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Comparable proportions of classes of experiences and intracerebral consequences for surgical stimulation and external application of weak magnetic field patterns: Implications for converging effects in complex partial seizures

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ABSTRACT

The similarity of the proportions of different types of experiences reported during surgical electrical stimulation of epileptic temporal lobes published in the scientific literature and those reported following exposures to weak, applied magnetic fields was supported by direct comparisons in a retrospective analysis. Of the 20 types of specific experiences, the surgical stimulation groups reported proportionally more fear experiences, while the groups exposed to temporally patterned magnetic fields applied across the temporoparietal regions reported more somesthetic and vestibular experiences. There were no group differences for the other 17 types of experiences. Calculations indicated that the spread of charge displacement from neuronal membranes by the currents employed in the surgical studies and the magnetic field energy associated with the applied fields could affect similar numbers of cortical neurons. The similar subjective experiences of the two techniques indicate that the less invasive procedures might be employed to systematically study complex partial seizures.

1. Introduction

Within two days of the episode in Morgan Freeman's *Through the Wormhole* series in which a young woman who had just been exposed to our standard protocol to generate sensed presences [1,2] reported profound and emotional phenomena, Vernon Mark, the quintessential pioneer of deep temporal lobe stimulation, called the first author. Although I was familiar with the many clinical experiments through the 1950s into the 1970s involved with elicitation of powerful experiences from direct surgical stimulation by electrodes and the gross similarity to the experiences reported following external application of weak physiologically-patterned magnetic fields across the cerebral hemispheres, Vernon Mark's comments were particularly poignant. He stated that the details and themes that the young woman had reported as well as her general demeanor appeared to be remarkably similar to those displayed by his patients during direct cerebral stimulation.

If very similar experiences were being evoked by both deep electrical stimulation and externally applied weak magnetic fields, then there should be a convergence of some physical quantity, as force or energy, for the operations for both technologies. In addition, the *proportions* of the different types of experiences reported by the patients who received the direct temporal lobe stimulation and the volunteers who were exposed to the externally applied transcerebral (across the caudal portion of the hemispheres) weak, temporally-patterned magnetic fields should be similar except for those modalities that involved the characteristics of the "application geometry" of the stimulation. The following analyses and calculations supported this contention.

2. Methods: comparisons of subjective experiences

The experiential details of the 24 patients who received deep temporal lobe surgical stimulation from Stevens et al. [3], Gloor et al. [4], and Bancaud et al. [5] were scored according to the 20 items (listed in Table 1) from our standard exit questionnaire [6]. The items within the questionnaire had been selected more than two decades previously from the most frequently reported experiences extracted from spontaneous narratives during the transcerebral stimulation by externally applied, physiologically-patterned magnetic fields. The themes included reliving past experiences, feeling of being somewhere or someone else, dream-like states, déjà vu, gustatory sensations, and vestibular effects. These motifs are also the most typical forms evoked by electrical brain stimulation of the hippocampal–amygdaloid region and middle (anterior) temporal gyrus as recently reported by the extensive review of 93 reports in the English scientific literature by Selimbeyoglu and Parvizi [7].

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Table 1
Within population z-scores for proportions of population reporting each experience for the surgical stimulation groups (as inferred by the case reports) and for university subjects (n = 18, with 10 repeats = 28 cases) and film crew subjects (n = 31) that had been exposed to the externally applied, weak, temporally-patterned magnetic fields.

Item	Surgical	University	Film
1. Dizzy or odd	1.02	1.25	1.29
2. Presence of someone or something	−0.81	0.04	0.01
3. Tingling sensations	−1.11	2.14	1.82
4. Saw vivid images	1.63	0.97	1.15
5. Pleasant vibrations moving in body	−0.81	1.25	1.38
6. Felt detached or “out-of-body”	0.10	0.66	0.64
7. Heard inner voice call name	0.44	−1.25	−1.33
8. Experienced anger	−0.81	−1.18	−1.33
9. Experienced sadness	−0.50	−0.76	−0.64
10. Experience not come from own mind	−0.50	−0.76	−0.75
11. Heard ticking sound	−0.50	0.97	0.51
12. Experienced odd smells	−0.50	−1.02	−1.02
13. Experienced terror or fear	2.55	−0.50	−0.41
14. Odd tastes	−0.50	−0.82	−0.87
15. Felt as if I were somewhere else	0.71	0.82	1.01
16. Experienced thoughts from childhood	1.32	−0.19	−0.10
17. Recurring ideas	−0.50	0.15	0.13
18. Felt spinning around	−0.54	−0.03	0.10
19. Dream-like images or from a dream	0.44	−0.71	−0.57
20. Red light became brighter/darker	−1.11	−1.02	−1.10

Bold print indicates statistically significant differences ($p<.05$) between brain electrical stimulation and applied magnetic field groups.

The three sources for our comparisons were selected because of the relatively large numbers of cases for which there were patient-specific detailed reports as well as their historical prominence. The reference to an experience indicated by an item in the questionnaire was scored as present (1) or absent (0). The details of the electrode stimulation protocols are available in each of those publications. However, in general, the electrodes and stimulation occurred within the mesiobasal and adjacent temporal cortical regions.

