THE DETECTION OF LOW-ENERGY, EXTREMELY LOW-FREQUENCY (ELF) ELECTROMAGNETIC RADIATION BY THE PIGEON AND BY THE RAT

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THE DETECTION OF LOW-ENERGY, EXTREMELY LOW-FREQUENCY (ELF) ELECTROMAGNETIC RADIATION BY THE PIGEON AND BY THE RAT

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SUMMARY

This study investigated the possibility of the detection of low-energy, extremely low-frequency (ELF) electromagnetic radiation by the pigeon and by the rat, through selected measurement of operant behavior. With the rat, a conditioned suppression procedure was used in which the signal to be detected was superimposed on a stable baseline of responding, a variable interval schedule, and terminated with a brief electric shock. Provided a stimulus was discriminable, a few pairings with shock resulted in the suppression of responding in its presence. A suppression ratio was computed by dividing the rate of responding in a 1-min interval prior to the onset of the signal into the response rate during the 1-min presentation of the signal. Detection of the ELF signal was operationally defined by a mean suppression ratio which fell outside the 99% confidence interval around the mean suppression ratio of a control condition in which a pre-shock signal was absent. For the pigeon, a conditioned acceleration procedure was used which could engender increases in the rate of responding in the presence of a detected stimulus followed by time-out from reinforcement period. An acceleration ratio was computed in the same manner as the suppression ratio. Detection of an ELF signal was operationally defined by a mean acceleration ratio falling outside the 99% confidence

interval around the mean acceleration ratio of a control condition in which a pre-time-out signal was absent.

No reliable evidence of detection of ELF electromagnetic fields at 45, 60, 75 Hz, 0.13-2.0 G, and 0 to 100 V/m was found.

CHAPTER I

BACKGROUND

Introduction

A broad region of the electromagnetic spectrum long thought to have little influence on living systems under natural conditions has been critically re-examined over the past decade. This spectral region extends from the microwave frequencies, through the radiowave frequencies, to and including essentially static-electric and magnetic fields. This renewed interest has stemmed from an increasing knowledge regarding the basic electromagnetic nature of many meteorological and geomagnetic phenomena, as well as from the increased use in modern society of external sources of electromagnetic radiation (EMR) such as radar, television and radio broadcasting, communications, power systems, and electrical appliances. This study has investigated the possibility that animal behavior might be affected by electric and magnetic fields of low intensity alternating at extremely low frequencies (ELF).

Electromagnetic Radiation

Since electromagnetic radiation phenomena are not widely understood, it will be helpful to describe the electromagnetic environment of concern prior to describing the effect of that environment on an organism. This section describes the basic nature of the energy and compares the energy with other, more familiar types. Although the information provided can be found in most any physics textbook, as well as in many literature reviews on the effects of EMR, this reviewer has relied heavily on Winch (1955), White (1959), and Presman (1970) to provide the reader with the necessary introduction to electromagnetism.

Electromagnetic fields alter the properties of space in their vicinity in a manner similar to that of a gravitational field. In the presence of a mass, the properties of space in its vicinity can be considered to be so altered that another mass brought into this region will experience a gravitational force. Comparable interactions occur between electric charges and magnetized particles in an electromagnetic field.

The nature of electromagnetic energy is reflected by its two components, the electric field and the magnetic field. An electric charge produces an electric field around it that interacts with any other charges present. The electric field created in the vicinity of an electrically charged body is a vector quantity. The magnitude of the force, acting on a unit charge situated at a particular point in space, is called the electric field strength and is measured in volts per meter (V/m). The direction of the vector is the direction in which a positive charge moves in this field. The trajectories of the motion of this charge, placed at one point or another in the field, are called the electric lines of force.

A magnetic field is formed around a conductor carrying a current or exists in the vicinity of a permanent magnet, and is also a vector quantity. The magnetic field strength is the magnitude of the force with which the field acts on an element of current situated at a particular point, and is measured in Gauss (G). The trajectories of the motion of an element of current, or the orientations of an elementary magnet in a magnetic field, are called the magnetic lines of force.

A flow of electric charge from one place to another is called an electric current. An electromagnetic wave may be thought of being made of moving fields of electric and magnetic force. Electric currents generate electromagnetic radiation. The lines of force in the electric field and magnetic fields are at right angles and mutually perpendicular to the direction of travel.

Many electrical household appliances generate electric and magnetic fields. Some of these and their respective field intensities, as measured in V/m for the electric fields and G for the magnetic fields, are listed in Tables 1 and 2.

Figure 1 shows the electromagnetic-frequency spectrum and some corresponding sources of radiation at various levels. Notice from the illustration that the ELF region, that is of experimental concern in this research, is the same region of the spectrum occupied by fields produced by commercial power systems. Power lines are not functional radiators, but they do radiate some electromagnetic energy.

Table 1

Electrical Fields Measured near Electrical Appliances in a Private Dwelling (Sanguine, 1972)

Appliance	Electric Field* (volts/meter)
Electric Blanket	250
Broiler	130
Phonograph	90
Refrigerator	60
Iron	60
Food Mixer	50
Toaster	40
Hairdryer	40
Vaporizer	40
Color Television Set	30
Coffee Percolator	30
Vacuum Cleaner	16
Clock Radio	15
Electric Range	4
Incandescent Light Bulb	2

*Measured 30 centimeters from device

Table 2

Localized 60-Hz Magnetic Flux Densities
Produced by Some Electrical Appliances
(Sanguine, 1972)

<u>10-25 Gauss</u>	<u>0.1-1.0 Gauss</u>
325-Watt Soldering Gun	Toy Auto Transformer
Magnetic Stirrer	Garbage Disposal
Power Feeder Cable	Clothes Dryer
Hair Dryer	Black/White Television Set
	Vacuum Cleaner
<u>5-10 Gauss</u>	Heating Pad
	Electric Toaster
Can Opener	Bell Transformer
140-Watt Soldering Gun	
Fluorescent Desk Lamp	<u>0.01-0.1 Gauss</u>
Kitchen Range	
Electric Shaver	Home Electric Service Unit
	Kitchen Fluorescent Lamp
<u>1-5 Gauss</u>	Dishwasher
	Laundry Washer
Bench Grinder	Phonograph
Arc Welder	Calculator
Food Mixer	Electric Iron
Power Transformer	
Induction Motor	<u>0.001-0.01 Gauss</u>
Color Television Set	
Food Blender	Refrigerator
Electric Drill	
Portable Heater	

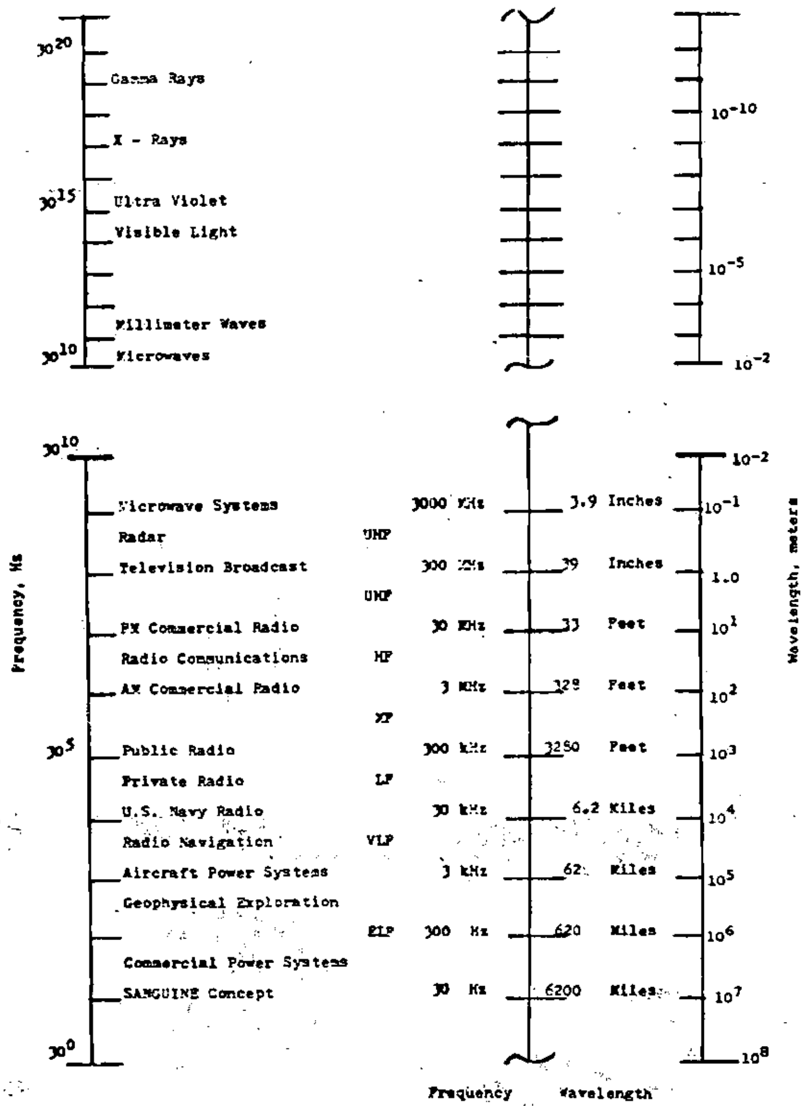

Figure 1. The Electromagnetic Wave Spectrum and Some of Its Uses.

The wavelength of the radiation of concern to this research, 10^6 to 10^7m, is much longer than radiation generated by commercial broadcast systems or radar stations.

Finally, the distinction between ionizing and non-ionizing radiation is useful when examining the potential effects of ELF fields on behavior. Although there is no fundamental difference in the radiation from various parts of the electromagnetic spectrum, the various radiations affect living organisms differently. The ability to produce ionization is related directly to the energy levels of the radiation. Ionizing radiation requires energy of the order of several electron volts in order for it to exert sufficient electromagnetic force to alter the outer electrons of the atoms they pass. The energy associated with electromagnetic radiation is proportional to frequency, and its value is sufficiently high to produce ionization at the frequency of x-rays and in the ultraviolet and visible portion of the spectrum. At the much lower microwave and radio frequencies, the energy levels are many times lower than the ionizing potential, i.e., they are non-ionizing radiation. At these positions on the spectrum, the principal effect is one of heating due to the resistance which matter presents to the passage of the electromagnetic wave.

Historical Background

Recently Becker (1963) and Kholodov (1967) have reviewed the early investigations of the effects of EMR on living systems. The following historical section summarizes their findings.

Distinguishing iron-attracting magnets from other minerals, physicians quickly ascribed healing properties to the mysterious rocks. Each doctor used them in his own manner. Galen used a magnet as a purgative. Avicenna treated diseases of the liver with a magnet. Paracelsus used a magnet to treat hernias, dropsy, jaundice, and other diseases. Mesmer treated nervous disorders with magnets. Finally, the French Academy of Sciences stated in a written report that the healing effect of a magnet is caused by the direct effect of a magnetic force on the nerves. In so doing, this commission gave its official approval of the use of magnets for medicinal purposes.

In 1879, Shiff repeated Charcot's experiments on the restoration of skin sensitivity in hysterical females by placing their hands in the field of a solenoid. In 1891, the biological effect of high-frequency fields on an entire organism was independently observed for the first time. Placing his subjects inside a solenoid that had a high-frequency current flowing in its windings, D'Arsonval observed increases in respiration and perspiration and decreases in weight and blood pressure in hamsters and mice.

One year later, Peterson and Kelly reported an extensive series of experiments using the very large electromagnets available to them in the Edison Laboratory. In one of the experiments, a dog was placed in a non-uniform field of 4,000 G to 14,000 G for five hours with no obvious discomfort. The investigators reported no subjective sensations in five human subjects who had placed their heads within a 20,000 G field, whether the field was on continuously or repeatedly turned off and on. In 1896, however, D'Arsonval reported that the application of changing fields to the human head produced a subjective sensation of light. This finding has since been referred to as "magnetic phosphene" and has been studied at length.

The problem of the biological effect of EMR was first extensively formulated in 1900. In a two-volume monograph, J. V. Danilewsky reported the effects of different frequencies of "electricity at a distance" on a frog. The original purpose of these experiments was to observe the electric-field stimulation of the frog motor nerve by means of open and closed secondary magnetic circuits. From this simple problem, however, Danilewsky went on to study such problems as the electrical properties of the motor nerve and the effects of EMR on excitability of sensory nerves and nerve centers. He also investigated the physiological effect of "electrical beams," magnetic flux, and combinations of various electrical effects. In general, the experimenter found that EMR stimulation did not differ from contact stimulation in that they both, for example, would cause muscle contraction in a frog. Stimulating human sensory nerves with EMR, Danilewsky recorded diverse sensations--labored breathing, warmth, tingling, pain. Sometimes, when the head was placed in the field, light flashes were sensed. When the entire subject was placed in the field, nervousness often resulted.

After the work of Danilewsky, it would seem that interest in the problem of the effect of EMR on an organism would have developed rapidly. Research declined, however, until the development of extensive vacuum tube circuitry made it possible to produce powerful EMR fields. Since then, there have been dozens of monographs and thousands of articles devoted to the effects of EMR published during this period (Kholodov, 1967).

Although the second World War abruptly cut off the development of this interest, the atomic explosions over Hiroshima and Nagasaki gave preeminence to the problem of the biological effect of ionizing radiation.

The post-war appearance of radar stations, the proliferation of electrical appliances, and the conquest of outer space have reintroduced the problem of the effects of EMR with renewed interest. For example, the earth's magnetic field varies in time and place from about 0.3 G to 0.6 G at ground level (Becker, 1963). Magnetic fields of many other planets are much less intense than the earth's. The question has arisen among space researchers of whether or not the human body, during its evolution, has become dependent on the presence of the earth's magnetic field for the maintenance of its normal functional integrity. Accordingly, it has become very important to determine whether a low-intensity magnetic-field exposure could possibly lead to an impairment of health or performance of an individual. Similarly, radiation effects from electrical appliances and power systems have aroused the public's concern.

Literature Review

Introduction

In examining specific environmental effects on behavior, it has been useful to think of behavior as segmented into units called responses and to think of the environment as segmented into units called stimuli. The responses composing behavior have been further divided into two classes. One class has been called operant, or instrumental, responses; the other has been called respondent, or reflexive responses.

