SOME EFFECTS OF ELECTROSTATIC FIELDS

ON BRAIN ACTIVITY IN RATS

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This study concerned the effects of short-term exposures to continuous (10 kv/meter) and pulsed 20 volts at 640 cps/100 msecs) electrostatic fields on the EEG recorded from external electrodes and hypothalamic activity recorded from implanted electrodes in rats. Each experiment lasted at least 90 minutes. The total energies of the waveforms recorded were integrated and printed out for plotting and analysis. Besides the brain activity, the ECG, respiration, and temperature of the animals were also monitored before, during, and after exposure to the electrostatic fields. No significant changes in the latter parameters were noted, however, distinct changes in both the EEG and in hypothalamic activity were observed. Every animal exhibited a distinct and sustained increase in the EEG immediately upon exposure to continuous fields of 10 kv/m. After cessation of the field, activity returned to control levels. On the other hand, a sustained decrease in hypothalamic
activity was noted in those animals exposed to 10 kv/m. Exposure to a pulsed electrostatic field brought about a slight but significant increase in the EEG activity. The same pulsed field brought about a more pronounced and sustained increase in the hypothalamic activity. In both instances the activity returned to control levels upon cessation of the field. The data clearly indicate that animals are "aware" of changes in their external electrical fields and the findings point out the need for further research into the effects of electrical fields on biological processes.
SOME EFFECTS OF ELECTROSTATIC FIELDS
ON BRAIN ACTIVITY IN RATS

THESIS

Presented to the Graduate Council of the
North Texas State University in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Harry B. McCain, B.S.
Denton, Texas
December, 1971
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INTRODUCTION

It is well known that in nature a positive electric power field encircles the entire earth (Kahler, 1937). This positive field has an average field strength of a few hundred volts per meter in free spaces at sea level elevations, and is known to increase as the elevation of the earth increases, often attaining a strength of up to several thousand volts per meter (e.g. in mountain regions). It has also been observed that the field of strength of this electric field remains relatively constant during fair weather and normal atmospheric conditions, but will fluctuate as the atmospheric conditions change (Konig, 1962).

Much research has come from Europe, concerning the production and effects of artificial electric power fields on living organisms. Folix and Rabeau (1951) have claimed that a person in this partially electrically shielded environment tends to become mentally fatigued and drowsy over a period of time, and they have shown that the creation of an artificial electropower field
within such shielded environment will tend to eliminate these undesirable effects. It has thus been determined that all living matter on the earth's surface may be dependent upon and affected by the existing natural electropower field in any particular area (Dull, 1941). In particular, it has been found that airplanes, vehicles, and certain buildings simulate an almost perfect electrically shielded environment or so-called "Faraday Cage" (Missenard, 1937).

Early work on the effects of electric fields on living matter was done primarily on microorganisms and cellular phenomena. Bernstein (1910) tried to explain certain membrane phenomena by placing membranes in electrostatic fields and noting changes in permeability. Marsh (1930) was able to control rate and direction of cell growth by applying various electric fields to tissue cultures. Angerer (1937) noticed that the viscosity of Amoeba protoplasm was greatly affected by the presence of an electrostatic field. Lutkova and Loeshko (1959) produced growth increases up to 24% in tomatoes by passing a
continuous electric current of $1 \times 10^{-5}$ amps between various types of electrodes. Kotoaka, et al. (1965) found that electrostatic fields produced profound changes in the respiration of cereal seedlings. L. E. Murr (1966) did experiments investigating numerous plant species in electrostatic fields by making the soil positive with respect to the negative upper electrode. These experiments showed that plant growth could be inhibited, facilitated, or damaged as a result of varying field strengths. Murr also tried to relate this phenomenon to atmospheric conditions which might exist in the natural environment. Respiration studies by Sidaway (1966) have pointed out the biological significance of polarity reversals in the environmental electric fields. Studies by Wehner (1964) and Hamilton (1967) on bacteria showed that growth of *Escherichia coli* could be enhanced or terminated with the application of alternating positive-negative electric fields.

Studies on intact mammals have not been overly abundant in this country, and it is difficult to access recent mammalian work because of translation difficulties in the work done in Europe. Reiter (1953) tried to
determine the effect of alternating fields on the pH concentration in guinea pigs in an alternating field of 20 kilocycles at 300V/cm. He found deviations of 0.1 to 0.2 units in the pH of the tissue and concluded that electric fields might alter the hydrogen ion formation in tissues. Schua (1954) studied the effects of electric fields on nesting behavior of golden hamsters. He found that hamsters exposed to electric fields moved their nests to less "electrical" areas in their cages. Hamsters with litters quickly removed (within 36 hours) their offspring from a nest exposed to electrical fields.

