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OPERANT BEHAVIOR OF RHESUS MONKEYS IN THE PRESENCE OF EXTREMELY LOW FREQUENCY-LOW INTENSITY MAGNETIC AND ELECTRIC FIELDS: EXPERIMENT 3

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The present study exposed two female rhesus monkeys to a magnetic field of 10^{-3} T alternating at 10 Hz and 60 Hz. Low intensity electric fields were simultaneously present. The fields did not influence operant response rates, reaction time, matching-to-sample or motor activity. This study, in addition to two similar studies with male animals, supports the contention that ELF electromagnetic fields of low intensity do not have effects on purposive behavior in rhesus monkeys.

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SUMMARY PAGE

THE PROBLEM

The U. S. Navy recently increased research efforts in the area of nonionizing radiation. Particular interest has been directed toward the biological effects of low intensity, extremely low frequency (ELF) electric and magnetic fields. Verification of effects purported to occur at low intensity exposure has been difficult to obtain. The present study continues a series of experiments in an attempt to validate, identify, and explain these reported effects in nonhuman primates.

FINDINGS

A magnetic field of 10^{-3} T with its associated electric field alternating at 60 Hz and 10 Hz had no discernible effect on behavioral and physiological measurements of two female rhesus monkeys. The results agree with those obtained in previous experiments on male rhesus monkeys.

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Experiments reported herein were conducted according to the principles enunciated in "Guide for Laboratory Animal Facilities and Care" prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences--National Research Council.

INTRODUCTION

Previous studies by the author attempted to discover behavioral effects induced by extremely low frequency (ELF) electromagnetic fields on nonhuman primates. Various behaviors were measured in rhesus and squirrel monkeys exposed to different frequencies and intensities of magnetic and electric fields. Reliable effects were not seen in any of these studies. Significant alterations in responding that occurred in one study (5) were not repeatable and failed to occur in other studies (4,7); significant effects that occurred in one animal were not repeatable or did not occur in another animal in the same experiment (5).

The specific behaviors observed in these studies were reaction time to an auditory stimulus, response rate on a fixed interval schedule of reinforcement, and performance on a matching-to-sample task (a measure of attention and immediate memory). In addition, a measure of general motor activity was obtained. Numerous precedents existed for making these observations. For example, a number of previous studies indicated that reaction time in man might be influenced by ELF fields. König and Ankermuller (10) and Muecher and Ungeheuer (12) reported that atmospheric electromagnetic fields had significant relationships to the reaction time of attendees at a transportation exhibition in Munich. König (9) further analyzed his data and found that 3- to 5-Hz signals were related to increased reaction time and 9-Hz signals were related to decreased reaction time. Others discovered that higher intensity (0.5 to 0.7 kV/cm) 50-Hz fields influenced operant response rates (18). Although no previous work exists that reports ELF effects on memory or attention, the matching-to-sample task seemed appropriate since such behavior is probably dependent on the hippocampal area of the brain (8) which is believed to be susceptible to ELF effects (6). Finally, many reports exist that demonstrate relationships between ELF phenomena and general motor activity in a variety of animals (1, 13, 14).

The present study utilized female rhesus monkeys and the same tasks as in the author's previous experiments (4,5) to control for possible variations due to sex differences of the animals. Because 10-Hz fields tended to have effects in the previous studies, they were also employed in the present study. In addition, 60-Hz fields were used. In this study the ambient electric fields and those produced by Helmholtz coils were measured directly. Previous investigations have, with few exceptions (2,5), failed to measure these fields and, in general, assumed that such fields were either insignificant or nonexistent.

METHOD

SUBJECTS

Two 6-year old, female rhesus monkeys (Macaca mulatta) were the subjects. These animals, 3Z5 and 4Z7, were experimentally naive. A medical examination immediately preceding the experiment found both subjects physically normal. Hematology and blood chemistry measurements included: W.B.C.; differential count - neutrophils, lymphocytes, eosinophils; R.B.C.; hematocrit; hemoglobin, urea N; glucose, protein total; transaminase - SGOT, SGPT, lactic dehydrogenase, Na, K.