Respondents show relatively simple relationships with changes in the environment. Reflexive behavior is considered as innate, inherited responses to certain environmental events, for example, pupillary constriction to a light in the eye or salivation to food in the mouth. Such behaviors are said to be elicited by the stimulus, that is, they follow the presentations of specific classes of stimuli. In addition, the magnitude and latency of a respondent is dependent on the magnitude, duration, and frequency of the preceding stimulus. When a stimulus elicits a response because of the inherited structure of the organism, and not because the organism has any specific previous experience with the stimulus, the response is called unconditioned, and the associated eliciting event, the unconditioned stimulus.

Although each respondent has an associated class of unconditioned stimuli, a new stimulus, previously ineffective, may acquire eliciting properties. After so doing, the stimulus is called a conditioned stimulus, and the response it elicits becomes the conditioned response. The process whereby new stimuli gain the power to elicit respondents is called respondent, classical, or Pavlovian conditioning and requires that the new stimulus be temporally paired with an unconditioned stimulus.

Despite the fact that respondents can come under the control of new stimuli through conditioning, elicited respondents represent only a small proportion of the behavior of the higher organisms. A more prominent class is designated as operant. Whereas the frequency of respondent behavior is determined mainly by the frequency of its eliciting stimulus (the environmental event that precedes it), the frequency of operant behavior is primarily determined by its effect (the environmental event that follows it). Because no specific stimuli can be identified that elicits operants, these behaviors are said to be emitted.

Manipulation and control of operant behavior by the use of reinforcing stimuli is referred to as operant conditioning. If the appearance of a stimulus as a consequence of a response results in an increased probability that the response will reoccur in the future, the stimulus is called a positive reinforcing stimulus, or positive reinforcer. If the offset of a stimulus, as a consequence of a response, results in an increased probability that the response will reoccur in the future, the stimulus is called a negative reinforcer. After the response has been reinforced in the presence of a particular stimulus a number of times, that stimulus may come to control the occurrence of the behavior, i.e., the rate and pattern of responding becomes a function of the stimulus value. Such a stimulus is called a discriminative stimulus. It is said to set the occasion on which the response has previously been reinforced.

The behavioral Anlage out of which specific operants are shaped is termed free operant behavior. The stimuli which generate this behavior are not specifiable. General motor activity is an example. Although the level of activity may be substantial enough to measure, the stimuli that control the activity are likely to be too complex to identify.

A detection experiment is one in which the presence or absence of some aspect of stimulation is indicated by the subject (Gibson, 1969). The stimulus to be detected might be a tone, a light, a pressure on the skin, or a more vague form of stimulation such as a pulse of electromagnetic radiation. The indicator response of a subject in a detection experiment may be verbal, such as a "yes" or "no," or it could be nonverbal, such as a change in the rate of keypecking or lever pressing.

The interpretation of nonverbal data has been considered a formidable obstacle to infrahuman psychophysics and believed insurmountable by early experimenters. In 1865, in his _Introduction to Experimental Medicine_, Claude Bernard wrote, "Experimental study of sense organs must be made on man because animals can not directly account to us for the sensations which they experience" (1949, p. 125). The attitude of many present-day animal psychophysicists, however, has been that the problem has become one of developing procedures to provide the necessary substitute for verbal instructions, and thus overcoming the "language barrier" between subject and experimenter. In _Animal Psychophysics: The Design and Conduct of Sensory Experiments_, William Stebbins explains that "procedures must insure that the animal can learn to attend to the relevant stimulus dimension and report on very small changes in the stimuli along this dimension" (1970, p. 8).

The behavioral demonstration of detection is dependent upon how detection is operationally defined. An operational definition must clearly specify the relationship between the dependent and the independent variable. For example, an operational definition of detection of a stimulus might be the occurrence of a reliable behavioral change in the presence of the stimulus. Depending on the procedure used, however, the behavioral change to be observed may be directly linked or indirectly linked to the stimulus to be detected.

In the direct procedure the response is explicitly controlled or elicited by the stimulus; the stimulus to be detected is utilized as an unconditioned stimulus, conditioned stimulus, or discriminative stimulus. The strength of the behavior tends to vary as a function of the intensity of the stimulus, particularly near threshold. If an EMR signal can be demonstrated as an unconditioned, conditioned, or discriminative stimulus for a response, its detection by the organism may be said to be directly demonstrated.

Indirect procedures study the effect of the imposition of a specific environmental condition on established behavior. In these procedures, the control imposed by the stimulus on the behavior examined is not as explicit as in direct procedures. The most that can be concluded is that a reliable change in behavior has occurred that accompanied the presentation of the stimulus; i.e., the detection of an EMR signal may be indirectly demonstrated if the presence of that field reliably affects the development or maintenance of respondent or operant behavior.

Figure 2 provides a further example which explicates this distinction among operational definitions. The diagrams depict two possible relationships between an ELF signal and a reaction time performance demonstrated via a keypress response. In order to demonstrate ELF detection with the direct procedure, reaction time might be measured to the presentation of an ELF signal. In this case, the latency of the keypress response is controlled by the onset of the ELF signal. However, detection might be operationally demonstrated with an indirect procedure by comparing reaction time to another stimulus, such

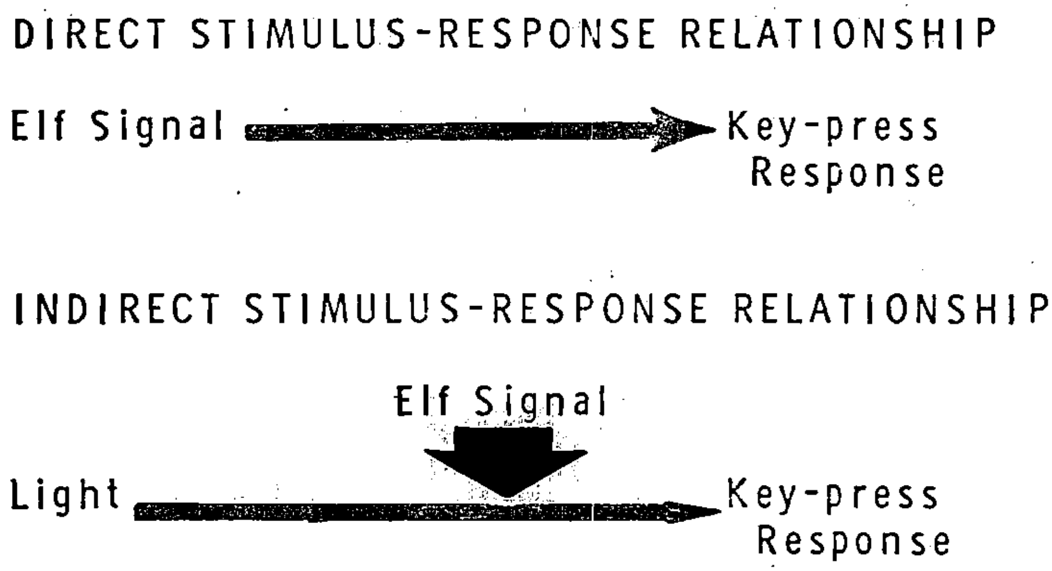

Figure 2. Two Procedures for Demonstrating the Detection of ELF Signals.

as a light, in the presence and absence of the ELF signal. If the subject's response time to the light would reliably change during ELF exposure periods, this procedure might be said to indirectly demonstrate detection. In this case, the effect of the ELF signal may be described as an ambient effect on the keypress response controlled by the light. The most that can be concluded from this procedure is that the change in reaction time can be associated with the presentation of the ELF signal. Other demonstrations of detection of ELF signals through indirect procedures might show the effect of ELF fields on the level of general motor activity, or on the pattern of responding under various schedules of reinforcement, or on such tasks as matching-to-sample.

The following section reviews the effects of EMR on behavior. The author agrees with appraisals of the literature by past reviewers, in that his summational beliefs have been reflected in their conclusions. The following reaction by Becker (1963, p. 293) clearly reflects that of the present author:

> To review the literature pertinent to possible biological effects of magnetic fields is a frustrating task. Many reports in the scientific literature are based upon insufficient data and experimentation of the crudest nature. Frequently, diametrically opposite results are reported under what appear to be identical conditions. In order to reach even tentative conclusions, some type of critical, organized review is necessary.

Papers reviewed have been limited to those published or presented within the last 20 years. Those studies based upon grossly inadequate techniques, and those which fail to specify in sufficient detail the techniques utilized, have been omitted. An outline of the material that follows is presented in Table 3.

Even though much information is available concerning the effects of electromagnetic fields, most studies have dealt with frequencies far different from ELF. The microwave region (1000 MHz and higher) has received the most attention (Thompson and Bourgeois, 1971). Much direct evidence that microwaves can be detected has been published in the Soviet literature (Presman, 1970).

Although different from microwaves, signals in the radio frequency region have often been considered with them in the more general reviews (Barnothy, 1964, 1969; Frey, 1965; Presman, 1970). This region extends from about 14 kHz to about 1000 MHz, where the microwave region begins.

Considerable research has also been performed using steady or alternating magnetic or electric fields (Becker, 1963, 1969; Busby, 1968; Aceto, Cornelius and Silver, 1970; Conley, 1969, 1970; Reiter, 1972). Steady magnetic fields may be generated by direct current sources or natural magnets.

As shown in the outline in Figure 3, Section 1 reviews the behavioral effects of non-ELF electromagnetic radiation, i.e., EMR at frequencies different from ELF. Only those studies which examine microwave, radio frequency, and static or alternating magnetic or electric fields are reported, since the physical characteristic of sig-

Table 3

Organization of Material in Literature Review Section

SECTION 1. BEHAVIORAL EFFECTS OF NON-ELF ELECTROMAGNETIC RADIATION

Indirect Procedure Results

Part a. Effects on free-operant behavior.

Part b. Effects on conditioned behavior.

Direct Procedure Results

Part c. Non-ELF radiation as unconditioned stimuli.

Part d. Non-ELF radiation as conditioned stimuli.

SECTION 2. BEHAVIORAL EFFECTS OF ELF ELECTROMAGNETIC RADIATION

Indirect Procedure Results

Part a. Effects on free-operant behavior.

Part b. Effects on conditioned behavior.

Direct Procedure Results

Part c. ELF radiation as unconditioned stimuli.

Part d. ELF radiation as conditioned stimuli.

nals from these regions most clearly resemble ELF signals. Section 2 considers those behavioral effects directly attributable to ELF field stimuli.

Before examining these studies, it is imperative to distinguish between high-frequency EMR physical reactions and low-frequency EMR physical reactions. According to Thompson and Bourgeois any object located in a non-ionizing radiation field absorbs power, and this power is dissipated in the form of heat. They explain that the amount of power absorbed is a function of the power density of the field, the physical size of the objects as related to the wavelength of the radiation and the radiation-absorption characteristics of the objects. The authors conclude that, generally speaking, living organisms are of such physical size that at frequencies below about 20 MHz, they constitute only a fraction of a wavelength thus absorbing relatively little power from the field unless power densities are inordinately high. It should be noted that in fields above 20 MHz and at above moderate intensities, behavioral effects are most likely due to heating of the organism (thermal effects). On the other hand, the source of effects associated with fields below this established criterion is yet to be conclusively determined. The possibility remains that these effects are due to some other intrinsic stimulation of the neural structures by the radiant energy itself (athermal effects).

No clear biological effects, like visibility, are apparent in the presence of low-frequency EMR. Because of this, it is beneficial to examine the effects of the surrounding frequencies, non-ELF, as well as the effects of the frequency range of primary concern, ELF. The value of this information lies in the identification of potential methodology by which ELF signals may be examined. In addition, since designations such as ELF, VLF, HF, VHF, UHF, MICROWAVE, etc., are arbitrary in respect to biological effects, the demonstration of behavioral effects of non-ELF fields would tend to strengthen the possibility of ELF effects.

A variety of behavioral approaches have been used for studying the detection of EMR in animals. Four categories of behavioral effects are reviewed in both the non-ELF section and the ELF section that follows.

Part a considers the effects of EMR on free operant behavior. The behavior elaborated in this part of the literature review refers to behavior that has been elicited or initially controlled by stimuli that remain unidentified. Studies are reviewed in which experimenters have used indirect procedures to demonstrate detection of EMR by associating reliable changes in behavior with exposure to EMR.

Various measurements of motor activity constitute a large portion of these behavioral changes. These include revolution of an activity wheel, transversals of squares in an open field situation, crossing from one cage compartment or section to another, jumping from perch to perch, or cage tilting.

Part b reviews the behavioral effects on conditioned behavior. Also focusing on results from indirect procedures, this analysis comprises EMR effects on Pavlovian or operant-conditioned behavior, such as the latency of a conditioned response, or scheduled behavior, such as the rate of responding under a schedule of food reinforcement. Stimulus-controlled behavior, such as reaction time in a simple one-choice task, is also reviewed.

If alterations in either free operant or conditioned behavior can be reliably demonstrated during or after exposure to EMR fields, the studies reviewed in Parts a and b will have demonstrated detection of EMR through indirect procedures.

Parts c and d review results from studies which used direct procedures to demonstrate detection of EMR. Part c focuses on studies which have used EMR radiation as unconditioned stimuli, and Part d considers studies which have used EMR radiation as conditioned stimuli. The unconditioned behavior elaborated in Part c refers to a larger variety of behaviors that evidence has indicated may be elicited by EMR signals, e.g., navigation and orientation responses, escape and avoidance responses, and visual and auditory sensations. Although the unconditioned responses may not be explicit, the role of the EMR as an eliciting stimulus is clear in all of the studies reviewed.

Patterns of keypecking, rate of lever pressing, directions of maze turning, etc., have been attempted to be brought under the control of EMR stimuli in studies reviewed in Part d. Stimulus control techniques of these studies provide examples of direct procedures for demonstrating detection. The following literature review considers each of the four behavioral approaches to demonstrating the detection of first, non-ELF signals, and second, ELF signals.

Section 1. Behavioral Effects of Non-ELF Radiation

Part a. Effects on free operant behavior. One of the most popular approaches utilized to study animal behavior in the presence of nonionizing radiation has involved the measurement of general motor activity. Considerable effort has been devoted to the idea that electromagnetic fields may interfere with the control exerted by naturally occuring, environmental events on behavior in various animals.