Data from studies on the effects of electric fields on man are inconclusive. Schliephake (1939) reported that certain individuals remaining for a long period of time in the proximity of a radio wave emitter insufficiently screened complained of symptoms such as headache, malaise, insomnia, and depression. Schafer (1949) believed these symptoms to be the effect of a "primary electrical warming of the entire organism" which (according to him) places a stress on thermal regulation and results in the above symptoms. Sunderman (1954) studied persons exposed to an electrostatic field varying in strength and frequency.
The subject's pulse rate, blood pressure, and electro-cardiogram (ECG) were determined before, during, and after exposure. No significant changes were found to occur. Konig (1966) claimed that electromagnetic signals varying in frequency and wave pattern increased or decreased physical activity depending upon wave form and frequency. Research at Lockheed Aircraft Corporation by Dr. C. Cristofv (circa 1965) tested the hypothesis of exposing aircraft pilots to negative ion electrostatic performance. Dr. Cristofv was not able to come to any definite conclusions from his work; however, his results did hint that some effect on some of the subjects was being elicited. One investigator, Puharich (1966), reported enhancement of extra sensory perception (ESP) scores by exposing subjects to continuous fields, while on the other hand he observed an inhibition of the ESP response when exposing the subject to pulsed or alternating electric fields.

It is clear from the foregoing information that the effects of electric fields on an organism are most diverse and inconclusive. After reading the literature on this subject one might ask several questions. How important
is the external electrical field in the total environment of living things? Does the external electrical environment really affect behavior of the entire organism? (Cellular effects have been known for years). To what extent are plants and animals cognizant of altered electrical fields? If they are, where might the receptor loci be?

The specific aims of this present study were three-fold: (1) to determine if an organism, a laboratory rat, is "aware" of changes in the external electric field, by using changes in brain wave activity as the determinant, (2) to determine if there are particular electrosensitive loci in the brain, e.g., the posterior hypothalamus, a radio-sensitive area, and (3) to determine if changes in certain physiological parameters such as ECG, heart rate, respiration, and temperature occur in animals exposed to electrostatic fields.
MATERIALS AND METHODS

A total of 60 adult, male, Sprague-Sawley rats with an average weight of 190 ± 70 grams were used in this study. This number does not include those used in developing the experimental technique. In this range the brain size and weight do not vary appreciably. Rats with electrodes implanted into the posterior hypothalamus and animals with needle electrodes placed under the scalp were used to study brain wave activity (encephalogram - EEG). Other physiological parameters monitored were the ECG, respiration, and body temperature. The following apparatus was used in this study:

1. Physiograph, Desk Model Type Dmp-4A (E & M Instrument Co., Inc., Houston, Texas).
2. Field Generator, Continuous (Electrofields, Miami, Florida).
3. Field Monitor, Rotating Electrostatic Field Measuring Instrument Type FM V (Berg. Feingerätebau, Wuppertal, Germany).
4. Electrode (Electrofields, Miami, Florida).


7. Wide Range Oscillator Model 200 CD (Hewlett-Packard, Dallas, Texas).

8. Audio Amplifier, engineered by H. L. Ferguson, North Texas State University, Denton, Texas.

The experimental apparatus is diagrammed in Figure 1.

Each one of the Faraday cages, one for test animals, and one for field monitoring, had two inputs. One input was for producing continuous electrostatic fields, and one was for producing pulsed electrostatic fields. Supplying the continuous field, amounting to 10,000 V/M, was a field generator. Supplying the pulsed field was a wide-range oscillator which also served as a frequency generator (640 cps); the oscillator was connected to an audio-amplifier. This amplifier set up a second frequency, 50% on and 50% off, which "chopped" the original signal of 20 V/640 cps every 100 msec. Simultaneously electrodes
Figure 1 -- Diagram of Experimental Apparatus