APPARATUS

The apparatus was the same as reported in previous studies (4,5) and consisted of two standard operant animal boxes each surrounded by large Helmholtz coils aligned in a north-south direction. The incandescent houselights and exhaust fans associated with each box were shielded with copper screens and connected to an earth ground. Other nearby lights in the room were disconnected. Under these conditions, with the coils energized, homogeneous alternating magnetic fields of 10^{-3} T ± 6% were produced in each animal box. The alternating fields were in addition to a static geomagnetic field of approximately 0.5×10^{-4} T. The geomagnetic field was in a northerly direction inclined at an angle approximately 55° below the horizon, and was measured with a Bell 620 gaussmeter. In addition to ambient electric fields produced by 60-Hz sources (houselights, fans, and temperature recorders), an electric field was produced when the coils were energized. Electric field measurements were obtained with a probe, where the charges are induced on two halves of a sphere, developed by NAMRL Electronic services and are shown in Table I. The electric fields in Table I were measured in the center of each box with and without the 10- and 60-Hz magnetic fields. Modulation of the electric fields due to the ambient 60-Hz field varied according to axis. The Z axis was vertical, the Y axis was horizontal and the X axis was front-to-rear. The coils were perpendicular to the X axis.

Temperature (regulated by room air conditioners), humidity and barometric pressure were recorded continuously. The boxes were mounted on vibration isolators and were independent of the coils. A white masking noise of approximately 75 db was present continuously in the animal boxes.

PROCEDURE

The subjects were trained to perform three separate tasks--Fixed Interval (FI), Reaction Time (RT), and Match-to-Sample (MS)--to obtain food and water. Reinforcement for appropriate responses was an 0.86 gm Purina Monkey Chow Tablet or 2.0 ml of water. Supplemental portions of apples, oranges or bananas were given prior to each session. Except for weekend feeding during noncontinuous sessions there were no other food sources. Initially, the subjects were trained to press buttons next to the food and water apertures when the apertures were illuminated. Next, the subjects were trained on one of the specific tasks to illuminate the food and water apertures thereby making reinforcement available. Each task was taught in succession, and the subjects were trained to work all three during a training session. Training occurred in a chamber similar to the experimental boxes and took approximately three months. The animals were next placed into the experimental boxes for adaptation and additonal training. When the animals were responding well, the reinforcement schedule was altered so that 50% of the reinforcement opportunities were replaced with a 0.7-second flash of the food and water lights. These flashes were programmed to occur randomly and reduced the reinforcement by 50%. Such presentations of a reinforcement-paired light were treated as conditioned reinforcers and allowed the animals to work throughout a daily session without becoming satiated with food or water. The animals were trained at 85-90% of their free-feeding weight and gained to more than 100% as the experimental sessions progressed.

Table I

Electric Field Values in Volts/Meter as a Function of Magnetic Field Frequency

Box	Hz (B-field)	Axis	E field	± Variation* (V/m)
	off**	Z	1.20	
		Y	1.10	
		X	5.00	
1	10	Z	4.20	.60
		Y	5.50	1.20
		X	16.60	1.80
	60	Z	2.60	.80
		Y	13.92	.90
		X	29.28	2.80
	off**	Z	.65	
		Y	1.90	
		X	4.10	
2	10	Z	5.50	.65
		Y	6.00	.90
		X	10.80	1.80
	60	Z	3.00	.80
		Y	16.60	1.60
		X	25.71	2.80

*Variation because of modulation between frequency of the B-field source and ambient 60-Hz E field.
**Ambient 60-Hz E field.

FI. In the presence of a green light on the lower center of the work panel, the subjects repeatedly lifted a lever directly below the green light. A lever lift after 20 seconds had elapsed resulted in reinforcement availability or a reinforcement light flash.

RT. In the presence of a red light beneath the FI light on the work panel, the subjects lifted the same lever as in FI until a 1500-Hz tone of 85 db occurred. In the presence of the tone the subjects released the lever which resulted in tone and red light extinction and reinforcement availability or reinforcement light flash. If the lever were held up more than 1.0 second while the tone was present, the red light and tone extinguished and a 10-second interval (intertrial interval) occurred between the lever release and the next onset of the red light. The interval between reinforcement and red light presentations, the intertrial interval (ITI), was always 10 seconds. The period between lever lift during the red light and tone onset was the foreperiod, which varied randomly between 0.5 and 10 seconds. Lever releases during the foreperiod (anticipatory responses) and lever lifts in the absence of the red light (ITI responses) reset the interval before the next red light.