Ultra-high frequency radio fields seem to affect activity in an inconsistent manner. Eakin and Thompson (1965) observed the effect on general activity level in rats exposed for 42 days to microwave radiation, 0.02 mV/cm^2, swept from 450 MHz to 950 MHz in 2-min cycles. Recording the number of squares crossed in an open field during 1-hr post-exposure session, the experimenters found that activity was significantly greater for the experimental subjects than for unexposed control subjects during the early portion of the experiment. The level of activity of the experimental group, however, approached that of the control group as the experiment continued and the total exposure time increased. By the 13th day of exposure the number of squares traversed by the experimental group was significantly less than those crossed by the control group. Thus there seemed to be a reversal of effects as the total exposure time increased.

Results from static field studies appear equally inconclusive. Barnothy (1960) measured the number of times a mouse would cross from one compartment of this cage to the other. He concluded that for 40 female subjects during their first 70 days of life, the average activity rate was 100 to 300 traversals per day. Ten mice designated as the experimental group were exposed to a steady magnetic field of 4200 G for 4 weeks by placing their cages in front of a 300-lb magnet. Beginning on the 223rd day after the subjects were removed from the field, activity measures were recorded for a period of 185 days. The activity of the magnetically treated animals was on the average of 50% higher than that of the 30 non-exposed control subjects.

Other studies have reported no behavioral effects due to exposure to magnetic fields. Jennings and Ratner (1963) found no significant differences in revolutions per day between mice in an activity wheel exposed to a steady magnetic field and mice in an unexposed apparatus. The magnetic field parameters varied from 200 G to 3500 G over the experimental condition but remained constant at one setting during each 24-hr exposure period.

Investigators also have examined the drinking and eating habits of mice during exposure to a steady magnetic field. Russell and Hedrick (1969) prepared a T-maze in which both ends provided food and water, but one end was constantly exposed to a high, steady magnetic field of 1100 G. In this study activity was expressed as the total number of trips each animal made to either location and the total amount of time spent there. The 11 mice were not deprived when observed. The total time spent in the unexposed end (2103.8 min) was greater than in the exposed end (1839.5 min), but the animals made more trips to the exposed end (2,240 trips vs. 17,044 trips).

Although the authors state that the animals showed a preference toward increased activity in the high magnetic field environment, the basis for their conclusion can be questioned since the two activity measures were in conflict.

Kholodov (1967) observed the effects of steady magnetic fields on the activity of fish and birds. The experimenter placed sticklebacks in a tank around which a solenoid was wound; this solenoid, connected to direct current, created a 50-G to 150-G steady magnetic field. Dorsal-fin motion as recorded on a kymograph indicated that motor activity of the fish during 1-hr exposure periods to magnetic fields was greater than before or after each exposure. In the absence of quantitative data, the author summarized the test results by showing how frequently the effect was observed. In 64% of the cases (54 test exposures), a magnetic field increased the motor activity where decrements were observed in 15% of the cases. Procedural irregularities again have marred the conclusions. The number of test exposures run for each subject varied greatly. Out of 11 subjects, 8 were tested less than 6 times each, and 3 were tested more than 16 times each.

El'darov and Kholodov (1967) observed the effects of low-intensity, static-magnetic fields on the motor activity of 10 birds from the sparrow family. Some of the home cages were exposed to a steady 0.7-G to 1.7-G magnetic field for 2-hr or 9-hr duration, and other cages were unexposed. The frequency of perch-to-perch movement was measured. Out of 28, 2-hr test exposures on 5 subjects with the number of exposures per subject varying from 1 to 12, increases were observed in perch-jumping behavior in 90% of the cases. Of the remaining 10% of the cases, either no effect or a decrease in activity was recorded. In the 9-hr exposure condition, a total of 20 exposures were given to 5 birds, where the number of exposures per subject varied from 1 to 7 exposures per bird. The results of this condition were similar to those of the 2-hr exposure condition. Increases in activity were noted in 85% of the exposures, and decreases in the remaining 15%. As in the Kholodov experiment reported earlier, the number of field exposures per subject varied enough to introduce the possibility that the observed results might be due to uncontrolled subject effects.

Some studies have demonstrated increments in animal activity during exposure to constant electric fields. Altman observed that tiltcage activity of white mice and zebra finches was clearly increased in a constant electric field of 1000 V/m.

The foregoing studies have indicated few reliable effects of EMR on the activity of higher organisms. The discussed motor reactions such as square crossing, perch jumping, wheel turning, etc., may be attributed to a number of variables. Because of this complexity, the use of general motor activity as a measure of the effects of EMR has provided little understanding, since the variables controlling these behaviors are little understood. More specific evidence of the action of EMR has been provided by studies of conditioned behavior.

Part b. Effects on conditioned behavior. Suppression of conditioned responding after exposure to a moderately high-power density microwave field has been reported by Tallarico and Ketchum (1959). Rats were conditioned to barpress for food under a schedule of continuous reinforcement (food was available after every barpress response). Then the experimenters restrained their subjects in a prone position and exposed the rats to 1.25-cm microwaves at 109 mV/cm^2 for 15-30 min. The subjects were exposed once a day for 3 days and placed in the Skinner box after each treatment. They showed an increase in response latency (interresponse time) and a decrease in the frequency of barpresses. This effect appeared reversible because after 1 month of no exposure, the subjects' responding returned to the original baseline. Because the restraint of the subjects was confounded with exposure to the radiation, the observed effect could be due to either variable.

Significant decreases in latency of conditioned respondent behaviors during exposure to low-power density microwave fields have been reported by at least two reviewers (Presman, 1970; Thompson et al., 1971). Both have described a series of experiments by Lobanova and Lobanova and Tolgskaya in which rats were subjected to pulsed microwave fields of low (athermal) intensity (10 mW/cm^2) in three frequency ranges--millimeter, centimeter (10 cm), and decimeter.

After the establishment of a conditioned response and a discrimination response, the specific nature of which was not described, the animals were irradiated daily for 45 days with the number of exposures per day per subject varying each day. The subject's behavior was assessed from the length of the latent period, the interval between the signal (a light or a tone) and the initiation of the motor reaction, and from the percentage of failures of discrimination.

According to Presman the irradiation with millimeter waves had a relatively weak effect. There was a slight reduction in the latent period and failures of discrimination in 62% of the total number of cases, but these effects did not occur until after 48-52 exposures. Irradiation with centimeter waves (36 exposures in all) had a greater effect. The first few exposures led to failures of the conditioned response, and by the end of the treatment the latent period had increased from 2 to 7 sec. Discrimination, however, was unaffected. After 50-52 exposures to decimeter waves, there was a slight reduction in the latent period, and discrimination was upset in 50% of the cases. After the next 54 exposures, opposite changes occurred. Presman concluded that in all of the described experiments, there was an increase in sensitivity and a weakening of discrimination in the first period of irradiation and a reduction of sensitivity and the development of discrimination in the second period. Presman, however, has provided the reader with too little specific information to accept his account without question.

Subbota (1958) also has reported the deterioration of conditioned responses after exposure to microwave fields. He exposed dogs for 1 to 2 hours a day at a power density of 5mW/cm^2. After irradiation, the dogs were allowed to walk about for 10-15 min and were then placed in the conditioning apparatus. A classical conditioning procedure that utilized the salivation response was used. As in many Soviet experiments, after preliminary conditioning trials the experimenter divided his subjects into two groups, those who were excitable and those who were not. In the excitable dogs the saliva response was decreased in quantity and the latency shortened after exposure to microwave radiation. In the other group, the response to the treatment was the opposite.

Electric field studies with rats and monkeys have demonstrated little effects on conditioned responding. Hirsch and Bruner (1972) examined the effects of high-intensity electric fields on rat maze-running behavior. After the animals had learned to run a maze without making any errors, they were subjected to three pulses of 600 kV/m. The observed startle responses at the instant of pulsing were probably associated with the uncontrolled, loud cracking noise of the discharge and most likely accounted for the immediate cessation of the maze running that followed. The effect was temporary, however, as the pre-exposure performance levels quickly recovered.

In another experiment reported by Hirsch et al. (1972), a rhesus monkey was trained on a shock avoidance task whereby a pressing response was required on one of four plastic keys whenever illuminated or on a fifth key when a 200-Hz to 20,000-Hz tone was presented. Failure to respond within 5 sec resulted in a brief, neck-collar shock of 10 mA. After the animal responded immediately with virtually no errors or emissions, it received ten successive electric field pulses spaced approximately at 10-min intervals. The first five pulses were about 300 kV/m; the next three were 450 kV/m; and the last two were 600 kV/m. Following the electric field exposure, the subjects continued to perform rapidly without error on the avoidance-discrimination task. The startle response was present again.

Beischer, Knepton and Kembro (1962) observed that rhesus monkeys stopped lever pressing for food upon exposure to a 60,000-G static magnetic field. Similar results have been observed in studies using rotating magnetic fields utilizing conditioning procedures based on aversive as well as appetitive motivation.

To summarize, non-ELF EMR has demonstrated some effects on conditioned behavior at high-frequency and intensity levels. Although the behaviors examined were better differentiated than general motor activity and the variables controlling these behaviors were more apparent, the effects do not appear especially reliable. More specific evidence of the detection of EMR has been provided by the studies that utilized non-ELF radiation as unconditioned or conditioned stimuli.

Part c. Non-ELF radiation as unconditioned stimuli. Many changes in sensory function and perceptual organization under the effect of non-ELF fields have been reported in the literature. Auditory, visual, and tactual sensations have been reported by subjects exposed to microwave, radio-frequency, or static magnetic or electric fields. Such responses imply that EMR signals may serve as unconditioned stimuli.

Frey (1963) observed that the human auditory system can respond to electromagnetic energy in the UHF portion of the spectrum. He reported that this effect occurred instantaneously and at moderate power densities (100 mW/cm^2). Frey established the following features: (1) People exposed to a pulse-modulated EMR hear various sounds depending on the modulation. The nature of the perceived sound was described as being a buzzing, ticking, hissing, or knocking. (2) Surrounding noise of up to 90 db does not dispel the "radiosound" or the sensitivity to it. (3) The use of earplugs enhances the radiosound effect. (4) There are certain threshold intensities below which there is no effect, and the greatest sensitivity was to the frequency range from 300 to 1200 MHz.

Frey's work with radiosound has clearly demonstrated a sensory effect. It has presented, however, rather formidable problems in the analysis of the nature of the effect. Although experimental data have not been complete enough for clear differentiation, Frey's explanation is that this phenomenon may be the result of direct-cortical or nerve-fiber stimulation (1965). Other evidence points toward the fact that in many of these cases electromechanical excitation of tissue may set up vibrations which would be carried by bone conduction to the inner ear stimulating the cochlea in the normal manner (Sommer et al., 1964).

A study by Jones (cited by King, Justesen, and Clark, 1971) yielded negative results. According to the reviewers, Jones reported that none of 20 college students examined could discriminate between the presence or absence of 30- or 60-cm microwaves. King et al. note, however, that since unmodulated energy was used in Jones' study, its negative findings agree with Frey's belief that modulation is necessary for the detection of microwaves.

Wieske (1963) has reported auditory effects due to the action of alternating electric fields from 60 Hz to 15 kHz (with maximum sensitivity at 3 kHz) and also in response to the application and removal of an electrostatic field. This report was more of a chronicle of the author's encounter with two women who appeared to be sensitive to the signals as opposed to an experimental investigation, and its data should be considered in this light. The subjects discussed had reported considerable discomfort in their homes due to noise which was systematically eliminated by the author through grounding and shielding procedures.

Thompson et al. (1971) has reported the results of an unpublished doctoral dissertation by Bourgeois that investigated the effects of exposure to UHF radiation on the auditory threshold of human subjects. Subjects were exposed to low-intensity (0.5, 1.0, and 1.5 mW/cm^2) radiation at 1 GHz for 2 min previous to and during the presentation of an auditory stimulus. Auditory stimuli were pure tones of 500, 2000, and 5000 Hz presented through headphones. Radiation modulation parameters included continuous wave (no modulation), 400- and 1000-Hz sine-wave amplitude modulation. The reviewer reported that exposure to UHF radiation resulted in a significant decrease in auditory threshold and that this decrease was directly proportional to the magnitude of the average power density to which the subjects were exposed. According to Thompson et al. thresholds were also found to be a function of the type of modulation used, since the auditory thresholds were significantly lower upon exposure to the 1000-Hz modulated radiation than upon exposure to 400-Hz modulated radiation.

Experiments with microwave radiation have also reported orienting or attentional responses in higher animals, implying that these subjects were aware of the radiation. Michaelson, Thomson and Howland (1958), in the course of studying temperature and blood changes, incidentally observed avoidance and orientation reactions in dogs. Moderately high-power densities, i.e., 45, 100, and 165 mW/cm^2, at 2800 MHz durations of 60, 90, and 120 min, respectively, were used. Michaelson notes that although dogs were sometimes quite agitated, they continued to face the source of the radiation. These responses have also been interpreted as thermal effects (McAfee, 1961, 1962) and auditory effects (Frey, 1965).

Data from studies investigating the potential of an electric field to serve as an unconditioned stimulus for an escape reaction have remained inconclusive. Schua (1953) and Zahner (1964) performed the same experiment and observed different results. Schua exposed two groups of golden hamsters to a constant field of 9 V/cm and observed no effect. However, upon exposure to a 9-V/cm electric field alternating at 10 kWz, the animals would move their nests to an unexposed area of their cage. After the first 24 hr, 40% of the animals had reacted; after 72 hr almost 100% of the nests had been changed.

Zahner replicated Schua's experiments using a 10 kHz, 6- to 7-V/m, electric field and found no effects.

Humans appear extremely tolerant to high-intensity constant magnetic fields. In his search for data on human exposures to magnetic fields, Beischer (1962) asked a number of nuclear physics laboratories to comment on the experiences of their personnel who enter high-intensity fields in their work. From the results of his survey, Beischer concluded that exposure of part- or total-body to magnetic fields up to 20,000 G for short periods of time can be tolerated by man without sensation. Also, there seems to be no effect of cumulative exposure to fields of 5,000 G, for a total of 3 days per year per man.

Studies investigating the phenomenon called magnetic phosphenes have been reviewed by Aceto et al. (1970) and Frey (1965). The magnetic phosphenes have been uniformly described as colorless or occasionally light-blue tinted, shimmering luminosities appearing in the borders of the visual fields. Most reviewers have noted that the intensity as well as the character of the sensation is strongly frequency dependent. Phosphenes are produced by the application of 10- to 100-Hz alternating magnetic fields with intensities as low as 200-1000 G. The intensity of the phosphene is greatest at about 20 Hz, and at such low frequency it appears to be synchronized with the magnetic field. Above 90 Hz the effect becomes less pronounced. Finally, the patterns of magnetic phosphenes appear to be identical to those produced by electrical stimulation of the visual cortex.