- Field Monitor
- Audio-Amplifier
- Pulsed Field Generator
- Physiograph
- Digital Print-Out
- Continuous Field Generator
- Model 23 EEG Integrator
- Faraday Cage (Reference)
- Faraday Cage "Animal"
attached to the animal recorded the EEG, ECG, respiration, and temperature during each experiment. The area under the EEG tracing on the physiograph was simultaneously integrated, and the resultant curve depicted on the physiograph. Moreover, the integrated EEG was further integrated and converted into digital form by means of a Model 23 EEG Integrator used in conjunction with Digital Data Recorder (Cold Springs Instrument Corporation). Specifically, these devices integrate and convert the total area under the EEG tracing into a numbered print-out every 60 seconds throughout the experiment. This number represents the total brain activity (energies) for one minute. Every precaution was taken to insure proper grounding of the electrical systems, in order that no electrical feedback would occur in either the animal chamber (Faraday Cage) or the recording apparatus. Grounding was checked before each experiment by crossing the electrodes in the Faraday cage and slowly turning up the gain on the EEG preamp to its maximum. If no feedback was present the tracing on the EEG was noted to be a steady, straight line.
The preparation of the electrodes for implantation into the hypothalamus was carried out in the following manner. Insect pins (stainless steel, #00) were insulated with a liquid insulator (Epoxylite Corporation, El Monte, California). The electrode was dipped into the insulator and drawn out slowly against the wall of the vessel. The vessel in this instance was a capillary tube filled with insulator material. This method was found to coat the electrode evenly and to eliminate air bubble formation. The electrodes were allowed to dry overnight at room temperature and were checked the next day for uniformity of insulation and the presence of air bubbles. The diameter of the electrode at this point was about 0.4 mm. The distal end of the electrode was scraped so as to expose 0.5 mm of the tip. The entire procedure was carried out under a dissection scope. Sterilization of the electrode was accomplished by soaking it one hour in Zepharin solution diluted 750:1.

The operative procedure for implantation of the electrodes was essentially the same as that described by Miller (1961) and Agnew (1967), with one exception. Instead of two jeweler's screws being attached to the
skull, only one, containing the probe electrode, was attached in this procedure. A reference electrode prepared exactly as the others was placed approximately 15 mm anterior to the probe electrode on the midline and no deeper than the jeweler's screw and then covered with dental acrylic. This maintained the rigidity of the electrodes and acrylic cap.

Placement of the implanted electrode was accomplished by means of a Horsley-Clark stereotaxic apparatus manufactured by the Kop Instrument Company, Tejunga, California. The Stereotaxic Atlas of the Rat Brain, by Pellegrino and Cushman, was used in determining the position of the electrode. Coordinate System B was employed. In this system, which is a simple modification of the DeGroot system, the rostral-caudal zero reference point is the bregma. Using this point as reference zero, it was assumed that any variation that might occur because of brain size might be more accurately eliminated. With system B coordinates, the section posterior to the bregma is numbered with a minus sign. For those investigators who prefer to measure the depth of their placements from
the dura, rather than from the stereotaxic zero. Using this system, the coordinates would be: rostral-caudal (-1.0), i.e., 1 mm posterior to the bregma; medial-lateral, 0.6 mm from the midline; dorsal-ventral, 8.5 mm ventral from the surface of the dura. These coordinates were used to position the tip of the stainless steel electrode (Clay-Adams Company, New York) in the posterior portion of the hypothalamus. The precise location of the electrode was later confirmed at autopsy by X-ray and histological examination.

In general the experiments were divided into the following series:

1. Sham-exposed rats, surface electrodes.
2. Sham-exposed rats, implanted electrodes.
3. Rats exposed to continuous fields, surface electrodes.
4. Rats exposed to continuous fields, implanted electrodes.
5. Rats exposed to pulsed fields, surface electrodes.
6. Rats exposed to pulsed fields, implanted electrodes.

After implantation of the hypothalamic electrodes, the animal was allowed to recover one week prior to the experimentation.
On the day prior to testing the animal was taken into the room where the experiment would be carried out. This was to allow the animal to acclimate to lighting, noise, temperature, etc., and to stabilize its brain activity. Constant lighting was maintained in this room and the temperature was relatively constant, 24°C ± 3°C. Each experiment was carried out at approximately the same time of day, between 2 pm and 6 pm. Prior to the time of testing the animals were injected intraperitoneally with nembutal (33 mg/Kg of body weight). When anesthesia was complete, as indicated by absence of the eye reflex, the animal was placed in a Faraday Cage. In the series involving brain surface recordings, the electrodes were pushed under the scalp starting at the ears and going cephalad. Care was taken to prevent the electrodes from touching. If an implanted rat was to be used, small alligator clips were attached to the implanted electrode and the reference electrode.

The experiments involving continuous field effects were 96 minutes in length and were divided into a 20-minute control period, a 50-minute test period and a
20-minute recovery or post-test period. Six minutes were arbitrarily added to the beginning of the test period to allow the recording instruments to stabilize following application of the charge to the electrode. The given stabilization period (6 minutes) were obtained from a series of preliminary experiments involving (a) crossed electrodes in an empty cage, (b) implanted but dead rats, and (c) dead rats with scalp electrodes. It was found that the period of recording in stability lasted no less than two and not more than six minutes. A stabilization period was not required in those experiments involving pulsed fields. This was assumed to be due to the considerably lower electrode voltage used in the pulsed field experiments.