MS. The animals were trained to press a disc (standard) centered on the work panel when it was transilluminated with 1 of 10 different stimuli (colors and symbols, Grason-Stadler pattern No. 153). Below the top disc were two similar discs (comparison). A response on the top disc was followed by removal of its stimulus and 1.0 second later the same stimulus appeared on either the right or left comparison disc. A different stimulus was on the opposing comparison disc. When the disc with the matching stimulus was pressed, all stimuli were removed and reinforcement became available or the reinforcement light flashed. When the disc with the nonmatching stimulus was pressed, all stimuli were removed and 15 seconds later the same stimulus appeared on the top disc again. Fifteen seconds after reinforcement was obtained (ITI), another stimulus appeared on the top disc. The presentations of the stimuli on the top disc following reinforcement and light flash were random and their presentation on the right and left comparison discs was also randomly determined.

Each task was available during an individual 15-minute component each hour. Each component was followed by a 5-minute extinction period in which no tasks were available. Throughout each daily session actuation of a movable rod in the floor of the cage gave a measure of general motor activity. During the first 38 sessions an experimental session lasted 8 hours except on Friday when a 6-hour session occurred. The subjects were confined to the boxes from 0830 on one day to 0730 on the following day. Between 0730 and 0830 the subjects were weighed, the boxes cleaned, and the equipment checked. Thirty minutes after being reconfined to their experimental boxes, the animals began their daily experimental session at 0900 when the program was turned on. On Friday the subjects were moved to a holding facility for the weekend. The final 30 sessions occurred consecutively without weekend interruptions. During these continuous sessions, after behavior on all tasks was occurring at relatively stable rates, the 60-Hz fields were introduced at session 48 for eight sessions. Four sessions with the fields absent were given next and then the 10-Hz fields were presented for four sessions followed by five sessions without any fields. As seen in Table I, even with the coils off, 60-Hz electric fields of up to 5 V/m were present in addition to the geomagnetic field.

At the conclusion of the experiment the animals were removed and again given complete physical examinations including clinical laboratory hematology.

RESULTS AND DISCUSSION

No abnormalities in hematological samples or general physical condition were observed in the animals at the close of the experiment. The clinical laboratory tests revealed values within the normal range with no large or consistent deviations from pre-experiment levels.

Performance on the FI schedule did not vary in the presence of either the 60-Hz or 10-Hz fields. Figure 1 illustrates three measures of FI behavior during 30 consecutive sessions when the fields were introduced. In the upper graph the average time to obtain reinforcement when it became available is plotted. Although a gradual decrement in reinforcement time occurred as the sessions increased, the change was independent of field effects. The slight increase in 4Z7's mean reinforcement time during the 10-Hz application was not statistically significant (Mann-Whitney $\underline{U} = 7$, $p > .15$). The center graph of Figure 1 illustrates the length of time an animal paused following reinforcement. Gradual increases for both animals occurred but, again, there were no changes related to the fields. Lever response rate is seen in the lower graph. The rates of 3Z5 gradually decreased while those of 4Z7 were relatively stable; however, no response rate differences were related to the presence of the fields.

Performance measures on the reaction time task are shown in Figure 2. The animals differed on the various indices, particularly in median reaction time. 3Z5 responded almost as fast as the average human while 4Z7 was more typical of an unrestrained rhesus in its reaction time, as seen in the lower portion of Figure 2. Both anticipatory responses and intertrial interval responses were very low, generally below 5% of the total reaction time responses. The intertrial interval responses of 4Z7 were initially quite variable but gradually decreased in number and variability as the experiment progressed. No clear differences resulted from the presence of the fields on any reaction time measures. A session-by-session analysis of the distributions of reaction times revealed that both animals reduced their reaction time during the first session in the presence of the 10-Hz fields. However, this reduction did not appear in the following sessions nor were these reaction times faster than those that occurred in earlier control sessions.

Figure 3 demonstrates that no definite differences in match-to-sample behavior were related to the fields. Both animals performed at approximately 90% accuracy on this task and had day-to-day variations greater than any control-experimental variations.

Body weight gradually increased during the continuous confinement of 30 days, and both animals gained considerably prior to the termination of the experiment. There was no obvious influence of the fields on body weight.

General motor activity remained level for 4Z7 and gradually decreased for 3Z5. Again, there was no obvious influence of the fields.