Studies reported by Jaski (1960) have indicated that people exposed to radio frequencies were subject to visual hallucinations. According to Jaski in 1935 an Italian university professor, Cazzamalli, placed human subjects in a shielded room and exposed them to high-frequency radio waves which ranged up to 300 MHz. The experimenter found that some of his subjects would hallucinate under the influence of the waves. Unfortunately, the details of his experiments have not been published.

Beischer has apparently carried out the only human experiments to date in which the effects of extremely low-intensity magnetic fields (below 1.0 G) were observed. Preliminary experiments indicated that the absence of the earth's magnetic field (0.3-0.6 G) caused a decrease in the scotopic critical flicker-fusion frequency (1963). During the post-exposure control period in which the subjects lived outside the field, frequency values returned toward pre-exposure levels over a period of several days. In a follow-up study, four subjects were exposed to magnetic fields of less than 1.0 G (50 gammas) in intensity for 10 days, with reference behavior in the earth's magnetic field established by a 5-day control period living in the same chamber before and after exposure (Beischer, 1966). As in the preliminary study, the scotopic critical flicker-fusion frequency again showed a tendency, in 3 of the 4 subjects studied, to diminish gradually during the exposure period and then recover rapidly to baseline levels in the post-exposure period.

Orientation reactions to magnetic fields have been frequently reported in lower organisms such as planarians and snails (Brown, 1962) and insects (Jaski, 1960; Lindauer and Martin, 1972). In addition, theorists have explained the navigation of birds by the Coriolis force for the measurement of latitude and by variations of the earth's magnetic field for longitude (Yeagley, 1947; Keeton, 1972). Much of the supporting evidence for such hypotheses have been from studies in which magnets mounted on birds have disoriented their homing behavior (Keeton, 1972).

Numerous variables, however, have consistently appeared uncontrolled in these field studies. Many subjects are not recovered. Others return missing their magnets, misplaced somewhere along the way. Considering such conditions, one is not surprised when neither Yeagley (1951) nor other investigators (Gordon, 1952; Van Riper and Kalmbach, 1972), attempting to repeat his experiment, ever obtain the same results again. Furthermore, well-controlled laboratory studies have often provided contradicting evidence (Orgel and Smith, 1954; Meyer and Lambe, 1966).

The studies reported above have demonstrated that electromagnetic radiation at frequencies lower than visible light and thermal radiation can serve as unconditioned stimuli. In this respect these stimuli may be called detectable, inasmuch as a reliable change in behavior has been associated with their presence or absence. In addition, physical characteristics of the signals such as frequency, intensity, and modulation have affected their detectability. Such revelations suggest that sensation, possibly similar to magnetic phosphenes or radio-sounds, may be associated with ELF electromagnetic fields as well. Before one pursues this question, however, it would be advantageous to investigate the possibility that EMR signals could serve as conditioned stimuli. Conditioning of behavior to EMR stimuli would establish their detection in that organism.

Part d. Non-ELF radiation as conditioned stimuli. Numerous Russian experimenters have used EMR signals as conditioned stimuli for the elaboration of Pavlovian conditioned responses (Presman, 1970; Barnothy, 1964, 1969). An extensive series of studies on a wide variety of animals have been reported by Kholodov (1967). His studies investigating effects on activity were reviewed earlier. The following studies represent the experimenter's attempts to condition a variety of respondents to constant magnetic fields. A head-shaking response in rabbits, originally paired with shock to the ears, was later conditioned to a tone. The response conditioned in birds and fish was a "food-getting" motion in the presence of a conditioned (discriminative) stimulus which was either a light or a tone. Since these "food-getting" motions were required to occur in the presence of the stimulus and were rewarded with food directly after their occurrence, the conditioning paradigm appeared to be more related to one of operant conditioning than one of Pavlovian conditioning. An "electrodefensive" reflex in fish was established by pairing dorsal-fin movement to an unconditioned shock stimulus and then pairing a light or sound stimulus with the shock.

Using electromagnets, Kholodov generated constant magnetic fields 100 G to 300 G. After a behavior had been conditioned, the experimenter introduced the field signal as the conditioned stimulus instead of the light or tone. It was found that "food-seeking" and "electrodefensive" conditioned reflexes can be produced in fish by static magnetic fields of 100-G to 200-G strength. Food-seeking responses (5 fish) occurred on the average after 5 trials; they were established (to a criterion of 5 successive times) after 23 trials and reached 60% stability. Electrodefensive conditioned reflexes (14 fish) occurred after 11 trials on the average. They proved established after 64 trials and reached 39% stability. According to the author's conclusions, it was easier to produce food-seeking conditioned reflexes in fish to a magnetic field than electrodefensive reflexes; however, the production of both by a magnetic field was more difficult than by light or sound stimuli. Attempts to condition rabbits and pigeons to magnetic fields of 200 G were unsuccessful.

Procedural irregularities, many of which were referred to earlier, again do not support the author's conclusions. Foremost among these are the complete neglect of stimulus control conditions. The experimenter simply conditioned behavior to light and sound stimuli and compared the S-R interval (the interval between the presentation of the stimulus and the experimenter's observation of the response as timed with a hand-held stopwatch) with that of behavior conditioned to magnetic field stimuli. After considering the author's previously reported finding of increases in activity during field exposures, the lack of pseudoconditioning controls in the present experiment can be questioned. Until a condition is examined in which conditioning can be observed separately from activity effects, one cannot conclude from the above data that magnetic fields can be weak conditioned stimuli.

Classical conditioning procedures have been employed by other investigators in well-controlled experiments. Orgel and Smith (1954) gave two female homing pigeons preliminary training on buzz-shock sequences until both animals were conditioned to walk, or run, at the presentation of the buzzer and before the onset of shock, in 19 out of 20 trials (95%). After 820 trials the animals were conditioned in the same manner to a light stimulus also to a criterion of 95%. After approximately 200 trials per bird, a constant magnetic field of 5 G was substituted for the buzzer and light used previously. After approximately 1000 trials per bird, no apparent learning had occurred during the magnetic field-shock sequence, despite the fact that training was continued for a longer period than in the other two sequences. The results gain added significance from the fact that previous buzzer and light-shock sequences might be expected to facilitate the learning of a later field shock; that is, positive transfer of training should occur.

Recently many experimenters have recognized the advantages that operant-conditioning methodology provide for determining whether or not EMR can serve as a conditioned stimulus. Standard animal psychophysical procedures incorporate control conditions too often absent in previous experiments.

A series of experiments by Justesen and King (1970) first reported that rats could not discriminate microwave stimuli. In these studies the experimenters intermittently presented 12.25-cm microwave energy to each of six rats as a cue for obtaining sugar water, but none of the rats discriminated the cue. The investigators believed that because this test of detection was based upon appetitive rather than aversive motivation, it may have lacked sensitivity. Recent experiments utilized a conditioned suppression paradigm and demonstrated that irradiation by microwaves (12.25 cm) could function as a conditioned stimulus for rats (King et al., 1971). Reinforcement of the tongue-lick response was presented at variable intervals averaging 2 min (VI 2-min) using discrete volumes of sugar water. The presentation of an unavoidable electric shock at the termination of randomly superimposed periods of irradiation produced a decrease in rate of licking for intensities above a specific value, thereby designated as a threshold. Although lacking the saliency of an auditory stimulus, irradiation by microwaves was observed to function as a reliable cue.

In another well-controlled study, the pigeon's ability to discriminate changes in magnitudes of constant magnetic fields from the earth's normal field was investigated (Meyer and Lambe, 1966). Four pigeons maintained at 80% food deprivation were trained to keypeck for access to grain for an interval of 4 sec. After steady responding was established on a schedule of reinforcement that required variable intervals averaging 1-min to elapse before a response was reinforced (VI 1-min), the birds were presented with either the experimental condition or one of the control conditions.

During the experimental condition, the subjects were presented a magnetic field as the discriminative stimulus (S^D) along with a VI 1-min reinforcement schedule. On the other hand, no reinforcement occurred (S^Δ) during periods when the earth's normal mean magnetic field for that area (0.582 G) prevailed. The magnetic fields presented as S^D were 0.560 G, 0.567 G, 0.585 G, 0.588 G, 0.591 G, and 1.000 G. The length of time intervals for the S^D and S^Δ varied from 2 to 4 min. to prevent the birds from learning to respond to time. Each daily session comprised 32 trials, 18 intervals of S^D and 18 intervals of S^Δ.

Four conditions were used to control for stimulus effects. A bird was presented a green keylight as the S^D and a white keylight as the S^Δ. In the second control condition, a red key was presented as the S^D and a green key as the S^Δ. The third method, no S^D or S^Δ magnetic field was given, and the key was white. For the last method, a magnetic field below the earth's normal field of 0.582 G was presented during the S^D periods and the normal mean magnetic field of 0.582 G during the S^{Δ} periods. Except for these procedures, the methods were similar to those for the experimental procedures.

Unfortunately, the birds did not serve as their own controls, since each bird received different conditions. In no case, however, did the birds learn to discriminate the magnetic fields. In general, half of the total responses during every experimental condition were made during the S^D periods. The birds that were given the control condition in which both S^D and S^{Δ} were different keylights quickly reached the criterion of 80% or more of the total responses during the S^D periods. The subjects that were presented white keylights for both S^D and S^{Δ} did not discriminate between the periods.

The studies presented above have clearly demonstrated the inability to condition behavior to most EMR signals. Although King et al. (1971) have successfully conditioned responding to 12.25-cm microwaves, sensitive conditioning procedures were required to do so. Before conclusions can be drawn about the detectability of EMR fields, more well-controlled research utilizing sensitive psychophysical techniques is needed on a greater variety of parameters (e.g., King et al., 1971, and Meyer and Lamb, 1966).

Section 2. Behavioral Effects of ELF Electromagnetic Radiation

Extremely low-frequency (ELF) electromagnetic fields have been associated with geomagnetic disturbances, weather perturbations, electrical appliance discharges, and possible outer-space environments. Many investigators have believed that ELF electromagnetic fields may be important biological stimuli because of their penetrability and long-range of propogation (Persinger, Ludwig and Ossenkopp, 1973; Marr, Rivers and Burns, 1973). This possibility has been furthered upon recognition that ELF field frequencies and intensities are within the magnitude and range of signals generated within living organisms.

The Sanguine Environmental Compatibility Assurance Program (Sanguine) represents the research and developmental effort organized to assess the total impact of an extremely low-frequency communications system on the environment. Designed to determine whether exposure to low-level ELF electromagnetic radiation has any effect on biological/ecological systems, this program has produced most of the studies on the behavioral effects of ELF fields. Consequently, this review has drawn much from this program's published reports (Sanguine, 1972, 1973).

As in the non-ELF section, those studies that examined the effects of ELF fields on free operant and conditioned behavior are reviewed first, with those studies that utilized ELF signals as unconditioned or conditioned stimuli following.

Part a. Effects on free operant behavior. Persinger, Persinger, Ossenkopp and Glavin (1972) report that rats exposed for 21 to 30 days to a 0.5-Hz, 3- to 30-G, 10^{-5} V/m, rotating magnetic field showed significant increases in open-field, ambulatory behavior after being removed from the field. The authors note, however, that the possible role of apparatus noise was not sufficiently controlled in this experiment.

Activity measures, after exposure to electric fields, have also shown no systematic effects. Utilizing a uniquely designed activity cage, in which the movements of mice in their individual compartments could be recorded, Moos (1964) observed the effect of exposure to a 60-Hz electric field of 8 V/m to 12 V/m on the general motor activity of mice. The cages were exposed to alternating 12-hr periods of light and darkness, and activity counts were taken after every period. Field effects were observed under exposure durations of 1 day, 5 days, and 1 month, for light periods, dark periods, and light and dark (24 hr) periods combined. The recording of the activity of the same animals during periods when no electric field was applied allowed the mice to serve as their own controls.

These data indicated a preponderance of nocturnal activity when the electric field was applied when compared with the control periods. Field activity increased approximately 69% over the no-field condition. As expected, the mice--being nocturnal animals--were quite inactive during periods of illumination and exhibited even fewer movements when the electric field was connected. On the average, the daily reduction in activity for experimental condition was 36% greater than the control condition. For the light and dark periods combined, electric field exposure accompanied a 49% increase in activity over control levels.

In the same series of studies that reported increments in activity during exposure to static electric fields, Altman also observed decrements in the activity of mice during exposure to electric fields alternating at frequencies of 1.75 Hz and 5 Hz at 40 V/m. Reiter (1972) reported similar activity decrements in studies by Ludwig and Mecke in which hamsters were exposed to alternating electric fields with frequencies from 5 Hz to 300 Hz and amplitudes from 10 mV/m to 1.0 V/m.

As with the EMR activity studies, the analysis of ELF activity studies not only has demonstrated few reliable effects of ELF on behavior but has also shown activity measures too complex to be of any use to the question of detection.

Part b. Effects on conditioned behavior. Spittka, Taege, and Tembrock (1969) have demonstrated alterations in operant behavior in rats during exposure to a high-voltage electric field of 500 to 700 V/cm alternating at 50 Hz. Deprived rats lever pressed for water under a continuous schedule of reinforcement. The electric field which surrounded the chamber was switched on and off in 2-min intervals. Although the effect varied in degree across the 16 subjects, on the average, the rats showed a decreased rate of lever pressing during exposure to the field as opposed to the baseline rate. It should be noted that this effect was observed at very high intensities.

Persinger et al. (1973) report that after training rats to lever press for water reinforcement, La Forge exposed the rodents to either a constant 0.2-Hz or 2.0-Hz magnetic field of about 800 G for 45 min per day for 2 days, or to a no-field control condition. Immediately after removal from the field, rats that had been exposed to either field showed significantly fewer lever presses, especially those which had been exposed to the 0.2-Hz field. When tested 24 hr later, no significant differences were found between the number of lever presses emitted under the control or constant field conditions. Persinger et al. believed that the increased activity in the rats exposed to the magnetic fields might explain the decrement in lever presses.

Persinger and Foster (1970) demonstrated that adult male rats, which had been continuously exposed during their prenatal development to a 0.5-Hz, 3- to 30-G, rotating magnetic field, emitted a significant decrease in lever presses in a free operant avoidance situation, contrasting with rats which had been prenatally exposed to control conditions. In addition, the data show that the field-exposed rats and the control rats acquired the free operant avoidance response equally well, as reflected by the non-significant difference between average number of shocks received.

