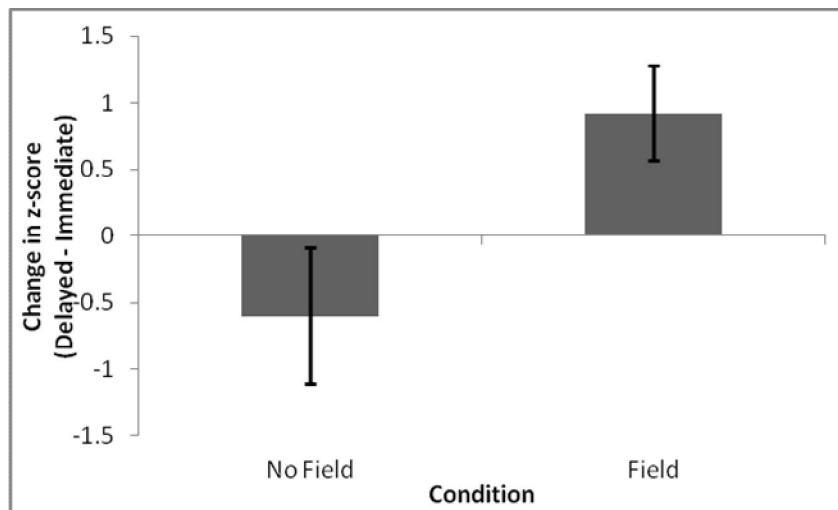

Figure 4: Change (Improved) In Z-Scores for Unrelated Word Recall for Individuals Exposed to the No Field (Sham) or Field (Regardless of Hemisphere) Conditions. Vertical Bars Indicate SEMs.

4.2 Quantitative Electroencephalographic Results

QEEG data were collected for the entire duration of the field or sham-field exposures. Initial analysis of brain activity was examined over the temporal lobes during the 5th, 10th, 15th, and 20th minute of exposure. A significant 4-way interaction between condition, time, hemisphere and anterior/posterior portion of the temporal region was found [$F_{(6,57)}$=2.34, p<.05, partial eta^2=.20] for power within the alpha range only (Figure 5).

Post hoc analysis revealed that the left-hemispheric exposure group had significantly more relative alpha power over the *right posterior temporal region* than the sham group at approximately 15 minutes after the initiation of the field exposure.
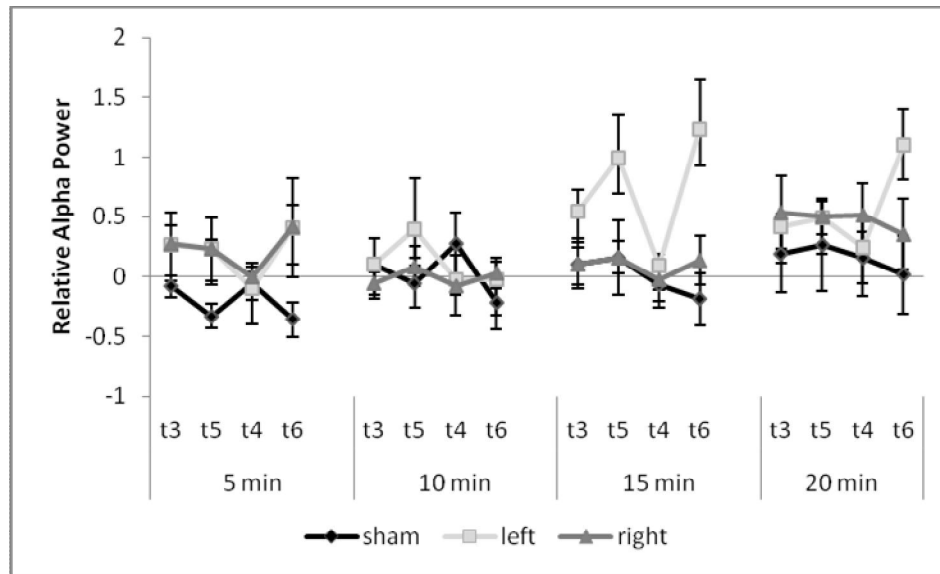

Figure 5: Relative Temporal Alpha Power During Different Periods for the three Treatments: Sham, Field Over the Left Temporal Lobe, Field Over the Right Temporal Lobe. Vertical Bars Indicate SEMs

