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DIFFERENTIAL RATINGS OF PLEASANTNESS FOLLOWING RIGHT AND LEFT HEMISPHERIC APPLICATION OF LOW ENERGY MAGNETIC FIELDS THAT STIMULATE LONG-TERM POTENTIATION

MICHAEL A. PERSINGER, PAULINE M. RICHARDS and STANLEY A. KOREN

Behavioral Neuroscience Laboratory, Laurentian University

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A total of 40 normal men and women were exposed under double blind conditions for 20 min to either sham-conditions or to 1 microT (10 mG) electromagnetic fields (known to produce long-term potentiation within hippocampal slices) that were applied primarily over the right temporal lobe, over the left temporal lobe or over both temporal lobes homogeneously. The men and women who received the stimulation over the right hemisphere rated their experiences as significantly more pleasant than those who received the same stimulation over the left hemisphere [eta = 0.51]. Covariance for the variation in ambient geomagnetic activity, which was negatively correlated with pleasantness, increased the significance of the experimental treatment. The potential clinical utility of applying computer-generated local and penetrative but weak intensity complex magnetic fields over portions of the human brain is discussed.

Keywords: hemisphere asymmetry, human, magnetic fields, long term potentiation, hedonism, pleasantness, temporal lobes, geomagnetic activity

The concept that the polarities of hedonistic (pleasant, unpleasant) experience are represented differentially within the left and right hemispheres has been developed by several authors (Budzynski, 1986; Goldberg & Costa, 1981; Gordon, 1986; Gordon, Frooman & Lavie, 1982; Vingiano, 1989; Persinger, 1993). Epileptogenic or surgical electrical stimulation of the right hemisphere is frequently associated with apprehensive vigilance (Andreasen, 1988; Reiman, Riachle, Butler, Herscovitch & Robins, 1984) while comparable activation in the homologous left hemisphere is associated with more positive affect or emotion (Bear, 1986; Bear & Fedio, 1977). Conversely, severe damage to the right hemisphere can result in a form of left hemispheric predominance that can encourage euphoria while analogous left hemispheric damage can encourage protracted anxiety and vigilance (Kolb & Whishaw, 1990; Masdeu, 1990; Persinger, 1993).

We (Persinger, 1993; Richards, Koren & Persinger, 1992; Richards, Persinger & Koren, 1993) have been pursuing the feasibility of treating the affective components of depression and anxiety by applying exogenous, weak (1 microT) complex magnetic fields whose temporal structures imitate the intrinsic electrical activity of specific regions of the brain that mediate these experiences. The subcortical (primarily hippocampal-amygdaloid) limbic regions are well known for their electrical lability and sensitivity as well as their strong concordance with emotional experiences in the primate brain (Nishijo, Ono, Tamura & Nakamura, 1993). If a discernable asymmetry in hedonistic quality is represented within the two hemispheres of the normal person (Budzynski, 1986), then the maximum polarity

Correspondence to: Dr. M. A. Persinger, Behavioral Neuroscience Laboratory, Laurentian University, Sudbury, Ontario, P3E 2C6, Canada.

of this subjective dimension should be demonstrable experimentally by application of weak electromagnetic pulsed fields over the left or the right hemisphere but not during bilateral (cancellation) exposures.

To test this hypothesis, a total of 40 right-handed (as defined by writing preference) volunteers (20 men; 20 women between the ages of 20 and 25 years), served as subjects; they were enrolled in undergraduate arts courses and received a 2% bonus for participation. On the day of the experiment, each subject was tested singly. The subject sat in a comfortable arm chair that was housed within a commercial acoustic chamber. After the eyes had been covered by a pair of goggles, a modified motorcycle helmet was placed over the head. Within each side of the helmet, four solenoids were embedded along the temporal plane; specific engineering and design for this equipment has been published in this journal previously (Richards, Persinger & Koren, 1993). Each homologous pair of solenoids was activated for 10 sec through a commutator such that a complete sweep of the brain region occurred once every 40 sec.

A personal computer was employed to generate a highly specific wave structure that has been demonstrated experimentally to double the amplitude of long term potentiation (LTP) within hippocampal slices for at least 30 min (Rose, Diamond, Pang & Dunwiddie, 1988). The pattern involved a 2 msec pulse (a primer) followed 150 msec later by four successive 2 msec pulses with each pulse separated by 10 msec. The computer was on and off for successive periods of 5 min for a total of 15 min of exposure to the magnetic field patterns.

Because strong affective dimensions of experience are correlated with ambient geomagnetic activity (Persinger, 1974; 1987), the global geomagnetic activity per 3 hr interval during, before and after the subject's exposure to the experimental conditions was obtained from the Geomagnetic Indices Bulletin. To insure specificity of effect, the daily, global aa (average antipodal index) value (in nT) for the day of, the day before and the day after the test day was obtained for each subject.