Although the area is cluttered with conflicting results, some investigators feel that there exists sufficient support for the conclusion that a primary effect of magnetic fields is to produce heightened sensitivity to novel and aversive stimuli (Persinger and Pear, 1972). Utilizing a conditioned suppression procedure, Persinger and Pear demonstrated support for their hypothesis. Male rats were exposed prenatally to a 0.5-Hz, 0.5-3.0- to 10-30-G, rotating magnetic field. The field-exposed rats showed greater suppression in response rate (relative to controls) during the 4-min conditioned stimulus preceding a 0.5-mA, 0.5-sec shock. Although significant, the suppression differences occurred only during the first few shock exposures. Subsequent conditioned stimulus-shock pairings were followed by similar suppression in both groups. The authors felt that these results along with those from Persinger studies reported earlier sufficiently support their novelty hypothesis. They stated:

> These findings are consistent with previous open field and Sidman avoidance data that suggest that the RMF-exposed animals are more reactive to novel and aversive stimuli, and underline the importance of understanding the effects of everyday geophysical-meteorological variables upon development and consequent behavioral changes (Persinger and Pear, 1972, p. 269).

In light of the evidence presented above, the hypothesis of Persinger and Pear seems tenable but premature. Even if one disregards the lack of reliability previously mentioned and accepts the reported data <u>prima facie</u>, it is difficult to understand how such evidence supports any hypothesis. First, each study reported was performed at specific intensities and frequencies, all of which varied across studies. Valid conclusions about the specificity or qualitative effects of EMR fields cannot be made on the basis of behavioral data obtained at a single intensity or frequency or duration (Persinger et al., 1973; de Lorge and Marr, 1973). After reviewing the ELF radiation literature, Persinger et al. concluded the following:

> . . . The measured changes in RT (reaction time), ambulation, colloidal suspension rates and brain electrical changes show selected susceptibility to different field frequencies.
>
> . . . ELF-induced changes exhibit an intensity relationship, static or high intensity fields usually producing different or opposite effects relative to intensities in the natural range. (1973, pp. 43-44).

Second, operant techniques have been shown to be extremely reliable in demonstrating effects of many physical agents, and the conditioned suppression and avoidance conditioning techniques have been shown to be among the most reliable of the operant techniques (Smith, 1970). Although Persinger appears aware of the advantages afforded to him by operant methodology (Persinger and Foster, 1970; Persinger et al., 1972; Persinger et al., 1973), he is still willing to accept effects that occur during the initial phases of his experiments and disappear during the later periods. Such initial effects should be deemphasized unless they can be replicated (Sidman, 1960).

Another study examined the effects on avoidance learning from exposure to ELF fields (Sanguine, 1973). In this study, 188 rats at 30-

32 days of age were used. The pups were the progeny of parents exposed to 45-Hz, 75-Hz, and no-field control conditions for 80 days prior to mating. The pregnant females and the litters were similarly exposed until the pups were tested. The procedure involved placing the subject on a safety platform which would collapse at scheduled intervals and dump the rat onto a grid floor. The platform was returned to horizontal immediately after attaining vertical. Three sec later, a 0.2-mA shock was delivered through the grid for a duration of 5 sec. If the animal had attained the safety platform prior to shock onset, avoidance response was scored. If the animal had been in contact with the grid when the voltage was turned on, but had reached the platform before it was terminated, an escape response was scored. Each rat received a maximum of 50 trials to attain the criterion of five successive avoidance responses. The experimenters reported that the data suggested no effect on avoidance learning ability from ELF exposure.

Investigators have also attempted to determine whether ELF electromagnetic fields exerted any effects on temporal discrimination in the pigeon. Marr et al. (1973) used a technique which established stimulus control along a dimension of duration. It involved differentially reinforcing a response dependent on the duration of a previously presented stimulus. In a 3-key chamber a center key was transilluminated with a blue light. A single keypeck changed the key to white for discrete durations ranging from 1 to 10 sec in an irregular order.

Following the selected duration, the white key was turned off and two side keys were transilluminated in random left-right alternation from trial to trial. One key was red and the other was green. If the white key had been on for 1 to 5 sec, a peck on the red key was correct. If the white key had been on for 6 to 10 sec, a peck on the green key was correct. Correct responses were followed by either a brief stimulus that had been paired with food presentation, or the stimulus and food together. On the average, every fifth correct response (VR-5) was followed by food presentation. An incorrect response produced a 10-sec time-out period (TO) during which all lights were extinguished. Three performance measures were calculated: number of errors, point of subjective equality (PSE), and d', a signal detection measure of detectability. The PSE is a "neutral" point above which the probability of a 6- to 10-sec choice is greater than 0.50 or below which the probability of a 1- to 5-sec choice is greater than 0.50.

Performance was observed under field-exposure conditions and no-field exposure control conditions. Field parameters investigated were frequencies of 45 Hz, 60 Hz, and 75 Hz at intensities up to 2 G and 100 V/m. No reliable alterations in any of the measures of temporal discrimination occurred under ELF field conditions.

Reaction time studies have been a method frequently used to investigate effects of EMR on stimulus-controlled behavior. Reaction times taken during field-exposure conditions have been compared to times taken under no-field exposure to EMR fields. Alterations in reaction time associated with exposure to EMR fields may indicate a form of detection. Similarly animal timing behavior has been investigated to determine whether it may be altered as a result of EMR exposure.

Humans have displayed alterations in their reaction time to stimuli during exposure to EMR fields. In many cases, reaction time has appeared to be frequency dependent, e.g., longer reaction times are recorded when the field contained low frequencies than when the field had high frequencies. This systematic effect has been reported recently by Friedman, Becker and Bachman (1967). Reaction times were measured during exposure to a magnetic field of 5-11 G alternating at 0.1 Hz or 0.2 Hz and during a no-exposure control condition. Where no effects were observed for the 0.1-Hz and control condition, reaction times were significantly longer during exposure to the 0.2-Hz field. In addition, experiments have shown that at 2 V/m human reaction time either increased at 3 Hz-6 Hz (Konig, 1962) or decreased at 9 Hz (Konig, 1960).

On the other hand, a series of studies demonstrated that magnetic fields have no general behavioral influence on nonhuman primates. Grissett and de Lorge (1971) measured the effects of a 3-G, 7-Hz, or 45-Hz magnetic field upon reaction time, reinforcement ratio, and efficiency ratio (correct responses/total responses) in squirrel monkeys trained on a simple discrimination task. No significant differences were found for any of the three measures between the control sessions and the exposure sessions.

Hamer (1968) conducted a reaction-time experiment on 29 human subjects to a 1000-Hz tone. Concerned with the frequency parameter, reaction time was tested during exposure to electric fields at two randomly applied frequencies--high and low--with a constant field strength of 4 V/m. A control condition with the field off was established in the first 5 days. The study utilized a double-blind experimental technique. Unfortunately, the subjects were run under differing pairs of frequencies within the range of 2-12 Hz. The presence of the electromagnetic field produced an abrupt increase in reaction time latency, with the higher frequency in each pairing producing longer reaction times.

Of those studies which have explored possible electric field influences on time-related behavior, several have utilized nonhuman primates. Gavalas, Walter, Hamer and Adey (1970) found a frequency effect on scheduled, controlled responding in Macara nemestrina exposed to electric fields of 2.8 V/m. Two monkeys performed under a schedule that reinforced a pause of 5 sec followed by a response within 2.5 sec. Interresponse times (IRT) greater than 7.5 sec or less than 5 sec reset the 5 sec timer and were not reinforced. In the presence of 7-Hz electric fields, an increase in the frequency of short IRTs occurred. With the absence of this effect during exposure to 10-Hz fields, the authors concluded that the shift was frequency dependent, occurring at 7 Hz but not at 10 Hz. This approach, however, has been subject to criticism by de Lorge and Marr (1973, p. 16), who contend that "the controlling relations and the inherent dynamic quality of the performance generated under such dependencies as the interresponse-time and fixed-interval schedules are too complex to be subsumed under any simple notion of timing behavior."

In a series of experiments, de Lorge (1972, 1973a, 1973b) observed the effect of ELF fields on reaction time, matching-to-sample behavior, and fixed-interval schedule responding in rhesus monkeys. All of de Lorge's experiments used 10-G magnetic fields and 7.4 V/m electric fields.

Reaction time was measured using a limited-hold procedure. In this task four monkeys were trained to lift a lever in the presence of a red light and to release it when a tone occurred in order to receive reinforcement (food or water). The period between the lever lift during the red light and the tone onset varied between 0.5 sec and 10 sec, and intertrial intervals (ITI) were fixed at 10 sec. If the tone came on and the lever was not released within 3.0 sec, the tone and red light went off and the ITI was reset (limited hold 3 sec). Reaction times were measured from the onset of the tone to the release of the lever. In addition, anticipatory responses, i.e., lever releases during the foreperiod, and ITI responses were also recorded.

Matching-to-sample tasks require a subject to respond to a stimulus on one display that is the same as a stimulus on another display. In these studies, pressing a colored center key was followed by the removal of the stimulus and the appearance of the same color 1 sec later on either a left or right lower key. When the key with the matching color was pressed, all stimuli were removed and reinforcement became available. Another trial was presented with a new stimulus color 10 sec later. If the key with the nonmatching color was pressed, all stimuli were removed for 15 sec, followed by the same stimulus on the top key. In the matching-to-sample task, percentage of errors and latency of response measures were recorded.

In the fixed-interval responding condition, monkeys were trained to lift a lever in the presence of a green stimulus light. The response was reinforced after a 20-sec interval had elapsed (FI 20-sec). The measures recorded were reinforcement time (the time between reinforcement being made available and a reinforced response), pause time (the time between a reinforced response and the next lever response), and response rate (the number of lever responses per sec).

Each of these tasks was presented for three 15-min components during an experimental session. Each component was followed by a 5-min extinction (ext) period in which no task was available. The sequence was as follows: FI 20 sec, ext, Reaction Time, ext, Match-to-Sample, ext. The sequence was repeated three times each experimental session. In general, the procedure was to produce stable responding on each task, turn on the ELF field, and after several sessions turn the field off again. Behavioral measures were taken continuously. Field exposure conditions were either 54 hr (1972), 33 days (1973a), or 12 days (1973b). Frequencies were either 75 Hz (1972), 45 Hz and 10 Hz (1973a), or 60 Hz and 10 Hz (1973b).

No influences of ELF fields on behavior were observed in any of the measures of behavior. The author concluded that these results provide supportive evidence that these specific electromagnetic fields have no behavioral influence on nonhuman primates.

As with effects on conditioned response, more work is needed to justify concluding that ELF fields reliably affect reaction time; however, these studies have been instructive in a different manner. They have served to emphasize the importance of the parameters being investigated. The importance of frequency (wavelength) has been recognized by reviewers other than Persinger. For example, after reviewing VHF, UHF, and SHF fields, Frey (1965, p. 335) reported "changes are seen, but sometimes the character of both functional and morphological changes are dependent on the wavelength." The importance of wavelength is also apparent upon the realization that humans clearly react to a specific portion of the EMR spectrum from about 3×10^{14} Hz to 8×10^{14} Hz, which represents visible light.

<u>Part c. ELF radiation as unconditioned stimuli.</u> ELF fields

are associated with 60 Hz power transmission lines. Although the concern of the power companies traditionally has been the health and safety of workers exposed to the intense electric fields produced in air near power lines, investigations by the power companies have been valuable in illustrating possible unconditioned responses to ELF fields. Sanguine reviewers (1972) reported that the most definitive work has been a series of papers published in 1966 and 1967 by the Institute of Electrical and Electronic Engineers (IEEE). These studies reported that currents produced in organisms by electromagnetic fields in air are negligible even at intensities over 100 kV/m. A particularly significant result of these studies were reports that "an electrical field intensity of 6000 V/m in air (approximately 236,000 V/m) causes a current density of about 0.5 mA/in^2 to enter the skin area which a man is barely able to feel. The sensation is like a gentle breeze blowing on the skin and is not associated with the sensation of electric shock" (1972, Annex C, p. C-5).

A variety of ELF-related behaviors have been reported in human subjects. Men exposed to a 3-Hz field reported headaches and fatigue within a few sec of a field application (Konig, 1962). Exposure to this frequency at 5 V/m was followed by decrements in skin resistance in 50% of the subjects. Persinger et al. (1973) reported that 20 human subjects exposed to 3-Hz or 10-Hz ELF fields do not differ significantly, in terms of types of complaints from 20 subjects who were inside the same radiation chamber with no field applied. They state that both groups reported pains in the neck, ringing in the ears, apprehension, flushes, stiffness, fatigue, and "slight headaches." They conclude that the report of private behaviors experienced in ELF experimental situations is probably subject to other controlling stimuli.

Another Sanguine study used a classical preference method to determine whether various animals would tend to leave, stay in, or behave indifferently to ELF fields. Test species included fish, turtles, ducklings, rats, fruit flies, and dogs. The animals were tested in their appropriate media: soil, water, or air. Both 45-Hz and 75-Hz frequencies were used with electric field intensities either 10 V/m or 20 V/m and magnetic field intensities either 1.0 G or 2.0 G. Although procedures differed slightly from species to species, Sanguine researchers report the general methodology as follows:

> In general each animal was placed at random in one pair of cells and allowed to acclimate. Then a series of tests was given as follows:
> 1. The appropriate electric field was turned on in the cell occupied by the animals at the end of the acclimation period.
> 2. Sixty minutes later the field was turned off and the position of the animals was recorded.
> 3. If the animals were out of the field, the position of the field was shifted.
> 4. If the animals were in the original cell (in the field) the position of the field was not shifted. (1973, p. 28).

The experimenters found that the ELF fields used were insufficient to promote a translocational movement in any of the animals tested.

In addition to the temporal discrimination experiment reported previously, Marr et al. (1973) also examined whether or not pigeons preferred ELF fields. The effects of 45-Hz and 75-Hz fields at the highest intensities available (2 G and 100 V/m) were explored in reference to influence on a choice baseline. The baseline for this experiment employed a concurrent chained schedule. Marr and de Lorge explain that "a concurrent chain schedule provides different consequences for executing alternative and incompatible responses" (1973, p. 21). In general, two keylights were available in this task and identical food reinforcement occurred for a response to either key. After the responding pattern was established, the ELF fields were applied after responses on the preferred key. No alterations in preference occurred.

In none of the foregoing studies has the assumption of detection of ELF signals been reliably supported through replication.

