THE EFFECT OF MAGNETIC FIELDS UPON THE CENTRAL NERVOUS SYSTEM

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The possible effects of magnetic fields on neural functioning and human behavior have been much discussed since the time of Mesmer. Only within recent years, however, has this problem been subjected to appropriate experimentation, and at this writing there would appear to be little doubt that some interaction exists between central nervous system (CNS) function and external magnetic fields. This concept has in the past been viewed with considerable skepticism in scientific quarters since civilized man is exposed to a multitude of electromagnetic fields, all apparently with no effect whatsoever. The writer believes, however, that an expanding technology may well be productive of magnetic environments in the future, that could have significant effects upon the human population, that may or may not be undesirable. It therefore appears desirable to briefly review the present state of knowledge in this area and to attempt to categorize it in some fashion. Hopefully, this will serve to indicate the direction in which we should proceed to determine the basis for the interaction between neural structures and magnetic fields, for it is only with this knowledge that we can intelligently predict the possible undesirable effects of human exposures to new and different types of such force fields.

There have been several general reviews of the literature on biomagnetics published within the past few years,[1–3] and their convention of classifying effects according to the type of field exposure will be followed in this paper.

Certain alternating or modulated fields have a definite and indisputable effect upon CNS structures which appears to be limited chiefly to the production of magnetophosphenes[4] through a direct action upon the retina.[5]

The possible mechanism of action appears to be quite unclear at this time and is the subject of some differences of opinion.[6,7] It should be noted, however, that the majority of workers concerned with neural effects have been primarily interested in steady-state fields and the possibility exists for other neurological consequences of alternating fields outside of the frequency and field-strength ranges known to produce the magnetophosphenes.

Reports of the effects of steady-state magnetic fields have been considerably more varied and at times contradictory. Most workers have utilized moderate-to high-strength fields (800 to 91,000 Oe) and have reported alterations in the electroencephalogram most commonly consisting of increased overall amplitude and increase in the number of spindles.[8,9] Other workers have noted a decrease in the frequency pattern with the appearance of delta wave forms,[10,11] and alterations in the DC electrical activity of the CNS.[12] More recently, Aleksandrovskaya and Kholodov have reported histological alterations consisting of increased gliosis in the rabbit brain on exposure to steady-state fields of 200 to 300 Oe.[13] This report is of considerable significance since, if it is substantiated, it will place a serious restriction on any possible therapeutic use of this modality. It should, however, be noted that rabbit brains characteristically evidence histological lesions resulting from endemic diseases (encephalitozoönosis) rendering the interpretation of experimentally produced lesions difficult.[14] No particular attempt has been made to detect any behavioral alterations resulting from exposure to any of the moderate- to high-strength fields. This is somewhat surprising in view of the fact that, whereas only a relatively few workers have utilized low-strength fields, the effects they report are entirely in the area of behavioral alteration.

Brown and his associates have reported a long series of experiments on exposure of lower animals to field strengths ranging from 1 to 10 G primarily aimed at detecting alterations in the biological cyclic activity.[15] Most recently, Brown and Park have demonstrated alterations in the cyclic pattern of activity of planaria produced by altering the vectorial relationship between a photic stimulus and the natural magnetic field of the earth.[16] One is forced to conclude that these organisms are capable of sensing some component of the earth's field and that its known circadian fluctuation may be the driving force for biological circadian rhythms. This would appear to substantiate the reports of Friedman *et al.* on studies relating behavioral alterations in human psychopathological population groups to geophysical parameters associated with naturally occurring variations in the earth's magnetic field.[17,18] In this case, one may conclude that at least a segment of the human population reacts to these alterations in the earth's magnetic field or to some other associated modality. This concept has been challenged in part by Pokorny and Mefferd in a similar recent study.[19] In order to clarify this relationship further, Friedman and his associates looked for neurophysiological correlates of exposure to artificially generated magnetic fields in the human using low-strength fields applied to the head in a bitemporal direction.[20] Simple reaction-time performance was examined in both schizophrenic and normal individuals so exposed. With steady-state fields of 5 and 17 G no changes could be detected. When fields of 5 to 11 G were modulated at rates of 0.1 and 0.2 cps, definite, statistically significant, temporary changes in reaction time were observed. A deliberate attempt was made with a small number of volunteers to determine any electrophysiological correlates of exposure to steady-state and similarly modulated fields up to 100 G in maximum intensity. No consistent alterations in either EEG patterns of frontooccipital DC voltages paralleling the alterations in reaction time were observed [21] The field strengths utilized were considerably lower than those reported to produce either EEG or DC changes in lower animals. In regard to the DC voltages particularly, it should be emphasized that the externally measured frontooccipital voltage is a crude determination and reflects only major alterations in the state of consciousness. It is possible that subtle alterations in both parameters occurred in these experiments and were not detected by the methods utilized. These experiments in humans have been suspended following Kholodov's communication to us of his observations of cerebral gliosis associated with field exposure A study parallel to his is currently underway in an attempt to duplicate his findings.