In each experiment 15-second recordings were displayed on the polygraph every 10 minutes. The tracing was then analyzed visually for changes in fast brain activity (10-20 µv amplitude at 6-12 cycles per second (cps) frequency) and/or slow brain activity (20-30 µv amplitude at 3-6 cps). Concurrently, one-minute print-outs of integrated brain wave energies were made during the
entire course of each experiment. Mean values were obtained from these figures and plotted.
RESULTS

The data reported here are the results from 60 experiments. This does not include the data from "aborted" experiments, e.g., when animals regained consciousness too soon, or in those implanted experiments in which it was found at autopsy that the electrodes were not in the hypothalamus.

The physiological parameters monitored during the study showed no variation within an experiment. Heart rate varied greatly from one rat to another but varied little during an experiment. What variation was present was attributed to the anesthetic wearing off through the experimental period of 90 minutes. EKG was seen not to change. No abnormalities in the T wave or PQRS complex could be detected. Respiration rate again varied from rat to rat but varied little within an experiment. Temperature was the most constant parameter between rats. The temperature ranged between 97°F and 101°F but varied only 0.2°F in any one experiment. It was concluded
that electrostatic fields in this experimental format have no measurable effect on respiration, heart rate, EKG, and body temperature.

The data in Figures 2-7 were obtained by visually determining the occurrence of fast (6-12 cps) and slow (3-6 cps) brain wave activity from ten-second samples in fifteen-second polygraphic recordings taken every ten minutes throughout each experiment. A frequency spectrum for fast and slow brain wave activity was then established and plotted. Each circle in the figures represents a mean of nine experiments. Figure 2 shows fast and slow activity in sham-exposed animals with scalp electrodes for a period of 90 minutes. Two observations of importance are in evidence in Figure 2. The first is that there was no significant change in either the fast or slow brain wave activity during the stated period. The second is that it was clear that during the experimental time period, the fast wave activity was more dominant (mean frequency: 25-40) than slow brain activity (mean frequency: 12-30).
60 A. High Frequency - Low Amplitude Waves  
(6-12 cps; 10-20 μv)

60 B. Low Frequency - High Amplitude Waves  
(3-6 cps; 20-50 μv)

Fig. 2 -- Frequency spectrum in sham-exposed rats using surface electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
Fig. 3 -- Frequency spectrum in rats exposed to continuous fields, $10^4$ V/M, using surface electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
Fig. 4 -- Frequency spectrum in rats exposed to pulsed fields, 20V at 640cps using surface electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
Fig. 5 -- Frequency spectrum in sham-exposed rats using implanted electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
Fig. 6 -- Frequency spectrum in rats exposed to continuous fields, 10^4 kV/M, using hypothalamic implanted electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
60 A. High Frequency - Low Amplitude Waves
(6-12 cps; 10-20μv)

60 B. Low Frequency - High Amplitude Waves
(3-6 cps; 20-50μv)

Fig. 7 -- Frequency spectrum in rats exposed to pulsed fields, 20V at 640cps, using hypothalamic implanted electrodes. Frequency values were determined by analyzing a 10 sec. period from a 15 sec. reading taken every 10 min. throughout the experiment. (Each circle represents a mean of nine experiments.)
Figures 3 A and B show the frequency spectrum of brain wave activity from surface electrodes in rats exposed to a continuous electric field (10,000 V/M). It is clear that there were no significant changes in slow wave activity; however, at the 40-minute segment during exposure a slight rise in fast activity occurred. The activity returned to the control values when the field was turned off. Whether or not this change was significant is not clear, due to the fact that the values were obtained visually rather than by the more accurate method of wave frequency analysis via computer. Another observation in Figure 3 was that there was a slight predominance of fast activity over slow activity as was the case in the sham-exposed group.

From Figure 4 A and B it is clear that no significant changes occurred in the brain wave activity recorded in those animals with surface electrodes and exposed to pulsed electric fields (20V at 640 cps). Again, a predominance of fast wave activity over the slow brain wave activity in the animals is indicated.

Figures 5 A and B depict frequency spectra obtained from sham-exposed rats with hypothalamus-implanted electrodes.
Two observations in this case were that (a) there were no significant changes in either the fast or slow brain wave patterns, and (b) neither activity was predominant over the other, i.e., the frequency of occurrence for both the fast and slow activity ranged between 30 and 50. When comparing the activity from animals with scalp electrodes with that of the implanted animals, the latter showed a higher fast and slow wave activity.

Figures 6 A and B also showed that no significant changes in either fast or slow brain activity occurred on animals exposed to a continuous electric field; moreover, there was no evidence of one brain wave frequency dominating another.

Finally, it is clear from Figures 7 A and B that exposing animals to a pulsed electric field had no significant effect of brain wave activity recorded from hypothalamic electrodes.