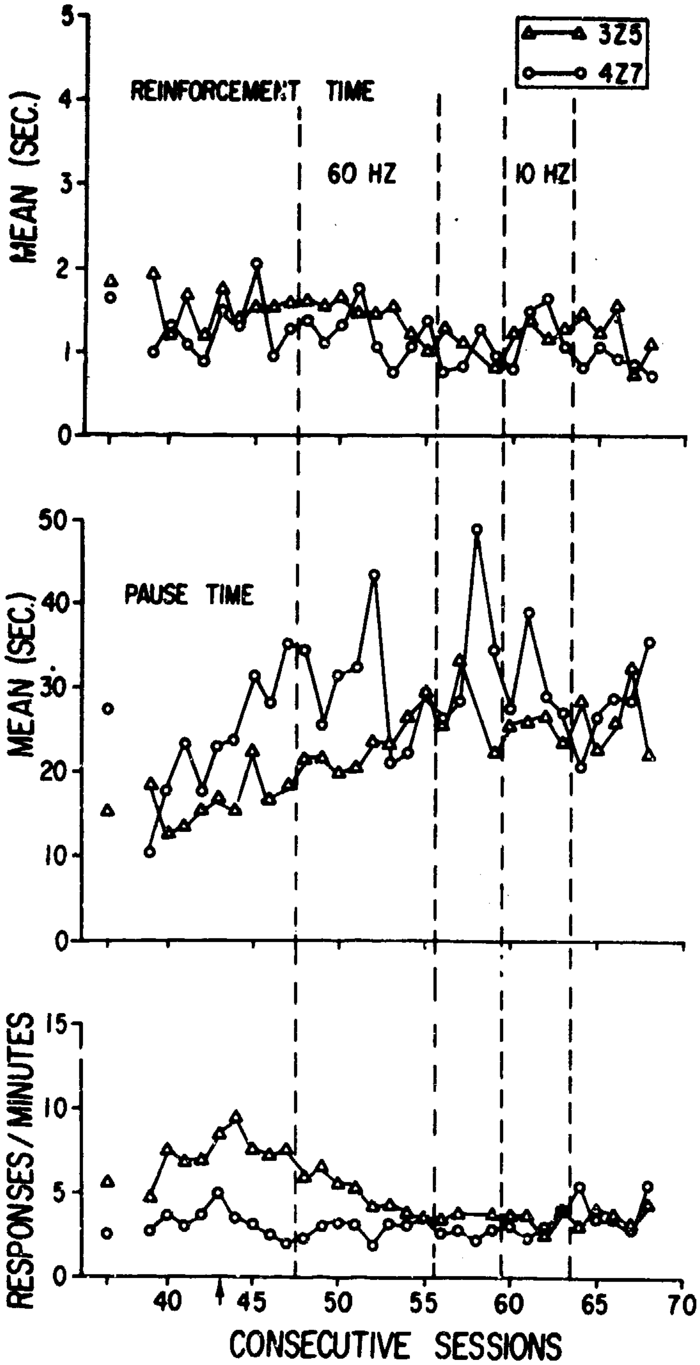

Figure 1

Fixed interval data of 3Z5 (triangles) and 4Z7 (circles). The single data points on the left of each chart designate means of the respective measures obtained during the 10 days immediately prior to the start of continuous daily sessions. The arrow on the abscissa denotes session 43 when the schedule was changed to FI 20-sec. The broken lines enclose sessions when the 60-Hz field was present (first pair of broken lines) and when the 10-Hz field was present (second pair of broken lines).