The relative temporal alpha power measurements over the posterior channels increased around 15 minutes for the group who was exposed to the left hemispheric application of the LTP magnetic field. In order to explore this further the posterior temporal channels were summed (regardless of hemisphere). Results revealed that there was significantly more relative alpha power at 15 minutes after the initiation of the field exposure for individuals in the left-hemispheric group compared to the sham group [$F_{(2,21)}=4.46$, $p=.026$, $eta^2=0.32$] (Figure 6).
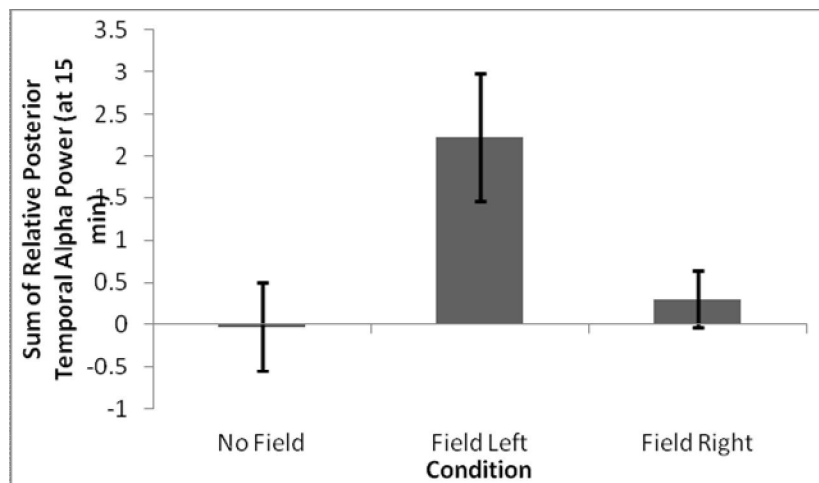

Figure 6: Sum of Relative Posterior Temporal Alpha Power after 15 Min of Treatment. Vertical Bars Indicate SEMs

Correlation analyses were employed to relate the QEEG results (μV^2 Hz^{-1}) with results obtained from the memory tasks. Analyses revealed that the magnitude of the posterior alpha power was significantly correlated with the change in story memory scores (z-scores) after only 5 minutes of exposure (rho=.522, p=.013; r=0.507, p=.016). When the posterior temporal channels were combined, significant correlations, depending on the order of the test administration, were found. If the individuals had been given the stories as the second test performed (where 5 minutes into the field exposure would be approximately 13 minutes after they were presented with the stories to be recalled) significant correlations were found after 5 (rho=.598, p=.040; r=.754, p=.005), 15 (rho=.598, p=.040), and 20 minutes (rho=.669, p=.017; r=.692, p=.013).

These results indicated that after 5, 15, 20 minutes of field exposure there were moderately strong correlations between the strength of posterior alpha activity and how well the participants *would* later recall the details of the stories.

4.3 Intrinsic Validation from Non-Memory Mood and Subjective Experiences

Although there were no significant changes in various mood scores between the sham and two field exposed groups, we discerned if there were any non-memory related associations between mood, subjective experiences associated with sitting in the chamber, and the QEEG patterns. Results indicated that participants who rated themselves as "feeling dizzy or odd" throughout the experiment as inferred by their responses on the Exit Questionnaire endorsed items indicative of more global mood disturbance between the pre- and post-treatment conditions [$F_{(2,10)}$=5.41, p<.05, eta^2=0.57] regardless of condition. *Post hoc* analysis indicated that the greater the increase in negative mood, the more dizzy or odd the participants reported feeling throughout the experiment.
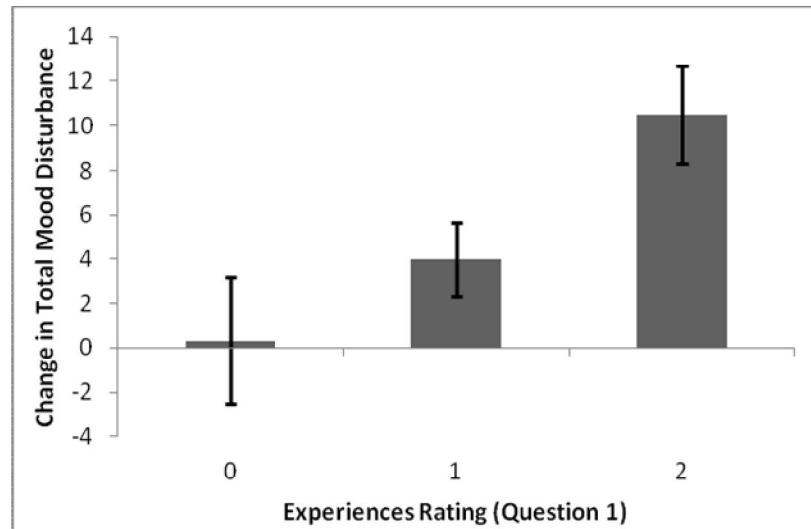