Our working metaphor is that the effects of weak "signals" from ambient patterns of magnetic fields can be amplified if the background "noise" is ameliorated. By *suddenly* reducing the ambient auditory input (acoustic chamber) and the visual input (by goggles), large populations of neurons might be released from passive registration of information and might be recruited into the ongoing neuronal ensemble or become susceptible to the resonance interaction from the induced currents of weak external magnetic fields.

At the end of the 30 minutes of exposure, each person was asked to rank the experience by completing a modified Likert scale: −2 very unpleasant, −1 mildly unpleasant, 0 = neutral, +1 = mildly pleasant and +2 = very pleasant. They also rated the incidence (0 = never; 1 = at least once; 2 = frequently) of various visual, vestibular, gustatory, olfactory, auditory and memory-related experiences during the treatments; an average score for all 20 items (Persinger, Koren, Makarec, Richards and Youlton, 1991) was calculated. Analysis of variance was completed for this measure as a function of field condition and sex. Analysis of variance and covariance, (which allows the shared variance between the geomagnetic activity during the period of the exposure to the chamber and the rating of the pleasantness of the experience to be removed before the comparisons between treatments are computed), was also employed.

Two way analyses of variance (4 treatments; 2 sexes) demonstrated a statistically significant treatment effect [$F(1,32) = 2.81$, $p = .05$; eta = 0.42] but neither a statistically significant gender effect [$F < 1$] nor a gender by treatment interaction [$F < 1$]. After the Kp indices during the time of the experiment had been covaried for each subject [$F(1,31) = 3.96$, $p = .06$], the significance of the treatment differences increased [$F(1,31) = 3.68$, $p = .02$; eta

= 0.47]. The results are shown in Table 1. The geomagnetic activity at the time of the experiment was negatively correlated ($r = -0.30$; $p = 0.06$] with the pleasantness ratings; a non-parametric (Spearman) correlation was statistically significant (rho = −0.40, $p < .05$].

As predicted, post hoc analyses (Tukey's set at $p < .05$) demonstrated that the most significant difference between the rating of the pleasantness of the experiences during the brief period of partial sensory deprivation occurred between the groups that received stimulation by the weak LTP magnetic field pulses over the right temporal lobe compared to those who were stimulated over the left homologous region. There was no significant difference for pleasantness scores between the bilateral field application and sham-field condition.

To insure that the association between the enhanced ambient geomagnetic activity and relative unpleasantness of the reported experiences was specific to the time of testing, the pleasantness scores were correlated with each of the 3-hr intervals (indicated + or − for before or after) of Kp indices before and after the exposure; they were −1 (−.38), +1 (−.10), −2 (−.28), +2 (−.14), −3 (−.26) and +3 (−.26); only the geomagnetic activity during the interval just before the experiment was also statistically significant. Although the daily average (aa) values were significantly correlated with overall pleasantness ratings (rho = −0.26, $p < .05$], there was no significant association between these scores and the daily geomagnetic activity for the day after or for each of the three days before the treatments. The mean and standard deviations (in parentheses) during this experiment were: 49 (20) nT for the daily aa averages and 4.0 (1.1) for the Kp value during the 3-hr interval of the experiment. There were no statistically significant differences between the four treatment groups [$F(3,36) = 0.55$; 0.44, respectively, $p > .10$].

To discern the maximum effect size of the magnetic field treatment, we compared only the three groups that received the three magnetic field treatments and employed both the ambient geomagnetic activity at the time of the experiment and the person's complex partial epileptic-like signs as covariates. This index of phenomenology (Persinger & Makarec, 1987) that is similar qualitatively to the experiences reported by individuals with verified electrical foci within the temporal lobes (Persinger & Makarec, 1993; Makarec & Persinger, 1990) is suspected to be a fundamental neuroprocess by which the effects of ambient geomagnetically suppressed melatonin-related mechanisms can lower the threshold (increase the probability) for electrical seizures within the amygdala and the hippocampus. These indices are routinely collected in our subjects during class periods between two to six weeks before the experimental procedures; for the present study the mean and standard deviation for the 30 subjects was 33% (19%) which is within the normal range (Persinger & Makarec, 1987).