Part d. ELF radiation as conditioned stimuli. Only one study (Reille, 1968) has examined whether or not ELF fields can act as conditioned stimuli. Reille presented a 5-sec conditioned stimulus previous to a 6-15 V, 0.5-msec shock and observed heart rate alterations in homing and nonhoming pigeons after the presentation of the stimulus but before the onset of the shock. For the experimental conditions, the experimenter used magnetic fields either of 0.2 Hz to 0.5 Hz at 0.15 G, 300 Hz to 500 Hz at 0.15 G, or continuous at 0.8 G. The control conditions consisted of light-shock and no-conditioned stimulus shock procedures. Each subject was given approximately 20 trials per condition.

Three measures of performance were taken--the average percentage increase in heart rate over the baseline rate per condition and the maximal and minimal percentage increase in heart rate per condition.

The experiments with light stimuli produced large increases in heart rates. A mean increase of 61% with a maximal increase of 94% and a minimal increase of 24% was observed for the homing pigeons. Only one nonhoming pigeon was presented a light-conditioned stimulus and its mean rate increase was 34%. The greatest field-associated increases occurred with the 0.2-Hz to 0.5-Hz signal. The homing pigeon's rate increased on the average of 37.5% with a maximum increase of 56%, and the nonhoming pigeon's rate increased on the average of 30.5% with a maximal increase of 46%. Similar increases were observed under the 300-Hz to 500-Hz condition in which the mean rate increase for homing pigeons was 34.6% and the maximal increase was 56% and 30.5% and 46%, respectively, for nonhoming pigeons. Performance was lower in the static field condition, where the average increase was only 21.5% and the maximum was 56% for the homing pigeons (the nonhoming pigeons were not presented this condition). It should be noted, however, that no increases were recorded in all the field conditions due to the fact that the behavior in 8 out of 26 homing pigeons and 9 out of 23 nonhoming pigeons exhibited an inability to be conditioned to magnetic field stimuli. Finally, performance in the no-field shock condition was remarkably constant. The maximum rate for the homing pigeon's increase being

13% and the mean being 9.4% (again the nonhoming pigeons were not presented this condition).

This experiment clearly demonstrated that behavior in the pigeon can be conditioned to ELF low-frequency and static magnetic fields. The difference between the performances obtained with the light stimuli and those obtained with the magnetic stimuli seem to indicate that the latter are more difficult to perceive for the pigeon. This difficulty may explain the failure of some previous experiments to demonstrate detection (Orgel and Smith, 1954; Meyer and Lambe, 1966) as well as the inability of some subjects in this experiment to detect the magnetic fields. In addition, the experiment appeared well-controlled. Mechanical noises from the electrical switches, the physiograph, and other extraneous sources were controlled as well as thermal effects from the Helmholtz coils and the possibility of pseudoconditioning. Although a frequency effect was not apparent from the data, the different intensity levels may have confounded the results. The large sample size can only add credibility to the results, but it is unfortunate that the participation of the nonhoming pigeons was limited. Here, as in EMR studies reported earlier, (King et al., 1971), aversive conditioning procedures have shown a greater sensitivity by demonstrating detection while appetitive procedures have failed (Orgel and Smith, 1954).

Definition of the Problem

After considering the preceding review, it is apparent that many more studies have dealt with non-ELF fields than with ELF fields. This lack of interest in ELF research has stemmed from attitudes which have discounted the significance of ELF fields as behavioral stimuli because of the difficulties technicians have encountered in measuring them, and because research accomplished so far with ELF has not produced data suggesting that a profound psychological hazard might be developing. For example, one Sanguine reviewer has stated:

> Hypothetical ELF biological effects almost certainly would be associated with high intensity fields. The electromagnetic fields defined by Maxwell's equations with their mutually orthogonal electric and magnetic fields are extremely weak at Sanguine antenna current levels and are comparable with ambient environmental fields. Their detection even by specially devised receivers is no trivial technological feat. The Navy therefore considers these electromagnetic fields an unlikely source of significant biological effects. (1972, p. 111).

Another Sanguine reviewer has stated:

> The fact that no gross biological effects have been reported along electrical power line routes over a period of many years of continuing accelerated growth of the power industry is probably the main reason why very little scientific research has been done at ELF. (Annex C, 1972, pp. C-3-C-4).

Frequently, such conceptualizations have been followed by fantastic and illogical accounts. For example:

> Synchronization of organisms and communities of organisms to environmental rhythms probably are examples of sub-threshold stimuli. Thus, they may be perceived, but they evoke no behavioral response. (Sanguine, 1972, p. 114).

> Simple and complex animals respond to fantastically weak stimuli for their orientation, food acquisition, circadian rhythms and other such phenomena. If one of these receptors were responsive to low-level ELF signals, a sensitive performance might be expected, but there is no reason to believe that such effects exist.

> Furthermore, there is no obvious biological advantage for having such a response mechanism. (Sanguine, 1972, p. 113).

One may ask that if animals respond to fantastically weak stimuli for their orientation, food acquisition, etc., why is there no biological advantage for having such a response mechanism? Also, how can a signal be detected without evoking a behavioral response?

Recently, renewed interest has stemmed from attitudes which have emphasized the significance of ELF fields because of the unique conditions realized in space explorations and because of greater awareness of earth's natural fields. Beischer (1962, p. 48) has pointed out the possibility that "man on earth may have become so accustomed to the geomagnetic field that only its absence can reveal any effects." Busby (1968) has described this predicament in relation to future space exploration. He has stated:

> Since astronauts will soon be exposed to magnetic fields which are much less in intensity than the earth's magnetic field, the question arises as to whether or not the human body has during its evolution become dependent on the presence of earth's magnetic field for the maintenance of its normal functional integrity. Accordingly it has become most important to determine if a low-intensity magnetic field exposure could possibly lead to an impairment of health or performance of an individual. (Busby, 1968, p. 27).

A more realistic approach to the effects of electromagnetic energy has evolved upon awareness of naturally occurring fields. After reviewing the literature, Persinger et al. (1973) have suggested that "natural intensities should be used to a greater extent if generalization of results to natural occurrences is to be possible." They have pointed out that "the assumption that greater than natural intensities will enhance the effect, as in ionizing radiation research, may not be valid" and that "organisms may show increased sensitivity to a narrow band of natural intensities" (p. 46).

There has been no greater advocate of this point of view than F. A. Brown, whose studies in biological rhythmicity and animal orientation have supported the contention that living things are sensitively responsive to physical factors of their environment, like ELF fields, which are above and beyond those commonly recognized as effective ones. Brown's hypotheses have centered around biological clocks which have been described as the "hereditarily transmitted ability of most living organisms to measure the time of day and to regulate their main physiological processes in accordance with it" (Presman, 1970, p. 203). The operation of the biological clock has been hypothesized to be correlated with periodically occurring processes in the environment such as the alternation of day and night, geomagnetic fields, and temperature.

While there is little controversy as to the existence of biological-clock mechanisms, Presman has stated, "One question, however, still remains unanswered: Is the periodicity of biological processes determined only by these endogenous regulators or is it affected by periodic changes in external factors?" Brown has supported the latter point of view which has come to be known as the "external-timer hypothesis."

This hypothesis advocates that the organism's biological clock comprises a capacity to receive timing information from the environment and transduce it into the observable biological rhythms. This controversy has focused attention directly on naturally occurring electromagnetic fields as a major source of timing information from the environment. Consequently, ELF low-intensity fields have been heavily emphasized. Brown's reasons for stressing natural occurring fields have been clearly stated as follows:

> In the last century experiments designed to show animal responses to magnetism were indecisive, but they dealt with fields much stronger than the half gauss of the earth's magnetic field. It occurred that the usual approach to this fascinating problem was wrong. The earth's magnetic field is very weak and relatively constant: the organism is normally submerged in it in much the same way as an aquatic organism in water or a terrestrial one in still, warm air. However, the magnetic medium, unlike water on still air, has direction; and both its direction and strength are slowly changing over a very small range. Organisms are very sensitive to small changes in other media--to changes in the "concentration" and temperature of water, for instance. But they respond only over a very small range--to temperature, for example, only between about 0^{o} C, and 40^{o} C. One would never seriously contemplate studying the perception of temperature over the range from--273^{o} C up to say $20,000^{o}$ C. Thus it is reasonable to assume that living things respond to changes in magnetic field only over or close to the natural range: and it is in these ranges that one should look for responses. (Brown, 1963, p. 18).

In summary, it seems that the psychological research on the influence of electromagnetic energy has identified few tangible effects. Other than the above study by Reille (1968), no detection of fields has been reported. For the most part, the experimental efforts to date lack a systematic approach to the examination of the critical variables involved, and parametric studies are the exception rather than the rule. This scarcity of research has been attributed to misguided attitudes which have regarded the absence of effects at higher frequencies sufficient reason for not pursuing studies at lower frequencies. Renewed interest in outer-space conditions and naturally occurring fields has stimulated research in ELF (Wilson, 1973).

There is a clear need for behavioral studies to investigate more carefully the possible detection of ELF electromagnetic radiation. In addition to the space program, the widespread interest and public concern that naturally occurring fields might cause biological effects constitute both an opportunity and an obligation to study the potential for detection carefully.

Investigators have noted that if a species of organisms could detect the presence of such fields, it might imply that natural environmental rhythms play a role in controlling significant behaviors of the species (Marr et al., 1973). If this is true, then the imposition of similar man-made fields such as those generated by power lines and communications equipment might interfere with those behaviors. Marr et al. point out an additional possibility. They state that although extremely low-frequency fields might be of no particular significance to species-specific behavior, the presence and detection of such fields could lead to active avoidance or approach. These behaviors could alter local animal population distributions with possible deleterious ecological effects. In addition, investigations into the detection of ELF signals may be used to increase our understanding of the nervous system and behavior. It is common knowledge that many animals can make discriminations in some sense modalities far more defined than man. According to Stebbins (1970) most lower animals clearly surpass man in their olfactory abilities. The frequency range of hearing of the domestic dog, the visual acuity of the hawk, the perception of ultraviolet rays by the bee or infrared rays by the snake represent only a few of countless other examples.

This research has utilized the sensitive, well-controlled psychophysical techniques of conditioned suppression and conditioned acceleration to investigate the possibility that ELF fields may be detected at a variety of values.

Methodological Background

Experimental Controls

Operant conditioning methodology can afford detailed, extensive, and precise control over the environment of the subjects in an experiment. An ELF exploratory study should profit directly from some of these controls.

One of three animals serve as subjects most often in operant conditioning research: the pigeon, the rat, and the monkey. One of the chief advantages of the standardized use of these animals, besides the fact that so much is already known about their behavior, has been "the relative ease of controlling their behavioral history and of providing them experimentally with whatever history is pertinent to a given investigation" (Sidman, 1960, p. 384). In respect to ELF studies, much is already known about their sensory functions as well as general behavioral effects due to ELF exposure. In addition, these animals are known to be responsive to the stimulus control procedures that will be used (Stebbins, 1970).

Second, an enclosed light- and sound-isolated chamber has been used most often in operant research. Not only can the conditions within such an environment be precisely controlled, but they can be done so automatically by programming equipment, thereby further minimizing participation of the experimenter and experimenter error. In ELF studies, these chambers can be easily inserted into Helmholtz coils and between electric plates. With the control or recording of environmental and behavioral events remotely administered, the interference of electrical or magnetic noise and other outside extraneous influences can be substantially eliminated. An additional advantage of automatic equipment has been that it allows for the exact repetition of the experimental conditions. In ELF exploratory studies, such replication will be essential in demonstrating reliable effects.

Finally, the reduction of intersubject and intrasubject variability resulting from the utilization of well-controlled and well-defined environments should provide a very efficient approach to an exploratory study.

In this respect it would seem more desirable to look for evidence of ELF detection in a small number of subjects under well-controlled conditions than in a large number of subjects under poorly controlled conditions.

Stimulus Control Procedures

In general, psychophysics has been an area of research concerned with the analysis of sensory functions. The stimulus has been an environmental event specified in physical units and varied along a physical dimension. The basic data have been the responses of an awake, intact organism. "The endpoint of a psychophysical experiment has been a functional relation between environmental stimuli and behavior" (Stebbins, 1970, p. 2).

Psychophysical methods refer to techniques for presenting stimuli to an organism to determine limits and dimensions of its sensory system. A basic question of psychophysics has concerned the ability of an organism to respond differentially to values along a stimulus dimension. It was noted in an earlier section that the essence of stimulus control is that changes in the pattern of operant behavior accompany changes in stimulus value. Thus, psychophysical methods may be incorporated into a more general category of procedures for establishing stimulus control.

Blough (1966) has categorized stimulus control procedures into two types, the differential type and the non-differential type. The differential procedure has emphasized stimulus differences to which the organism is required to vary its behavior. Absolute and differential threshold determination procedures are examples. The stimulus is varied along a narrow physical dimension. Human subjects may respond, "yes, I detect it" or "no, I do not detect it." Animal subjects may press one lever for intensities above the threshold and another lever for intensities below the threshold. The temporal discrimination study by Marr et al. (1973) discussed earlier used a differential, animal-psychophysical procedure.

Blough (1966) explains that the non-differential experiment has tended to stress "similarity." Stimulus generalization and magnitude scaling have been examples. The stimulus has varied along a wide physical dimension. The number of categories of response are greater for the non-differential experiment than for the differential types. For example, a human subject may assign numbers to different intensities or an animal may respond at different rates.

An experiment by Herrnstein and van Sommers (1962) has utilized a non-differential, animal-psychophysical procedure. Investigating magnitude estimation in pigeons, the experimenters trained birds to respond at different rates to a number of different stimulus intensities. Using a power function, an "estimation of magnitude" was calculated from the data which predicted the response rates under intermediate intensities not yet presented. After the animals' performance was studied under the intermediate stimuli, the recorded rates were found to agree with the calculated rates--an interesting result in view of recent arguments and data in human psychophysics (Stevens, 1957, 1962).

It has been specified earlier that an organism may be said to detect a stimulus if that stimulus has acquired eliciting or discriminative properties. In this context, it has been noted that procedures which establish these properties can be utilized to determine whether or not an organism can detect the presence of a stimulus. Studies have been reviewed where either respondent-conditioning techniques (Kholodov, 1967; Reiller, 1968; Orgel and Smith, 1954), as well as operant-conditioning techniques (Meyer and Lambe, 1966; Justesen and King, 1970; King et al., 1971), have been utilized to assess detection of electromagnetic fields in various organisms.