Figure 7: Average Change in Total Mood Scores for Groups of Individuals Who Reported Various Frequencies of Feeling Dizzy or Odd Frequently During the Experiment

Correlation analyses were performed in order to determine if there was a relationship between the change in total mood disturbance scores and relative spectral power in electroencephalographic activity. The relative power scores were correlated with change in mood. Only one relative power score was significantly associated. The "I felt dizzy or odd" item score was correlated with power within the beta frequency band over the central parietal region after 15 minutes into exposure (rho=-.771, p<.01; r=-.785, p<.01). The association suggests that as the relative beta power in the central parietal channel decreased (around 15 minutes) the dizzier or odder the participants later reported they felt and the more disturbed the general mood was endorsed. Given that many neuroimaging studies have localized some vestibular functioning to parietal (intraparietal sulcus) regions it is not surprising that this region could be involved with this sensation and facilitated the change in mood.

5. *Discussion*

The presentation of a patterned weak electromagnetic field over the left hemisphere during the consolidation of declarative memory had been shown previously to facilitate the accuracy for a narrative (5 minutes in length) when it is recalled around 10 days after the initial presentation (Richards et al., 1996). Consolidation of declarative memory is a process within the human brain that requires both chemical and electromagnetic factors to facilitate long-term potentiation (LTP). The "hippocampal field" which was the magnetic field employed in the present study was the exact pattern that when applied to hippocampal slices evoked protracted alterations in neuronal thresholds after about 10 to 15 min, the time usually required for spine formation on dendrites. The LTP field was based on the algorithm for induction of LTP (Rose et al, 1988) within the hippocampus.

In the present study participants who had been exposed to the hippocampal field over the left hemisphere for 20 minutes recalled two-thirds of a standard deviation (almost 25%) more details from the stories compared to the immediate recall than the participants who were exposed to the sham field condition. The effect size also indicated that the experimental treatments accommodated 60% of the variance in the number of memories.

This effect size was within the range reported by Richards et al (1996) and is well within the range of having practical applications. In the present study we also ensured that the persons interacting with the subjects and scoring the data were not aware ("blind") of the field treatments so that subtle influences would have been eliminated even though the responses were collected by intercom between where the subjects were sitting and the experimenters recorded their comments.

The specificity for the hemisphere of application for the stories but not for the unrelated list of words is congruent with the differences between the left and right hemisphere. As reported by Budzynski (1986), the right hemisphere exhibits the semantic capacity of a young adolescent but the syntactic capacity of about a six year old. Consequently for unrelated words, such as the word list, stimulation of the right hemisphere should have produced the same effect as stimulation of the left hemisphere. This was observed. On the other hand verbal memories depending upon syntax, such as the stories was not facilitated by right hemispheric stimulation but was enhanced by left hemispheric stimulation. We appreciate there may be other explanations.

Memory and memory retrieval are affected by the emotional or affective components of the experiences. In previous studies we (Corradini and Persinger, 2013) found that transcerebral (again across the area of the temporal lobes) exposures for 30 min to a burst-firing magnetic field (1 µT) reduced scores for depressed mood. The pattern of this field was an accelerating phase modulation. It was generated by converting 230, successive varying increments of voltage (-5 V to +5 V), each with a duration of 3 ms, to a magnetic pulse. The packet was 690 ms in duration and presented once every 4 s before being repeated and was very similar to the protocol employed for depressed patients by Baker-Price and Persinger (1996; 2003). This same pattern produced marked analgesia in rats (Martin et al, 2004). In the Corradini study the presentation of the field resulted in an increase in the power in high beta (20 to 30 Hz) frequency band over the frontal lobes bilaterally and over the left temporparietal lobe. Activation within the left hemisphere is often associated with increased retention for new information.

Other experimenters (Tsang et al, 2009) found that brief (approximately 15 to 30 min) exposures to transcerebral magnetic fields created by a different technology than the one employed in the present study affected mood as inferred by significant changes in scores for the Profile of Mood States. They found that *different temporal patterns* produced different changes. Unlike the results reported in the present study which was based upon optimal production of LTP, subjects exposed to the same field but pulsed every 20 ms reported significantly elevated scores for confusion compared to subjects exposed to the sham field or even magnetic fields of even greater complexity. Compared to subjects exposed to random variation field patterns or to a combination of the burst-firing and LTP field employed in this study, only those subjects exposed to the burst-firing displayed marked increases in mood levels.