The two way analysis of variance again demonstrated a statistically significant [$F(2,24) = 4.28$, $p < .05$; eta = 0.47] difference between the three treatments. When the geomagnetic activity [$F = 4.04$, $p = .05$] during the time of the experiments (3 hr Kp value) and the com-

TABLE 1
Means and Standard Deviations for the Subjective Ratings of Unpleasantness-Pleasantness (range −2 to +2) for Subjects Who were Exposed to Computer-Generated Magnetic Fields (10 mG) for 20 min or to Sham-field Conditions

Group	n	*Mean*	*SD*
Sham field	10	+ 0.9	0.9
Stimulation both hemispheres	10	+ 0.8	0.9
Primary stimulation of left	10	+ 0.1[a]	0.6
Primary stimulation of right	10	+ 1.2[b]	0.7

[a] vs.
[b] = $p < .05$.

plex partial epileptic-like signs [$F = 1.59$, $p > .05$] were held constant, the difference in pleasantness ratings between the three treatment groups was enhanced [$F(2,22) = 7.80$, $p = .003$; eta = 0.57] and a marginally significant sex effect emerged [$F(1,22) = 3.77$, $0.05 < p < .10$; eta = 0.28]. By quantifying the variance associated with the experimentally applied magnetic fields, gender, complex partial epileptic-like signs and the ambient geomagnetic activity, 45% of the variance in the pleasantness scores could be accommodated.

There were no statistically significant group differences with respect to the numbers of different specific experiences (e.g., gustation, olfaction, visual, auditory) of which the subjects were aware and that were reported. The mean and standard deviation for the mean score of the different types of perceptual experiences was 0.4 (0.4) for the experimental population. There were no statistically significant sex differences with this sample size although the propensity for the women (M = 0.4; SD = 0.3) to report a more frequent "sense of a presence" than the men (M = 0.2; SD = 0.3) approached this level [$F(1,38) = 2.64$; $p < .10$].

DISCUSSION

The results of this study supported our general hypothesis that heterogeneous presentation of biorelevant magnetic fields within brain space is required to evoke alterations in affect. However the direction of the ratings was opposite to our hypothesis. Subjects whose right temporal lobes received the pulsed field reported that the experiences were more pleasant than those who received the same stimulation along the left homologous region. That the group differences were spurious or influenced by experimenter procedure is not likely in light of the total effect size (equivalent to a correlation of about 0.50) and the double blind conditions of the study.

This antithetic result could be explained if the application of the field to one hemisphere *evoked* normal electrophysiological activation within the homologous region of the *opposite* hemisphere. Consequently, stimulation within the area of the right temporal lobe by the field could have induced elevated activity within the left temporal structures (and hence evoked pleasurable experiences) while stimulation of the left temporal lobe by the pulsed field induced activity in the right temporal structures (and hence evoked relatively less pleasant experiences). Because the mean hedonistic rating following left-sided stimulation was effectively neutral, an absolute symmetry of the effect, i.e., evoked negative experience, was not present.

If the amygdaloid region within the right hemisphere was the primary focus of the effect during the exposures to the electromagnetic fields then the pleasantness could be similar but less intense than the orgasm-like experiences that have been reported when electrical foci within the right mesiobasal structures are activated (Remillard, Andermann, Testa, Gloor, Aube, Martin, Feindel, Guberman & Simpson, 1983); specific slowing of right hemispheric electroencephalographic activity relative to continued normal alpha activity over the left hemisphere has been shown to occur during sexual orgasm (Cohen, Rosen & Goldstein, 1976). Subtle but relative right hemispheric dominance has been suggested as a major correlate of REM (rapid eye movement) or dream sleep during which time very pleasant and orgasmic experiences can occur. That at least experiences that are attributed to dreams are associated with relative right temporooccipital activity is strongly suggested by the propensity for individuals ($n = 150$), who experience sensations along the left peripheral visual field within homogeneous and dim ambient red light, to report twice the frequency of "images from a dream" compared to those who report right-sided or bilateral visual sensations (eta value for group differences = 0.35; Persinger, unpublished manuscript).

The caveat to this conclusion is determined by the capacity for the electrical induction to remain spatially localized since relative recruitment of the right parahippocampal gyrus should evoke anxiety and panic (Reiman, et al., 1984); in fact this affect is the predominant theme of dreams (Hall, 1959). The occurrence of nonlinear relationships between the intensity of current induction (intracranial stimulation) and inferences of pleasantness has been reported for non-human subjects. There is usually an intensity threshold for the evoked stimulation after which the escalating pleasantness catastrophically collapses and is associated with intense displeasure or panic (Grossman, 1967).

As suggested by Sandyk (1992), the ultimate application goal of this research is to employ such treatments (once the optimal parameters are established) as supplements with or even replacements for traditional pharmacological treatments. Whereas magnetic fields whose temporal patterns are extremely redundant (such as sine-waves or square waves), are either not bioeffective or require high intensities to be effective, weak complex fields whose wave structures immolate the firing pattern of neuronal aggregates have been shown to be effective after short (in the order of kilosec) periods of exposure. The counterargument that the inductive consequences of applied EM fields are "too diffuse" is not necessarily applicable because the homogeneous availability of a pharmacological agent within the pervasive and intricate matrices of capillaries that supply neurons throughout the brain volume is just as diffuse as the application of a whole-brain magnetic field.