Again, one must be reminded that the data depicted in Figures 2-7 were obtained via visual analysis and not by a more accurate computerized wave frequency analysis.
A more accurate analysis of the changes in brain wave activity is depicted in Figures 8-13. In these figures are curves showing changes in total brain waveform energies in animals under the varying conditions of electrode placement and exposure to electric fields. In each of these figures a circle represents the mean value of nine experiments, taken at one-minute intervals throughout the 90-minute experiment. The values were integrated and printed out by a digital computer.

Figure 8 shows the mean brain activity in sham-exposed animals with scalp electrodes. The brain activity was found to be relatively constant throughout most of the experiment. The slight increase during the last ten minutes may be due to the animals' recovery from the anesthetic.

Figure 9 shows a distinct effect of a continuous electric field (10,000 V/M) on the total brain waveform energy taken from scalp electrodes in the animals. The effect was most striking when the field was initially applied, and again following cessation of the field. Indeed, the brain activity almost doubled upon application
Fig. 8 -- Total brain activity in sham-exposed rats using surface electrodes. (Each circle represents a mean of 9 experiments analyzed each minute for 90 minutes.)
Fig. 9 -- Total brain activity in rats exposed to continuous fields, $10^4 \text{ V/M}$, using surface electrodes. (Each circle represents a mean of nine experiments. Readings were not taken for 6 minutes following application of the field.)
Fig. 10 — Total brain activity in rats exposed to continuous fields, $10^4$ KV/M, using hypothalamic implanted electrodes. (Each circle represents a mean of nine experiments. Readings were not taken for 6 minutes following application of the field.)
Fig. 11 -- Total brain activity in sham-exposed rats using hypothalamic implanted electrodes. (Each circle represents a mean of 9 experiments analyzed each minute for 90 minutes.)
Fig. 12 -- Total brain activity in rats exposed to pulsed fields, 20V at 640cps, using surface electrodes. (Each circle represents a mean of 9 experiments. Readings were not taken for 6 minutes following application of the field.)
Fig. 13 -- Total brain activity in rats exposed to pulsed fields, 20 V.

Field on
Field off

TOTAL MEAN BRAIN ACTIVITY

TIME
of the field (for about 10 minutes). The increase was noticeably less when the field was turned off. Moreover, there was a sustained increase in the level of activity throughout the test period. The activity failed to return to pre-test levels during the post-test period.

Surprisingly, as shown in Figure 10, the level of hypothalamic activity in animals exposed to a continuous electrostatic field was depressed throughout the experiment. The degree of depression of the hypothalamic activity, however, was not as striking as that achieved in the animal from which the activity was recorded from scalp electrodes. Moreover, there appeared to occur a slight recovery or return to pre-test levels following the cessation of the field.

Figure 11 depicts the hypothalamic brain activity in sham-exposed animals. Following a decrease in activity during the initial phase of anesthesia a relatively constant level of activity was reached within 25 minutes following the anesthesia and was sustained throughout the remainder of the experiment.
The level of activity obtained from surface electrodes in animals exposed to an electrostatic field was also increased in this condition. However, as shown in Figure 13, the increase was not as great as that observed in the hypothalamic-implanted animals. Another interesting difference was noticed, i.e., "spiking, activity was observed during the exposure period, particularly at the 25-minute interval and between 35- and 40-minute periods.

Summaries of the data represented by Figures 8-13 are presented in Tables 1 and 2. The data are based on the Comparison of Sample Means: Paired Observation Test (Steele and Torrie, 1960). The numbers presented in the Activity Index Column were calculated by dividing the first minute reading of the digital recorder print-out into itself and into each subsequent reading throughout a particular experiment. Therefore, the first reading represents one total unit of activity, or 100%. Readings following the initial one would fall above or below this reading depending upon the trend set by the experimental animal's brain activity. One can see from this procedure that variability between experiments in terms of actual
TABLE I
A Summary of the Effects of Electric Fields on Rat Brain Activity, Recordings from Scalp Electrodes.

A. Continuous Fields (10,000 V/M)

<table>
<thead>
<tr>
<th>Time Period Compared</th>
<th>Mean Activity Index</th>
<th>% of Change*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control S.D.</td>
<td>Test S.D.</td>
</tr>
<tr>
<td>10-20</td>
<td>96.4±1.9</td>
<td>101.9±2.1</td>
</tr>
<tr>
<td>Field on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>95.7±2.0</td>
<td>134.2±10.7</td>
</tr>
<tr>
<td>40-50</td>
<td>103.5±2.0</td>
<td>116.1±2.4</td>
</tr>
<tr>
<td>60-70</td>
<td>109.6±1.4</td>
<td>116.6±4.4</td>
</tr>
<tr>
<td>Field off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-80</td>
<td>110.8±2.6</td>
<td>131.3±6.3</td>
</tr>
<tr>
<td></td>
<td>103.3±2.0</td>
<td>120.0±5.2</td>
</tr>
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B. Pulsed Fields (20 V at 640 cps)