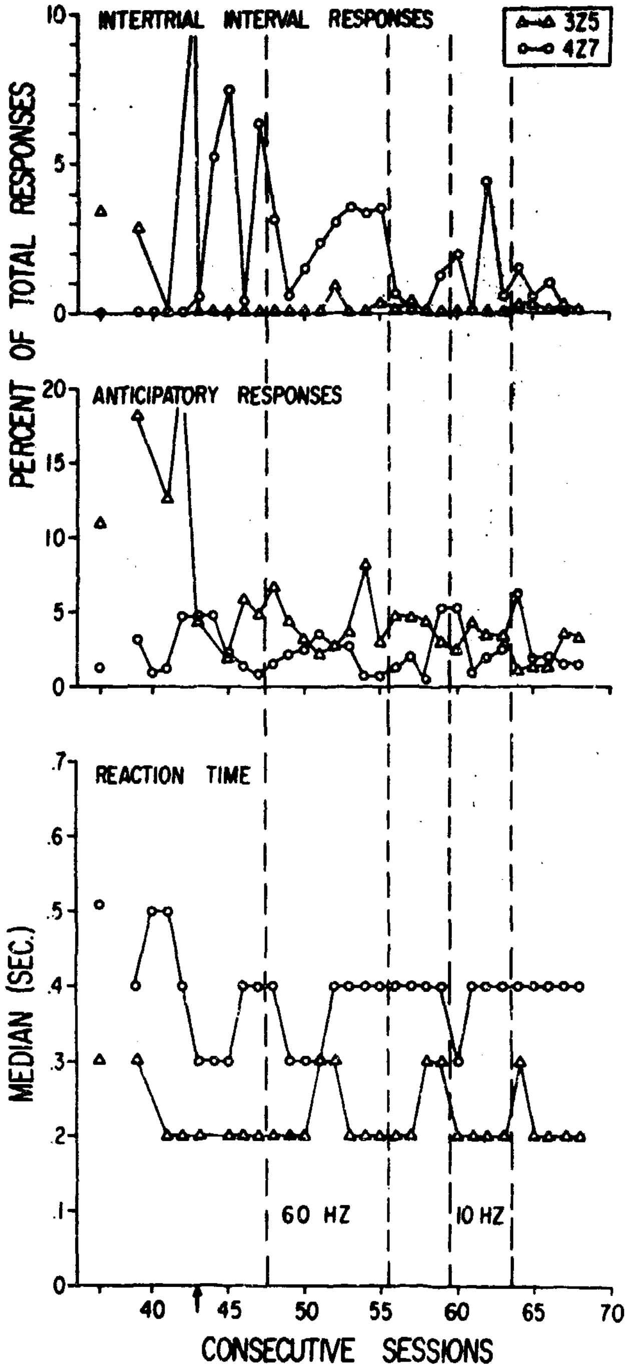

Figure 2

Reaction time data. Intertrial interval responses were lever lifts before the reaction time light, and anticipatory responses were lever releases in the presence of the light but prior to the tone's presence.