The conditioned suppression paradigm has been a useful operant method for determining if an organism is sensitive to the presence of a stimulus. A sensitive non-differential procedure for establishing stimulus control, the technique has been applied extensively in animal psychophysics. Thresholds in vision, audition, olfaction, and somesthesis have been measured in a wide variety of organisms. References for some studies have been summarized in Table 4.

The conditioned suppression paradigm has combined methodological features of both operant and respondent conditioning (Estes and Skinner, 1941). In general, the procedure has been as follows:

> First, a stable rate of responding is established under an intermittent schedule of reinforcement. The variable interval (VI)

Table 4

A Summary of Research Using the Conditioned Suppression Technique for Sensory Threshold Measurements (Smith, 1970)

SENSORY MODALITY	SPECIES	REFERENCES
Vision		
Critical flicker fusion	pigeons	Hendricks, 1966; Powell, 1967; Powell & Smith, 1968; George, 1968;
Critical flicker fusion	rhesus monkeys	Shumake, 1968; Shumake *et al.*, 1966; Shumake, *et al.*, 1968
Brightness difference thresholds	pigeons	
Color vision and acuity	opossum and tree shrew	Masterton *et al.*, 1969b
Audition		
Audiograms	opossum, hedgehog, tree shrew, bushbaby	Masterton, *et al.*, 1969a
Audiograms	potto, slow loris, rabbit	Masterton *et al.*, 1969b
Audiograms	pigeon	Dalton, 1967
Frequency difference thresholds	pigeon	Price *et al.*, 1967
Olfaction		
Absolute intensity thresholds, quality discriminations	pigeon	Henton, 1966, 1969; Henton *et al.*, 1966, 1969
Somesthesis		
Temperature sensitivity	rhesus monkey	Duncan, 1968
X-ray Discrimination		
Exposure rate thresholds and role of olfaction in x-ray detection	rats, pigeons, rhesus monkeys	Dinc & Smith, 1966; Morris, 1966; Smith *et al.*, 1964; Smith, 1967; Smith & Tucker, 1969

schedule, during which reinforcement is presented at irregular periods of time, is most often used. Its frequent use is mainly due to the relatively constant rate of responding that it generates and maintains throughout a lengthy experimental session.

After stable performance is established, a stimulus of short duration (e.g., 1 min) is superimposed on the operant performance at varying intervals. It is terminated independent of the animal's behavior and coincident with a brief, unavoidable, noxious electric shock. Pairing of the stimulus with shock represents a respondent conditioning paradigm, although the conditioned and unconditioned stimulus are not specified.

After a number of stimulus-shock pairings, the operant responding is suppressed during the pre-shock stimulus presentations and relatively unaltered in their absence. This decrease in the rate of responding during a stimulus which precedes shock is called conditioned suppression. The extent to which responding is suppressed depends on the detectability of the stimulus with which shock is associated. Thus, the extent of suppression can be related to stimulus intensity allowing threshold determination. The extent to which a subject is able to detect the signal is quantitatively reflected by the suppression ratio, the measure often calculated by dividing the rate of responding before the presentation of a pre-shock stimulus, into the rate of responding during its presentation.

Conditioned suppression procedures have proven valuable in x-ray detection research by enabling the experimenter to obtain reliable threshold values without subjecting the organism to prolonged exposure to harmful radiation. In one such experiment, rhesus monkeys were trained to lick a tube for sucrose presentations and this behavior was maintained on a VI 2-min schedule during which sucrose was available at irregular intervals averaging 2 min. This was followed by periodic pairing of brief exposures of x-radiation with shock to produce suppression. All monkeys were suppressing significantly to a 3-sec x-ray exposure by the end of the 20th trial (Smith, 1970). Experiments utilizing a conditioned suppression paradigm to investigate detection of microwaves were discussed earlier (King *et al.*, 1971).

Terminating the conditioned stimulus by events other than shock, such as time-out from positive reinforcement (TO), may cause enhancement of responding rather than suppression. This is called conditioned acceleration. Similar to the conditioned suppression paradigm, the conditioned acceleration procedure also superimposes a conditioned stimulus of short duration on an operant performance and terminates it independently of the animal's behavior. It differs from conditioned suppression by pairing the termination of the stimulus not with shock but TO, a period in which no response produces reinforcement. The extent to which a subject is able to detect the signal is measured by changes in the acceleration ratio, the measure relating the rate of responding before the presentation of a time-out stimulus with the rate of responding during its presentation.

Incorporating TO with a conditioned suppression paradigm, Herrnstein (1955) was one of the first investigators to demonstrate conditioned acceleration. He observed that the pre-TO stimulus suppressed behavior only when the reinforcement was given very frequently--approximately once every 30 sec (variable interval schedule of reinforcement or VI 30 sec). At higher mean values of a variable interval schedule such as 7 and 9 min, the pre-TO stimulus controlled higher rates of keypecking in pigeons than the prevailing interval rate. Herrnstein also found that when the VI schedule had a mean interval of 7 min and the TO duration was increased from 30 sec to 50 min, the degree of response acceleration in the presence of the pre-TO conditioned stimulus progressively increased. Further support for conditioned acceleration was provided by Ferster (1958, Exp I), who found that chimpanzees' rate of response on a VI 3-min schedule of reinforcement accelerates in the presence of a 30-sec, pre-TO stimulus.

Both Ferster and Herrnstein, in their studies with TO, used a procedure somewhat different from the usual response-independent, conditioned suppression procedure employed with shock. In their response-dependent procedure, the first response after the conditioned stimulus has been on for 30 sec produced the TO; the longer the subject delayed responding, the longer the conditioned stimulus remained on and the longer TO was delayed. In order to clarify whether it was the difference in the contingency or the difference in the nature of the event that is responsible for conditioned acceleration, Leitenberg (1966) compared both the usual response-independent and the response-dependent procedure that Ferster and Herrnstein used with TO. Pigeon keypecking behavior maintained by a VI 2.5-min schedule of reinforcement was suppressed by a red keylight (approximate duration of which was 30 sec) before shock of 40 msec duration, whose intensity varied from 1.0-3.5 mA across subjects. The same baseline response rate was accelerated by a green light before a 10-min TO and was unchanged by a stimulus before loud noise or a stimulus before loud tone. Conditioned acceleration with TO and conditioned suppression with shock were obtained regardless of whether a response-dependent or response-independent procedure was employed.

Although the stimulus control attained through the conditioned acceleration method has not yet been demonstrated to be as reliable as the control attained through the conditioned suppression method, it remains a desirable modification inasmuch as it allows for threshold determination of ELF electromagnetic radiation without the involvement of shock. Since it is technically difficult to shock many animals, like pigeons, without interfering with EMR-field uniformity, the conditioned acceleration procedure shows great potential for future investigations.

Statement of Purpose

The purpose of this study was to investigate the possibility of the detection of low-energy, extremely low-frequency (ELF) electromagnetic radiation by the pigeon and by the rat, through selected measurement of operant behavior. These organisms occur in large numbers in a variety of natural environments, and they are convenient laboratory subjects whose behavior has been explored extensively. Inherent in the execution of the research has been the development and utilization of conditioned suppression and conditioned acceleration techniques suitable for behavioral studies with ELF.

CHAPTER II

METHOD

Subjects

Two Sprague-Dawley rats designated R-5 and R-9, two Holtzman rats designated R-4 and R-8, and four White Carneaux pigeons designated P-237, P-74, P-354, and P-276, served as subjects. Each subject was maintained at 80% of its free-feeding weight. At all times in their home cages, rats had access to water and pigeons had access to grit and water. Experimentally naive, the rats were about 90 days of age at the initiation of the study. Prior to this experiment, all birds had extensive histories of responding under various schedules of food presentation.

Apparatus

The subjects were tested in a standard operant-conditioning chamber located inside an electromagnetic field-generating apparatus. The magnetic field was generated by a Helmholtz coil approximately 3 ft in diameter. Maximum potential field strength was 3 G. Current directed to flat metal foil plates, 14-in square, generated the electric field. The electric field was mutually perpendicular to the magnetic field and could be continuously varied from 0 to 300 V/m. The cages were all constructed of plexiglas and ventilated by a blower. All switches, controls, feeding apparatus, etc., were remotely located or replaced with dielectric materials. Detailed design and calibration information can be found in an earlier report (Marr et al., 1972).

The rat chamber contained a houselight and a stimulus light, both of which could be transilluminated by a white 6-W lamp. The rat was required to press a lever with a minimum force of 0.2 N in order to obtain food. The reinforcer consisted of a 0.97-mg Noyes rat pellet. A grid floor was wired to a Grasen-Stadler, Model E1064GS, shock generator.

The pigeon chamber contained a white 6-W transilluminated houselight and a response key that could be transilluminated by a red, green, or white 6-W lamp. The response key required a minimum force of 0.1 N to operate. Reinforcement was 5-sec access to mixed grain.

Conventional relay equipment located in an adjacent room scheduled stimulus events. The data were recorded by impulse counters, running elapsed time meters, and cumulative recorders. A white noise generator was used to mask extraneous noise.

Procedure

Conditioned Suppression

After magazine training, lever pressing of the rats was shaped by successive approximations in the presence of a white stimulus light.

Stable performance was developed on a variable interval 1-min (VI 1-min) schedule of food presentation. Thus, the first response that occurred after an average interval of 1 min had elapsed from the last pellet presentation was reinforced. Daily sessions comprised 50 pellet presentations.

The conditions of the conditioned suppression procedure are presented in Table 5. The sequence of the events within each condition is diagrammed in Figure 3.

The first ten sessions following the establishment of a stable VI 1-min baseline, represented the flicker-no shock condition (F-$\overline{S}$). During this condition, a flashing (1.3/sec) stimulus light was superimposed on the operant performance. This stimulus had a duration of 1 min and was scheduled to occur at variable intervals averaging 10 min apart. With the absense of a difference between the rate of responding during the 1-min interval immediately prior to each presentation of the flicker signal, and the rate of responding during the 1-min interval in which the flicker stimulus was presented, the neutrality of the flicker stimulus was established.

The second set of sessions comprised the flicker-shock condition (F-S). In these sessions the 1-min flicker signal was terminated coincidentally with 0.5-mA, 0.5-sec shock delivered to the feet through a grid floor. The flicker stimulus now served as a warning signal for impending shock. As responding during the flickering light decreased

Table 5

The ELF Field Parameters and Control Conditions with the Number and Order of Sessions at Each Value, for Each Subject, for the Conditioned Suppression Procedure

Condition	Subject			
	R-9	R-8	R-4	R-5
F-$\bar{S}$	10	10	10	10
F-S	10	10	10	10
$\bar{F}$-S	5	5	5	5
45Hz, 2G, 0 V/m	10	10	10	-
75Hz, 2G, 0 V/m	4	11	11	-
F-S	1	2	2	1
$\bar{F}$-S	1	1	1	1
75Hz, 2G, 1.0 V/m	3	5	7	3
F-S	5	4	2	3
$\bar{F}$-S	5	1	1	-
75Hz, 2G, 0.1 V/m	5	8	7	7
F-S	-	1	1	1
$\bar{F}$-S	1	1	1	1
45Hz, 2G, 1.0 V/m	10	9	10	9
F-S	2	2	4	1
$\bar{F}$-S	1	1	1	3
45Hz, 2G, 0.1 V/m	9	9	8	6
F-S	5	5	5	2
$\bar{F}$-S	5	7	7	2
45Hz, 2G, 10 V/m	6	6	6	5
75Hz, 2G, 10 V/m	9	8	11	6
F-S	1	2	2	1
$\bar{F}$-S	1	2	2	1
75Hz, 2G, 100 V/m	4	5	5	4
45Hz, 2G, 100 V/m	6	6	6	6
45Hz, .2G, .06 V/m	6	6	6	6
75Hz, .13G, .07 V/m	4	4	4	4

CONDITIONED SUPPRESSION

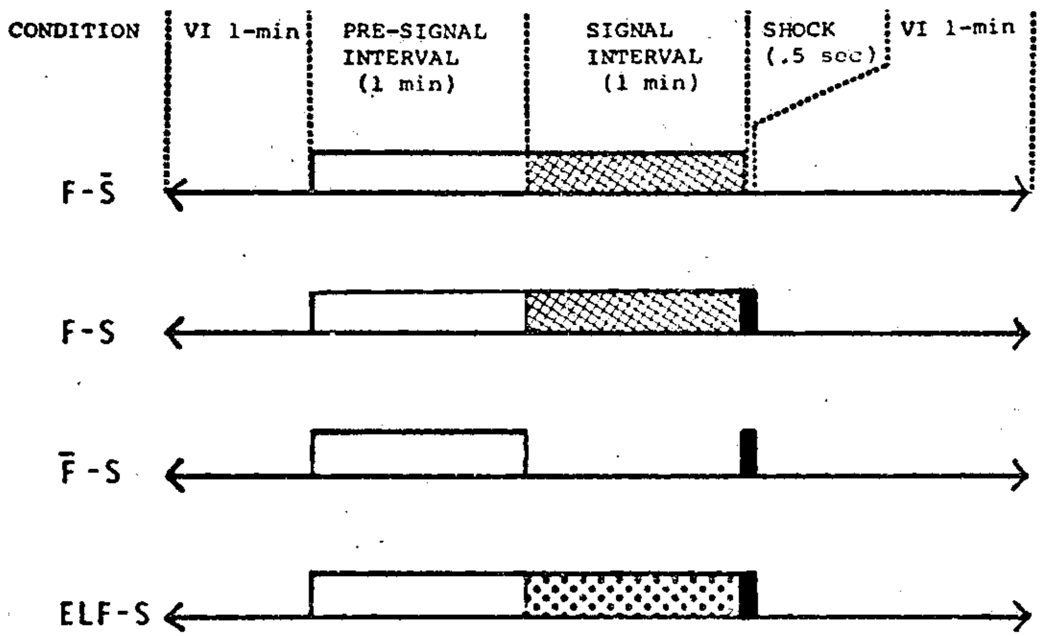

Figure 3. The Sequence of Events under the Conditioned Suppression Procedure.

to a low level relative to the baseline, conditioned suppression was established. The rate of responding in the 1-min interval prior to the onset of the signal was compared with the rate during the signal, and a suppression ratio (rate during/rate prior) was computed. Detection was defined as a mean suppression ratio less than one. The extent to which the subjects were able to detect the signal was manifested by the differences between the suppression ratio of the F-S condition, and the response ratios of the other conditions.