Given that such strong and hemispheric specific treatment effects are evident from the behavioural results one would expect easily discernable quantitative measures within concurrent brain activity within classically associated regions. Analysis of the QEEG data revealed that the posterior temporal (specifically within the right hemisphere) regions displayed increased relative power (μV^2) after approximately 15 minutes of the field exposure for individuals that received the treatment over the left hemisphere. The intricate and strongly correlated coupling between verbal memory and left temporal lobe function is pervasively documented within both experimental and clinical historical literature (e.g., Kolb and Whishaw, 2003). References to the role of alpha activity over the temporal lobes during memory tasks are also replete within the scientific literature. That increases in alpha power over the posterior temporal region are related to improvements in memory has been demonstrated by Jensen et al (2002) and Meeuwissen et al (2011).

Interestingly, the condition that produced the effect was application of the LTP magnetic pattern over the left hemisphere whereas the QEEG spectral power differences were noted primarily over the homologous region of the right hemisphere. This may not be contradictory. Enhanced alpha activity over the right temporal lobe, (which is often the initial processing region for novel information) could reflect diminishment of input from this novelty processing into the left hemisphere so that verbal representations within left temporparietooccipital tertiary areas are less disrupted. This would later increase the accuracy of the verbally labeled and cognitively reconstructed information during the recall tasks.

This supposition is consistent with results for individuals who have reportedly enhanced visual 'eidetic' memory. Brang and Ramachandran (2010) studied an individual who reported grapheme-colour synesthesia and a seemingly separate ability for visual imagery/memory, i.e., eidetic memory. They found the subject exhibited a right-hemispheric bias in his grapheme-colour synesthesia. Assuming eidetic memory is predominantly associated with visual/spatial stimuli it is not unlikely that the right hemisphere plays a dominant role in this ability considering its propensity for visual/spatial processes. Because the task that showed the difference in this study was the recollection of details in stories it is likely that individuals used imagery as a tool to enhance their memories and when the field was applied over the left hemisphere the transference from verbal (left hemisphere) to visual (right hemisphere) could have been facilitated.

The results of this study support the data found in previous work indicating that the pattern not necessarily the intensity of the applied magnetic field produces the largest effects (Sandyk, 1995). If this feature of physiologically-patterned magnetic fields is generally valid, then more precise and individualized patterns of applied magnetic fields across the temporal lobes might be employed as an adjunct facilitator for memory consolidation when maximum information is required. As the demands of information acquisition and memory increase within a very competitive 21st educational world, even small effects from portable and easily implemented technologies could be the difference between "passing" or "failing" criteria for success.

There is experimental evidence that whole body applications of LTP-patterned magnetic fields to rats that display severe learning and memory deficits secondary to experimentally-induced brain injuries (from example uncontrolled epilepsy) facilitate learning and memory. Mach et al (2009) found that the capacity to inhibit responding within discrete temporal increments, one of the most difficult demands for a rat brain, was enhanced during days when the "virtual" LTP magnetic field (similar to the one applied in the present study) was induced compared to other days when the rats were exposed to no field (sham conditions). More recent studies (Tessaro et al, 2013) have shown that the inter-response times of rats more closely approximate the demands of the task if the rats were exposed to the LTP field during those demands.

From a societal perspective and considering the rapid growth and proliferation of the complex patterns of electromagnetic fields that penetrate the body and brain from countless sources of communication, electronic, and computer-based technologies, the subtle effects of certain patterns that can occur as *synergisms* or emergent phenomena (Whissell and Persinger, 2007) upon human behavior in a rapid-demanding memory-based future could be considered. The technological precision of many of the most effective circuits that now constitute computers, solid-state processors, and electronic tunneling junctions are approaching the spatial dimensions (~ 1 μm^2) of the neuronal synapse. Although the carrier waves may be generated within the upper MHz and lower GHz range there are innumerable variations in modulation of subharmonics. The "beats" from superimposition of these fields with much lower base frequencies and irregular shapes approach the capacity for complete resonance with those generated within the brain.

We envision a future time when more aesthetically constructed and embedded microcomputer-driven complex patterned devices worn as caps or hair adornments are routinely worn by those who require the additional 20% of information accuracy to achieve maximum performance. These weak, safe field strengths would be coupled to direct measurements of the person's own brain activity such that "smart" circuits would provide feedback from the cerebrum in response to the immediate, real time effects of the applied fields. This would produce the "custom constructed" and individualized feedback that would promote optimal effects for the student.

6. *References*

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