<table>
<thead>
<tr>
<th>Time Period Compared</th>
<th>Mean Activity Index</th>
<th>% of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control S.D.</td>
<td>Test S.D.</td>
</tr>
<tr>
<td>10-20</td>
<td>96.4±1.9</td>
<td>98.4±6.8</td>
</tr>
<tr>
<td>Field on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>95.7±2.0</td>
<td>111.1±12.4</td>
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<td>40-50</td>
<td>103.5±2.0</td>
<td>112.1±4.1</td>
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<tr>
<td>60-70</td>
<td>109.6±1.4</td>
<td>91.1±5.8</td>
</tr>
<tr>
<td>Field off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-80</td>
<td>110.8±2.6</td>
<td>90.3±3.4</td>
</tr>
<tr>
<td></td>
<td>103.2±2.0</td>
<td>100.6±6.5</td>
</tr>
</tbody>
</table>

*Control value - Test value x 100
**Statistically significant (p 0.01)
***Statistically significant (p 0.001)
+Activity per Interval
Initial Activity
TABLE II
A Summary of the Effects of Electric Fields on Rat Brain Activity, Recordings Taken from Hypothalamic Implanted Electrodes.

A. Continuous Fields (10,000 V/M)

<table>
<thead>
<tr>
<th>Time Period Compared</th>
<th>Mean Activity Index</th>
<th>% of Change*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control S.D.</td>
<td>Test S.D.</td>
</tr>
<tr>
<td>10-20 Field on</td>
<td>100.7±2.7</td>
<td>100.0±2.4</td>
</tr>
<tr>
<td>20-30</td>
<td>110.5±2.4</td>
<td>91.1±6.4</td>
</tr>
<tr>
<td>40-50</td>
<td>114.9±3.3</td>
<td>89.7±2.4</td>
</tr>
<tr>
<td>60-70</td>
<td>116.3±1.8</td>
<td>92.0±1.6</td>
</tr>
<tr>
<td>Field off 70-80</td>
<td>116.2±1.4</td>
<td>93.4±4.4</td>
</tr>
<tr>
<td></td>
<td>111.7±2.3</td>
<td>93.2±3.4</td>
</tr>
</tbody>
</table>

B. Pulsed Fields (20 V at 640 cps)

<table>
<thead>
<tr>
<th>Time Period Compared</th>
<th>Mean Activity Index</th>
<th>% of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control S.D.</td>
<td>Test S.D.</td>
</tr>
<tr>
<td>10-20 Field on</td>
<td>100.7±2.7</td>
<td>106.9±7.0</td>
</tr>
<tr>
<td>20-30</td>
<td>110.5±2.4</td>
<td>124.1±4.1</td>
</tr>
<tr>
<td>40-50</td>
<td>114.9±3.3</td>
<td>126.4±3.1</td>
</tr>
<tr>
<td>60-70</td>
<td>116.3±1.8</td>
<td>120.4±5.8</td>
</tr>
<tr>
<td>Field off 70-80</td>
<td>116.2±1.4</td>
<td>105.0±7.3</td>
</tr>
<tr>
<td></td>
<td>111.7±2.3</td>
<td>116.5±5.4</td>
</tr>
</tbody>
</table>

*Control value - Test value \times 100
**Statistically significant (p 0.01)
***Statistically significant (p 0.001)
+Activity per Interval
Initial Activity
brain activity reading is eliminated while the trends set by these readings are amplified. This allows one to compare a certain time interval of the test period with the same time interval of the control experiments.

Table 1 contains data showing the effects of a continuous (A) and pulsed (B) fields on rat brain activity recorded from scalp electrodes. All of the changes observed, when the field was applied and when the field was turned off, were statistically significant from the changes observed in the sham-exposed animals. This included both experimental conditions, i.e., pulsed and continuous fields. The differences in effects on the EEG in the animals exposed to pulsed fields and continuous fields were striking. The latter brought about a sustained increase in activity, whereas the former produced a distinct biphasic effect—an initial increase in activity followed by a distinct decrease in activity upon cessation of the field. Of course, these differences may be due to the differences in magnitude of the fields (10,000 V/M vs 20 V at 640 cps pulsed field).
The data in Table 2 shows the effects of (A) continuous and (B) pulsed fields on hypothalamic activity. They also show statistically significant changes in relation to one another. The pulsed field produced a sustained decrease in hypothalamic activity while the continuous field brought about a slightly biphasic response, i.e., an initial increase in activity followed by a return to control levels following the cessation of the pulsed field.