For comparison, the occurrences of these experiences (0,1) from a population of 31 volunteers from film crews who visited the laboratory and the 18 individuals (some with repeated exposures to different patterns, resulting in 28 separate records) recently involved with the experiments by Saroka and Persinger [8] were obtained. All of these individuals had been exposed to our standard procedure where each person sat blindfolded in a comfortable chair in a dark acoustic chamber. Each person wore the Koren helmet for about 1 h during the two, 30-min presentations of fields. At the end of each 30-min presentation, the subjects had completed the 20 items of the questionnaire.

The Koren helmet is a skidoo helmet within which an array of solenoids is embedded on each side at the level of the temporoparietal lobes. At any given time, one pair (a solenoid on the left and right sides) received current from a +/−5 V input from a digital to analog converter. The voltage range was graded by numbers between 0 and 255 (127 = 0 V) that were programmable by computer software as rows of numbers within this range.

The row of numbers related to the voltage increment originated from the software from personal computers. Each number or voltage was activated for 3 ms. Consequently, with the number of points as the horizontal axis and the values between 0 and 255 as the vertical axis, very complex patterns associated with potentially specific neuronal information can be generated either as copied digital patterns from human electroencephalographic measures or from theoretically-constructed sequences.

In the present studies, one of two frequency-modulated magnetic fields (~5 μT along the edge of the scalp, nearest the source solenoids) was presented across the temporal lobes for 30 min each. The average strength in the air midway between the two sides within the helmet, roughly in the middle of the cerebrum, was about 1 μT. We have shown experimentally that these magnetic fields penetrate cerebral space. Whereas the skull attenuates the *electric* fields generated by neuronal fields within the cerebral cortices, the skull does not impede penetration of our applied magnetic fields into the cerebrum.

In fact, there is no significant attenuation of the field strengths of the frequency modulated pattern, as sampled at 250 times per second for increments of 30 s, when two 2.6 cm (thick) by 12 cm (wide) by 20 cm (long) pine boards (thicker and more dense than the skull) are repeatedly placed or removed between the two clusters of solenoids and the power meter in the center space that is occupied by the subject's cerebrum. In addition, placing 1500 cm^3 of physiological saline or 155 mM KCl in plastic bottles between the clusters of solenoids, to imitate the conductive nature of the whole brain volume, does not attenuate the field strength.

For each of the three populations, the z-scores for each of the items were calculated by SPSS-16 PC software. Discrepancies of >2 between z-scores for each item between groups were considered statistically significant. To verify discrepancies, standardized residuals from regressions were obtained for each item. After removal of the items whose residuals exceeded 2, Pearson correlations between the z-scores were completed between the three populations.

3. Results

For the 24 cases of surgical stimulation with inserted electrodes from the three published sources, the numbers (out of 24) of individuals who reported experiences for each item ranged from 1 to 13. The within population z-scores for each item for the surgical stimulation and for the two populations who were exposed to the weak external magnetic fields are shown in Table 1. Only three items displayed discrepancies between population z-scores: tingling sensations, pleasant body vibrations, and fear. The external magnetic field groups reported significantly more proportions of somesthetic and vestibular experiences, while the surgical group reported more fear. There was no significant discrepancy (z-score differences less than the absolute value of 2) for any of the other 17 items. The correlations between the z-scores for the student and film crew groups (intercorrelation of 0.93) and the surgical stimulation group for those items were 0.56 and 0.60, respectively. Both were statistically significant ($p<.05$).

4. Energetic comparisons of deep stimulation vs. TCS

To compare the quantity of effect within the cerebral space, the physical consequences of applying the specific currents from inserted electrodes within the mesiobasal or adjacent temporal region were compared to the transcerebral presentation of externally applied, physiologically-patterned magnetic fields. The parameters for the three experiments employed by the different surgical teams (for comparison) were: Stevens et al. [3]: 100 Hz, 1 ms per rectified square, 0.1 to 3 mA; Gloor et al. [4]: square wave bipolar symmetrical pulses, 0.5-ms duration, 1 to 2 mA (rarely between 3 and 4 mA); and Bancaud et al. [5]: ~5-ms duration trains of rectangular, unidirectional pulses (50 pulses$\cdot s^{-1}$), each 1-ms long, between 2 and 12 V.

For the surgical stimulations, the median currents from the inserted electrodes were about 1.6 mA (10^{-3} A). With $1.6 \cdot 10^{-19}$ A·s per charge presented for ~1 s, there would be a total of $3 \cdot 10^{16}$ charges involved. The passive membrane potential of the average resting neuron is maintained by $2 \cdot 10^6$ charges [9]. Hence, a total of $1.5 \cdot 10^9$ neurons could be affected by that current and duration. This would be equivalent to about 10% of all neurons in the cortices (~15 billion) of the hemisphere [10] involved. Even if the application of the current was for 5 s rather than 1 s, the order of magnitude of the effect would be similar.

Our estimated numbers of neurons activated by deep electrical stimulation would appear contradictory to other interpretations that assume that currents from inserted electrodes are constrained within less than a cubic mm. However, the creation of this very focal electromotive force would generate an energy potential through the cerebral volume. Adey's [11] calculation of $V^2 = 4kTB\Omega$, where k is