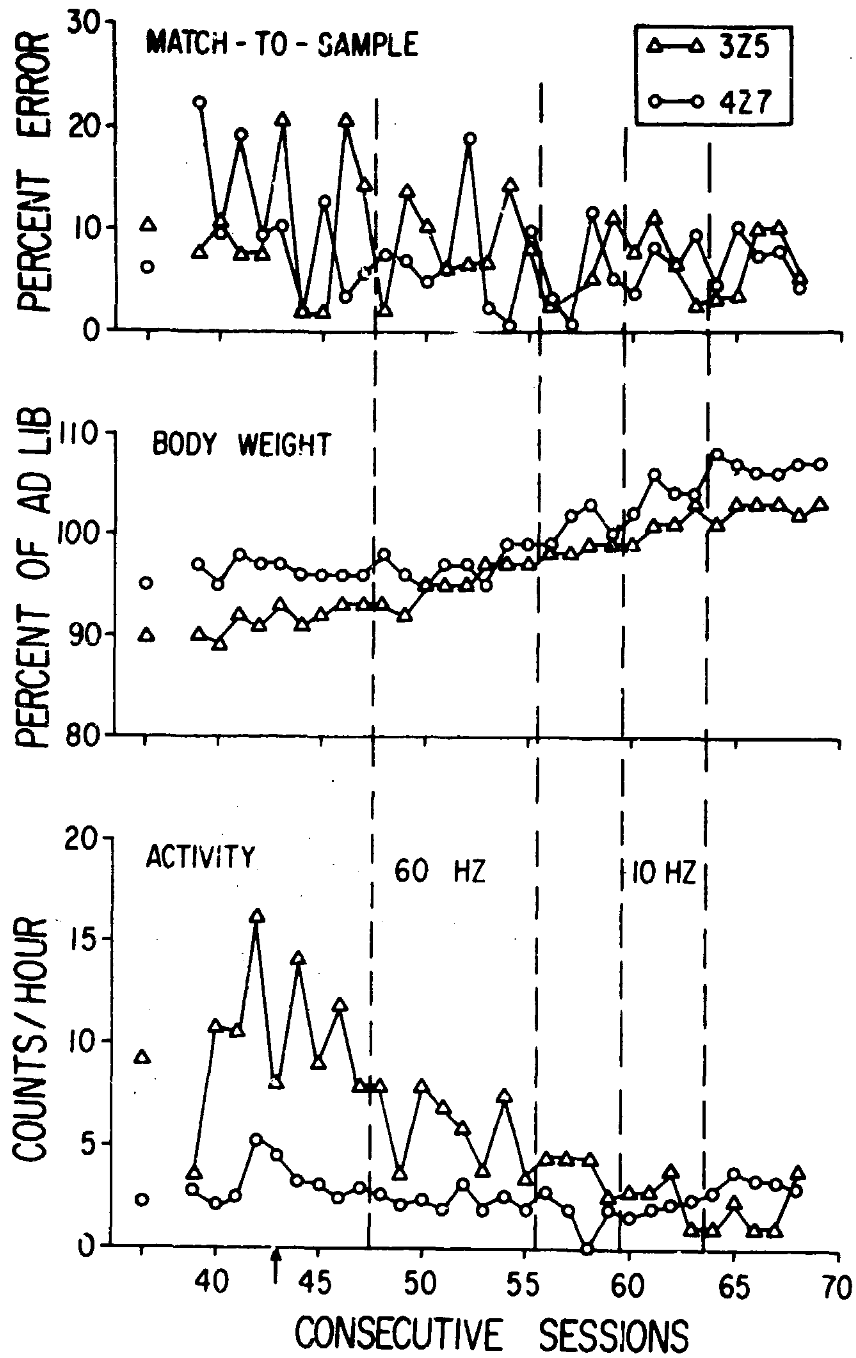

Figure 3

Match-to-sample, body weight and activity measures. Match-to-sample errors were calculated as the proportion of errors to the total responses.

CONCLUSIONS

The results of the present experiment parallel those of two similar studies with male rhesus monkeys (4,5) in which no consistent effects of various ELF fields were obtained. The failure to obtain effects similar to those reported by others is somewhat perplexing since Persinger, Ludwig, and Ossenkopp (15, p. 1152), after a thorough review, consider the main ELF effects to be "...disturbances in reaction time in primates, ambulatory behavior in rats, circadian variations and time perception of human beings, along with electrical changes in the parts of the brain involved with these changes...." Yet, in another recent review, Reiter (16) considers the evidence for ELF effects to be relatively unconfirmed or contradictory.

It is possible that one of many variables influenced results of previous experiments that concerned ELF effects. For example, barometric pressure changes have been found to influence activity levels of mice (19). Barometric pressure changes also occurred with the electromagnetic atmospheric changes purportedly affecting reaction time at the transportation fair in Munich (12). In the present study a positive but nonsignificant correlation existed between the reaction time of subject 4Z7 and the barometric pressure ($r = .25$). Weather influences on general monkey behavior have been reported by others (3), and definite relationships between barometric pressure and acute myocardial infarction in humans have been established in some hospitals (20). In essence, perhaps it is not ELF electromagnetic radiation that induces biological effects but a correlated variable such as barometric pressure.

The present series of studies finds some support in extensive experiments by colleagues in our laboratory and elsewhere. Beischer, Grissett, and Mitchell (2) failed to find any reaction time changes in humans exposed to 45-Hz, 10^{-4} T fields. Marr, Rivers, and Burns (11) also did not establish any behavioral effects of ELF fields on pigeons and rats. Purposive behavior such as reaction time performance and performance on operant schedules of reinforcement may be insensitive to nonionizing radiation at low intensities. In other words, the behavior is so strongly controlled by other variables that low intensity ELF fields cannot override the control. Behavior that is less well determined, such as ambulatory activity, might be more susceptible. But again, such behavior is also susceptible to other variables and it may be extraneous variables (unmeasured and uncontrolled) that determine the behavior when animals are exposed to ELF fields. Schmitt and Tucker (17), for example, claim their studies reveal that, as better and better controls are imposed, the evidence for magnetic field perception decreases to the questionable level.

Some of the ambiguities in the literature may well be resolved with better measurement of the independent variables involved. With few exceptions (2) previous experiments have not measured the electric fields, either ambient or those produced by Helmholtz coils and other devices. In the present study it was seen that electric fields were present during control periods (in the absence of the 10- and 60-Hz magnetic fields) and that a static magnetic field was always present. Nevertheless, the additional electric and magnetic fields produced by energizing the coils failed to produce observable changes in the animals.

In summary, the present study, in addition to previous work, provides cumulative evidence that ELF nonionizing radiation as produced in our laboratory does not influence animal behavior in either a beneficial or detrimental manner.

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