Even more striking are the differences in effect of the same electric field on the activity recorded from surface electrodes as compared with the hypothalamic activity (Table 1 A and B).

Animals exposed for one hour to 10,000 V/M exhibited a significant and sustained increase in surface activity. On the other hand, a significant decrease in hypothalamic activity was observed during the same time period. Differences in the brain response of the animals to pulsed fields was not as striking as those seen with the continuous fields; however, there were differences. Animals exposed to pulsed fields showed a more distinct biphasic effect on the recordings from the brain surface than on hypothalamic activity. Moreover, the magnitude of the effects were not as apparent in those recordings from the hypothalamus.
DISCUSSION

In assessing the present study one must appreciate some of the problems that were encountered with the experiment. Alignment of the experimental apparatus so as to get accurate results was a problem throughout each experiment. Proper grounding of the apparatus was essential so as to not form ground loops and consequently develop electrical feedback that would interfere with accurate monitoring of the biological parameters. The apparatus used in this experiment was especially sensitive to jarring. The slightest touch to the power inputs to the Faraday cages was enough to completely obliterate an EEG tracing for several seconds.

Variation in the animals' physiological states made direct analysis of data, at times, difficult. Many animals recovered from the anesthesia 30 minutes into an experiment for no apparent reason causing that particular experiment to be aborted. It was learned during the study that if an animal showed an absence of
the pupil reflex ten minutes after nembutalization, that animal would probably remain anesthetized during the entire experimental period.

Proper implantation of the hypothalamic electrode was another very critical factor. Indeed, several experiments were of no value because the electrode was found, at autopsy, to be improperly positioned. Moreover, once the electrodes were properly implanted it was difficult to make good connections to those electrodes without applying pressure and thereby deflecting the electrode from the region of the hypothalamus. Good connections were achieved by applying very small alligator clips that were filed to allow maximum contact with the electrode jutting from the acrylic cap. Another difficulty lay in establishing a suitable method for creating an identifiable heat lesion in the rat brain. After this was accomplished, the histological determination of the location of the electrode tip was greatly facilitated.

Another problem, semantic as well as scientific in nature, is the fact that not all physicists are in complete agreement on the definition of the term electrostatic field (Reiter, 1953). Therefore, one can only describe
the manner in which one produces such a field and then include the type of apparatus used in measuring or monitoring that field. It was a surprise to learn that very few electric field monitors are on the market at this time.

Generally, it is difficult to compare the data presented here with those of other workers owing to (1) the nature of the problem and instrumentation, (2) the scarcity of similar work in the literature, (3) differences in the methodology used, and (4) poor translation of foreign papers.

In the experiments dealing with fast and slow activity it was not possible to show any changes which occurred when the field was turned on or off. A reason for this might be the method of EEG analysis. The method used in this study was a visual one, employing an EEG analyzer grid. With this method it would have been possible to miss a subtle change in brain wave frequency. Chizhenkova (1966) showed that differences in cortical electrical responses in different types of fields were more marked when the method of automatic analysis of EEG frequencies was used. If a Walter frequency analyzer had been available, perhaps
frequency changes would have been noted in this study. However, the occurrence of fast and slow activity when compared across experiments did show some changes. With continuous fields—surface electrodes there was an increase in both fast and slow activity. This finding agrees with those of Kornbleugh (1955), who exposed animals to varying concentrations of positive ions, and those of Lukyanova (1965), who used the Students' criterion for relative variability to show that fast activity (spindles) and slow activity increased significantly during exposure to "static magnetic" fields. On the other hand, a reduction in the hypothalamic activity was noted in this study in those animals exposed to both continuous and pulsed fields. Pulsed fields also reduced the surface activity in the animals, but not to as great an extent. The reduction in the hypothalamic activity may be explained on the basis of Muller's work (1964). He reported that a stimulation of the posterior hypothalamus attenuated amygdaloid responses. Since the continuous field was of a greater magnitude than the pulsed field, one might assume that the
increase in surface activity observed in those animals might well have depressed other deeper brain centers including the posterior hypothalamus. This type of neurological interplay (feedback) is well documented (Hansell, 1962; Brazier, 1968).

Again one must be careful in comparing the data involving such a magnitude of differences in the experimental variable used, i.e., the electric field per se (10,000 V/M) versus the pulsed field used (20V at 640 cps).