If Brown's thesis relating the cyclic pattern of the geomagnetic field to biological cycles is correct, then exposure of an organism to an environment lacking this factor should produce detectable alterations in some physiological or psychological parameter. Beischer has reported the only full-scale study in this area with human volunteers exposed for lengthy periods of time to a markedly reduced field at the center of three large mutually perpendicular coils at the Naval Ordinance Laboratory, White Oak, Maryland.[22] This apparatus was capable of maintaining a steady-state field of less than 50 gammas in the occupied area. However, the time constants of the automatic regulating systems were such that the micropulsations (range 0.1 to 10 cps) of the geomagnetic field were, at least in part, not negated. A gradual decrease in the subjects critical flicker fusion frequency was noted with continuing exposure to low-field conditions while a variety of psychological tests demonstrated no statistical differences between experimental and control subjects. At this time, no experiments have been reported on human exposure to null fields produced by resistive shielding methods. The interest in this procedure is that all field components, steady-state and modulated, would be reduced to the same extent. This may be of considerable importance in the light of Friedman's report on the production of temporary reaction-time alterations only by low-strength fields modulated in the 0.1–0.2 cps range. The micropulsation activity of the geomagnetic field was present in Beischer's experiment and in those of Brown involving the natural field. The possibility exists that while the amplitude of the micropulsation activity is quite small, the frequency range of the major components is perhaps biologically significant (0.1 to 10 cps). Furthermore, alterations in the frequency and amplitude accompany magnetic storm activity[23] and there appears to be a diurnal rhythm in the micropulsation activity.[24] Therefore, the possibility that the biological effects of the geomagnetic field are in part associated with this modulation activity, rather than with its steady-state level, cannot be dismissed at this time.

While all these reported observations of the effects of magnetic fields on neural structures appear to be so diverse as to be unrelated, I believe a tenable simplification is that low-field strengths are productive of subtle behavioral alterations without demonstrable effects upon the measurable electrical activity, while high-strength fields are related to observable alterations in electrical activity. Since no attempts have been made to assess subtle functional changes with high-strength fields, these may be present and as yet undetected. In addition, there appears to be considerable evidence indicating a vectorial relationship between the field direction and the neuraxis and some evidence for the geomagnetic field exerting an effect on the function of higher neuronal centers.

For a number of reasons, it is important to determine the actual mode of action of the magnetic field on neural structures. Such knowledge could lead to testable hypotheses and possible therapeutic uses as well as increasing our knowledge of neural functioning itself. In considering this, I believe that we can discount any possibility of the effect being primarily upon the action potential *per se*. Liberman, for example, has reported no alterations in a variety of action-potential parameters with exposure to high-strength fields.[25] It is conceivable that effects at the molecular level (via dipole moments, *etc.*) could produce alterations of the membrane characteristics; if this is so, such effects appear to be nonproductive of major functional changes in the action potential at least of isolated nerve fibers. Nevertheless, the intact CNS with its complexities of anatomical arrangement and multiplicity of synaptic connections (whose sensitivity to magnetic effects has not been determined *in vitro*) could theoretically be sensitive to this effect. Such consideration, *a priori*, would indicate that no specific vectorial relationship between the field and CNS would be necessary for a detectable effect with fields of sufficient strength. Some specific, as yet undescribed, effect at synaptic junctions would similarly be nonvectorial in nature. While some observers have reported alterations of electrical activity with high-strength random oriented fields, others have specified a definite vectorial relationship and most reports of low-field effects have made similar specifications. In addition, the well documented behavioral effects of low-strength fields, including the geomagnetic, are impossible to explain on such a generalized effect. I believe that the bulk of observations reported indicate an interaction between the applied magnetic field and some active functional property of the CNS that is both acutely sensitive to such a modality and associated with the overall functional–organizational pattern of the CNS.

There are certain aspects of the DC potentials of nerve tissue that indicate their possible role as the target mechanism. The DC or steady-state potentials display analog-type variations with certain basic stimuli and also are related in possibly a causal fashion to the efficiency of the action-potential system.[26] It would seem tenable to propose that they serve as a primitive data-transmitting and control system which regulates the ability of the CNS to process data via the more sophisticated action-potential system.[27] It is interesting that Von Neuman discussed the need for an analog-type of data system, additional to the action-potential system, on a cybernetic basis some time ago.[28] Representatives of all animal phyla possessing even a rudimentary CNS have been found to have evidences for a DC system, in each case displaying a field pattern expressing the overall anatomical arrangements of the CNS itself.[29] Certain evidences have been obtained in our laboratory indicating that this DC system is based upon some solid-state, possibly semiconduction, property of the tissue organization generating and transmitting the steady-state potentials.[30–32] From a theoretical point of view, the existence of standing potentials in a conducting network implies a current flow sufficient to maintain the potential. If such current flow is semiconducting in nature, the interaction between the charge carriers and an applied magnetic field, the Hall effect, would be many orders of magnitude greater in this case than in the case of such interaction between similar magnetic field and similar current values in a metallic conductor with an even greater difference over an ionic conduction system of the same current value.[33] Thus, if our thesis that the DC-field system is basically semiconducting is correct, then we have a system exerting some regulatory effect upon the overall functioning of the CNS that is at the same time acutely sensitive to applied magnetic fields. Some evidence has been acquired for the existence of the postulated interaction with a vectorial relationship between the applied field and the neuraxis.[34] In addition, observations in our laboratory of frequency modulation of the cerebral DC potentials during changes in the state of consciousness served to indicate the appropriate frequency range for Friedman's experiments.[20] In our experience, the DC systems of the lower phyla appeared to play a larger role in CNS functioning and to be more acutely sensitive to external fields. Thus, the observations of Brown on the variations in the biocyclic activity of planarians, *etc.* produced by extremely low-strength fields are possibly explainable.

While the foregoing is proposed primarily as a working hypothesis, it seems to lend itself well to explaining the majority of the reported phenomena. In addition, it provides a testable hypothesis subject to experimental verification. Provided exposures to magnetic fields are proven to be without the production of pathological lesions, the hypothesis leads one to some conclusions of therapeutic interest such as the induction of sleep or anesthetic states by properly applied and modulated magnetic fields, and provides us with another means of exploring the role played by the DC potentials in integrated neural functioning.

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