The critical factor is the specific *biorelevant information* (Jahn & Dunne, 1987) that is ultimately (by receptor binding or other processes) delivered to functional aggregates of neurons. In the present study, the application of hemispherically localized and neuroelectrically relevant information altered subjective pleasantness while bilateral application did not. The possibility that even more focused and biorelevant information within brain space could generate even more powerful effects should be carefully evaluated. Although the effect size of the relationship between pleasantness and the treatment was analogous to a correlation coefficient of 0.51, we cannot estimate the duration of the effect at this time. Other studies have suggested a residual effect of 20 min applications of specific field patterns if they are administered twice per week (Gillis and Persinger, 1993).

From a more general perspective we have been attempting to delineate the neuroanatomical-functional bases for the traditional and fundamental distinction between the affective and cognitive dimensions of human experience. The gross structure of the human brain suggests that experiences of meaningfulness and (pleasant-unpleasant) affect are mediated by the mesiobasal (amygdaloid-hippocampal formation) portions of the left and right ventral hemispheres, primarily through the anterior commissure. The more cognitive (linguistic and visuospatial) components of human experience are generated by cortical activity and intercalate hemispherically through the corpus callosum.

Under normal conditions both the callosal and anterior commissural pathways and properties are activated simultaneously or sequentially within an extremely brief period; consequently cognition and affect are strongly correlated. The present results and well as previous research (Richards, Persinger and Koren, 1993) suggest that the emotional (affective) dimensions of the words one employs to describe experience as well as the ratings of hedonic tone can be affected without concomitant changes in the qualitative or quantitative characteristics of the conscious experience; there were no significant treatment differences between the intensity of the different perceptions that were experienced during the stimulation.

Some neuroscientists (Edelman, 1989; MacLean, 1990) have hypothesized that the concordance of both systems is required for the emergence within the primate brain structure of a property that we crudely label as human consciousness. If these conjectures are valid, then the dissociation between these two powerful domains could also affect consciousness or covert behaviors without the person's awareness by neuroprocesses that must still be defined. A technology that evokes a predictable change in the person's hedonistic experiences could have both clinical and political consequences since affective factors often determine serious decisions relating to the sense of self when rational processes are not operational.

The direction of the statistically significant correlation between geomagnetic activity at the time of the experiences and their pleasantness suggests that increased variations in the geomagnetic field are subjectively more aversive than quieter conditions. If unpleasant experiences are associated with decreased subclinical electrical thresholds within the hippocampal-amygdaloid system, then the frequent association between increased geomagnetic activity and more frequent convulsions and seizures of temporal lobe epileptic patients could be partially explained; the effect size of the unpleasantness-geomagnetic correlation in the present study was comparable to other studies.

Because the index of geomagnetic activity is a crude estimate of amplitude and not of frequency or of biorelevant information within the field, the specific parameters that were responsible for this association are not clear. At this time the resolution of this effect is analogous to increasing and decreasing the loudness of a radio program without attending to its contents (frequency variations). We have suspected that different increments of intensity of geomagnetic activity are accompanied by particular power spectra. This relationship is analogous to the inverse association between frequency and amplitude that is generally characteristic of electroencephalographic measures.

There are three methodologically important consequences of this observation. First, concurrent geomagnetic activity may have a greater impact upon diffuse, affective states such as the pleasantness-unpleasantness dimension of experiences, than previously suspected. However this effect should be masked by the dominance of normal visual and auditory modalities and would require sensory amplification, such as sitting in an acoustic chamber or a cave. Secondly, the enhancement of the hedonistic effects of the experimental magnetic fields once geomagnetic activity had been removed suggests that both of these classes of stimuli may be mediated by similar neurocognitive processes. Consequently to enhance the "signal/noise ratio" of experimental effects, the ambient variations (noise) must be reduced.

Third, the general immunofacilitation that is associated with left hemispheric activation and the general immunosuppression that is associated with right hemispheric activation may play a pivotal role in the treatment of autoimmune disorders (Behan and Geschwind, 1985). The results of this study suggest that hemispherically focused magnetic field treatment may be a prerequisite for the activation of the appropriate immunosuppressive or immunofacilitative response by external (extracranial) electromagnetic sources while the consequences of bilateral hemispheric stimulation may not differ from sham-field or placebo exposures. Such localized cerebral activation by extracranially applied magnetic fields could help explain successful treatments of autoimmune disorders such as multiple sclerosis (Sandyk, 1992) by even weaker, complex pulsed fields.

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