The integrated data depicting the total energy of the brain activity more clearly define the effects of electric fields on the nervous system. The increase in brain surface activity observed in both continuous and pulsed fields concurs with the findings of Livanov (1962), who used "electromagnetic fields" of varying frequencies. The major drawback in attempting to compare the data reported here with those of Livanov is due to the poor description of his methodology. The spiking observed upon cessation of the continuous fields is similar to that observed in animals exposed to ionizing radiation (Grigor'ev, 1963; Garcia et al., 1963). It appeared that the animal
"knew" when the field came on and went off, thus indicating the presence of an electrosensory system in the animal. One cannot rule out a possible indirect field effect on the animal, where sensors external to the brain "inform" the brain of changes in the external electric field, thereby altering the brain activity.

The decrease in posterior hypothalamic activity observed in those animals exposed to $10^4$ KV/M was somewhat unexpected, since it has been shown that ionizing radiation brings about increased activity in various lower brain centers, e.g., hippocampus and hypothalamus (Kimeldorf and Hunt, 1965), in addition to changes (desynchronization) in the EEG. This was not observed here. Instead, an opposite effect of the continuous field on the EEG (increased activity) and the posterior hypothalamus (decreased activity) was observed. These findings may be explained on the basis of some negative feedback mechanism previously mentioned (Sheer, 1963; Hansell, 1964; Brazier, 1968).

The results observed using pulsed fields at a relatively low energy (20V at 640 cps) were even more surprising.
In this case, only sporadic "spiking" was noted in the EEG, and a significant and sustained increase in posterior hypothalamic activity occurred. One is tempted to conjecture that there may be various levels or different loci of electro-sensitivity in the brain. In this case the posterior hypothalamus appears to be more suitable in sensing smaller changes in the external electrical environment than the brain in toto. One wonders at what frequency and voltage levels the EEG begins to sense the change in the external electric field.

The findings that continuous fields had no significant effect on such physiological parameters as heart rate, respiration, EKG, and temperature are in agreement with those of Cristof (1965), etc. The similar findings with the pulsed field were in slight discord with those of Puharich (1966), who observed rather drastic changes in humans (nausea, confusion, anxiety) exposed to pulsed fields of a higher magnitude in a Faraday cage. Based on Schau's findings with the golden hamster (nest relocation), one would think that pulsed fields were "harmful" to the animal. Sensing an abnormal and perhaps harmful change in the
external environment, the animal began to move her young and her nest into another area. One would expect a change in at least the heart rate and respiration under these circumstances. Such changes were not observed in this study. This might have been due to the lower frequency and/or voltage of pulsed fields used here, as opposed to the magnitude of pulsed fields used by Puharich and Schua.

Along the same lines is the well known "radarman syndrome" common to many workers who are near large electronic communication systems. These people complain of headache, malaise, nausea, and vertigo — all nervous in nature. Are these symptoms due to the effect of microwaves and/or pulsed electric fields being emitted from the electronic device in the Faraday cage-like rooms in which they work?

Again, one would expect during such a syndrome, changes in heart rate and respiration. The literature is relatively sparse on work reporting measurements of electric fields in radar rooms and around communications equipment.
At this point one might ask why the brain should respond at all to external electrostatic fields. Lund, in his book, *Bioelectric Fields and Growth* (1947), presents a provocative piece of work which might answer this question. Lund maintained that each cell, each organism, has an electrochemical system, an intra- and extracellular electric polarity. Moreover, he states that any externally applied electrostatic field either opposite in polarity or opposite in intensity may quite possibly alter the "behavior" of the cell or organism. This possible change in behavior based on permeability changes is stated by Lund:

The pattern of transfer of ionic materials is probably of the same order of complexity as the pattern of the electrical field. It is certain, however, that electrical energy is used in transporting ionic materials, and a distortion of the electric field would distort the pattern of transport of materials, possibly with observable results as for example, in a gross manner such as polarization. PP.288.

Lund has extensive data which prove the existence of his "electrochemical system." If such a system does exist, in this study an external electrical field was
applied to it and an effect was noticed.

In summary, the data presented here indicate clearly that animals are capable of sensing changes in their external electrical environment. Such findings point to the need of further experimentation on the effects of electrical fields, both continuous and pulsed, on all levels of biological activity. In western Europe, there are devices now in operation in clinics, offices, printing companies, schools, and homes that attempt to stimulate the external electrical field inside enclosures which act as Faraday cages (Bonnevie, 1960). These devices are nothing but large pole electrodes suspended from the ceiling and charged positively. The walls and floor are by their nature (connected to ground) already charged negatively; therefore, a field can be established and maintained at levels found on the outside of buildings. Some clinics claim that certain pathological states can be treated with electric fields (Wehner, 1962).

In view of the present, more scientific, findings of this study, it would appear that we in the western world might investigate further into the field of
bioelectrics. We should consider electric fields, along with pressure, temperature, humidity, etc., as an important component of man's external environment.