The following five sessions comprised a no flicker-shock condition ($\overline{F}$-S). By presenting an unsignalled shock on a VT 10-min schedule and dividing the response rate 1 min previous to the 1-min pre-shock interval into the response rate during the pre-shock interval, a rate ratio was computed for comparison against the signal-shock conditions. This condition assessed the effect of shock alone on performance.

Following the $\overline{F}$-S condition, an ELF signal was used as a pre-shock stimulus in the manner of the flashing light. This condition was called the ELF-shock condition (ELF-S). The extent to which ELF field was detected was directly assessed upon comparison with the previous conditions. If an ELF signal was detectable, its use as a pre-shock stimulus would result in response suppression, particularly when compared to the unsignalled shock condition. Detection of the ELF signal was operationally defined by a mean suppression ratio which fell outside the 99% confidence interval around the mean suppression ratio of the $\overline{F}$-S condition.

Several combinations of intensity and frequency were studied in an attempt to determine if the subjects could detect the presence of the signal. Both F-S and $\overline{F}$-S sessions were interposed between field sessions. The field parameters explored for each subject and the number of sessions at each value are shown in Table 5.

Conditioned Acceleration

Essentially the same procedure was used for the conditioned acceleration experiment as for the conditioned suppression experiment. The conditions of the conditioned acceleration procedure are presented in Table 6. The sequence of the events within each condition is diagrammed in Figure 4.

After establishing stable keypecking under a variable-interval 2-min (VI 2-min) schedule of food presentation in the presence of a white keylight, a red-keylight no-time-out condition (RL-$\overline{TO}$) was initiated. In this condition a change in key color from white to red was programmed to occur at irregular intervals averaging about 10 min apart. The red light had a duration of 1 min. With the absence of a difference between the response rate during the 1 min prior to presentation of the red light and the response rate during the 1-min duration of the red light, the neutrality of the red light was established.

In the red-light time-out condition (RL-TO), the red keylight was terminated after its 1-min duration coincidentally with the initia-

Table 6

The ELF Field Parameters and Control Conditions with the Number and Order of Sessions at Each Value, for Each Subject, for the Conditioned Acceleration Procedure

Condition	Subject			
	P-237	P-276	P-74	P-354
RL-$\overline{TO}$	10	10	10	10
RL-TO	10	10	10	10
$\overline{RL}$-TO	5	5	5	5
75Hz, 2G, 0 V/m	5	5	4	5
RL-TO	7	7	7	7
$\overline{RL}$-TO	2	2	3	3
60Hz, 2G, 0 V/m	5	10	10	10
RL-TO	3	3	4	3
$\overline{RL}$-TO	3	2	4	3
45Hz, 2G, 10 V/m	5	5	5	5
75Hz, 2G, 10 V/m	11	11	11	11
RL-TO	3	1	2	2
$\overline{RL}$-TO	1	1	1	1
75Hz, 2G, 1.0 V/m	6	7	7	7
RL-TO	1	1	1	1
$\overline{RL}$-TO	2	1	2	1
75Hz, 2G, 0.1 V/m	9	8	9	10
RL-TO	3	1	1	1
$\overline{RL}$-TO	-	3	3	3
45Hz, 2G, 1.0 V/m	8	8	9	9
RL-TO	1	1	1	1
$\overline{RL}$-TO	2	1	2	1
45Hz, 2G, 0.1 V/m	9	9	9	9
RL-TO	1	1	1	1
$\overline{RL}$-TO	2	1	2	4
45Hz, 2G, 100 V/m	15	10	16	15
RL-TO	1	1	1	1
$\overline{RL}$-TO	2	3	3	1
75Hz, 2G, 100 V/m	7	6	7	8
RL-TO	1	1	1	-
$\overline{RL}$-TO	2	1	2	2
75Hz, .13G, .07 V/m	8	8	9	10
45Hz, .2G, .06 V/m	6	5	6	6
45Hz, 2G, 0 V/m	4	4	4	4

CONDITIONED ACCELERATION

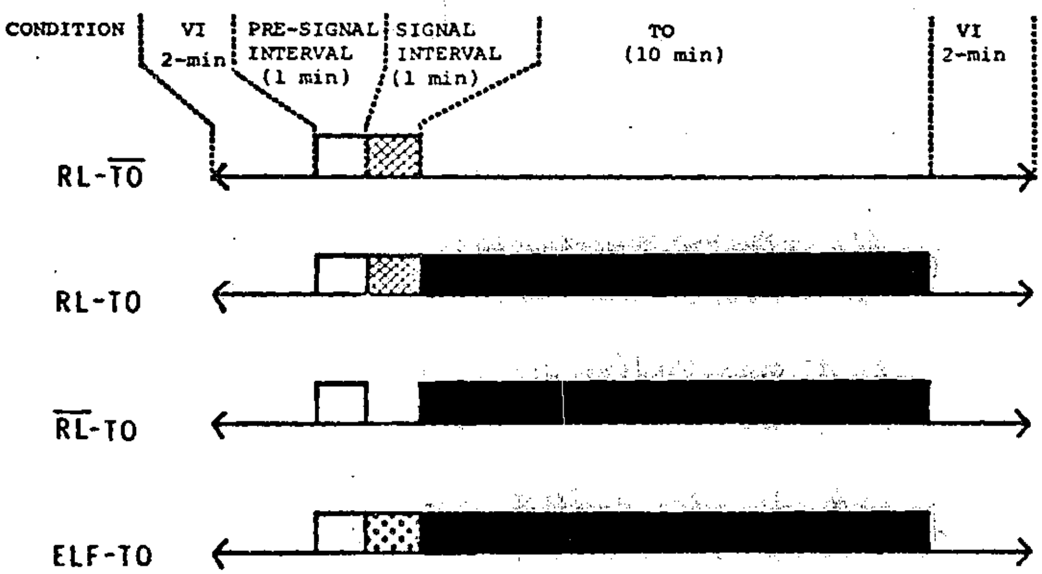

Figure 4. The Sequence of Events under the Conditioned Acceleration Procedure.

tion of a 10-min extinction period. Signalled by a green keylight, this extinction interval was served as time out from positive reinforcement (TO). During this TO, not only were keypecks not reinforced, but each keypeck that occurred reset the 10-min clock, thus delaying the onset of the white keylight and the availability of reinforcement. The green keylight therefore controlled a very low rate of responding. As responding increased over the baseline rate during the 1-min, pre-TO, keylight period, conditioned acceleration was established. The rate of responding in the 1-min interval prior to the onset of the red light was compared with the rate during the signal, and an acceleration ratio (rate during/ rate prior) was computed. Detection was defined as an acceleration ratio greater than one. The extent to which the subjects were able to detect the signal was manifested by the differences between the suppression ratio of the RL-TO condition and the response ratios of the other conditions.

The following five sessions were a no-red keylight TO condition ($\overline{\text{RL}}$-TO). By presenting an unsignalled TO on a VT 10-min schedule and dividing the response rate 1 min previous to the 1-min, pre-TO interval into the rate during the pre-TO interval, a rate ratio was computed for comparison against the signal TO conditions. This control condition assessed the effect of the TO alone on performance.

Following the $\overline{\text{RL}}$-TO condition, an ELF signal was used as a pre-TO stimulus in the manner of the red keylight. This condition was called the ELF-TO condition and corresponds to the ELF-S condition in the conditioned suppression procedure. If an ELF were detectable, its use as a pre-TO stimulus should result in response acceleration. Detection of an ELF signal was operationally defined by a mean acceleration ratio falling outside the 99% confidence interval around the mean acceleration ratio of the $\overline{\text{RL}}$-TO condition.

Several combinations of intensity and frequency were studied in an attempt to determine whether the subjects could detect the presence of the signal. Furthermore, RL-TO and $\overline{\text{RL}}$-TO sessions were interposed between field sessions. The field parameters explored for each subject and the number of sessions at each value were shown in Table 6.

CHAPTER III

RESULTS

Figure 5 shows the behavior of R-4 on the four conditions of the conditioned suppression experiment. The signal interval and the shock presentations are identified by the offset of the response pen. The downward pen deflection represents both the termination of the 1-min pre-signal interval and the initiation of the 1-min signal interval; the upward pen deflection represents both the end of the signal interval and the occurrence of the 0.5-sec shock presentation.

Suppression is clearly exemplified by the response decrements during the pre-shock signal intervals in the F-S condition. As evident in the record, the stable, moderate response rate typical of VI schedules was not disturbed in the $\overline{F}$-S of F-$\overline{S}$ controls. This lack of effect confirmed the initial neutrality of the flicker stimulus and indicated the ability of the subject to recover after nonsignalled shock. Upon comparison, the response during the field condition (ELF-S) is similar to that of the $\overline{F}$-S condition in that no baseline alteration is apparent. Failure of the field signal to produce suppression similar to that of the flicker signal in F-S attests that at the parameters and exposure times investigated, the ELF signals were not detectable by those subjects using these methods.

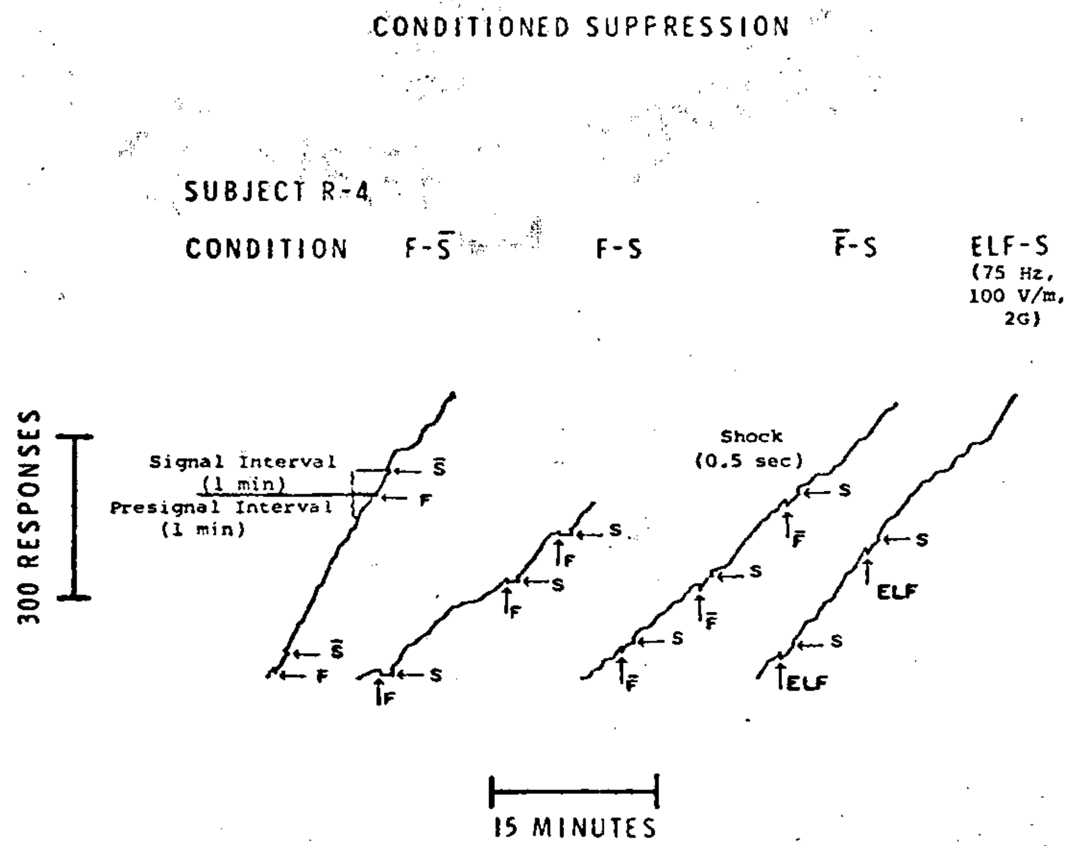

Figure 5. Behavior of R-4 on Four Conditions of the Conditioned Suppression Procedure. The Arrows Point to the Onset of the Events (F-Flicker, $\overline{F}$-No Flicker, S-Shock, and $\overline{S}$-No Shock).

In an attempt to reflect the dependency between the rate of baseline responding and the detection of a stimulus, rate ratios were calculated for each procedure. Each rate ratio compared the response rate during the 1-min interval previous to the stimulus presentation with the response rate during the 1-min stimulus interval.

For the suppression procedure, the response rate decreased during the presentation of a detectable stimulus followed by shock. By dividing the rate of responding during the 1-min pre-shock signal by the rate of responding during the 1-min interval preceding the onset of the signal, a rate ratio of less than unity would result if the stimulus were not detected. Thus detection of a stimulus under the conditioned suppression procedure can be represented as follows:

$$\text{DETECTION} \quad \frac{\text{RATE OF RESPONDING DURING THE 1-MIN, PRE-SHOCK SIGNAL}}{\text{RATE OF RESPONDING 1-MIN PREVIOUS TO THE ONSET OF THE SIGNAL}} < 1$$

$$\text{NO DETECTION} \quad \frac{\text{RATE OF RESPONDING DURING THE 1-MIN, PRE-SHOCK SIGNAL}}{\text{RATE OF RESPONDING 1-MIN PREVIOUS TO THE ONSET OF THE SIGNAL}} = 1$$

Rate ratios were calculated by two general methods, one by sessions and the other by trials. The session method consisted of accumulating the total number of responses made during all the stimulus presentation intervals for the entire session and dividing this sum by the total stimulus presentation time for the entire session, resulting in a conservative estimate of the rate of responding during the pre-shock signal interval. This estimate was divided by the rate of responding during the 1-min interval previous to the onset of the signal, which had been calculated in a similar manner using the total number of responses accumulated over the entire session. This ratio was called the rate ratio by sessions and proved to be a reliable measure.

The trial method consisted of calculating a rate ratio for each individual stimulus presentation trial during the session and computing the mean rate ratio by trials over the entire session. This measure proved to be too variable to be of any use.

The results for the conditioned suppression procedure are shown in Figure 6. The figure shows the mean rate ratio per session for each subject under each condition enclosed by the 99% confidence interval. When a flashing light (F) was used as a pre-shock stimulus, the rate during that stimulus decreased by at least 50%, and in the case of R-4, over 80%. When no pre-shock stimulus was used ($\overline{F}$), the rate ratio remained near unity, i.e., no rate change occurred. Such was the case for all of the field conditions, indicating that at the field parameters and

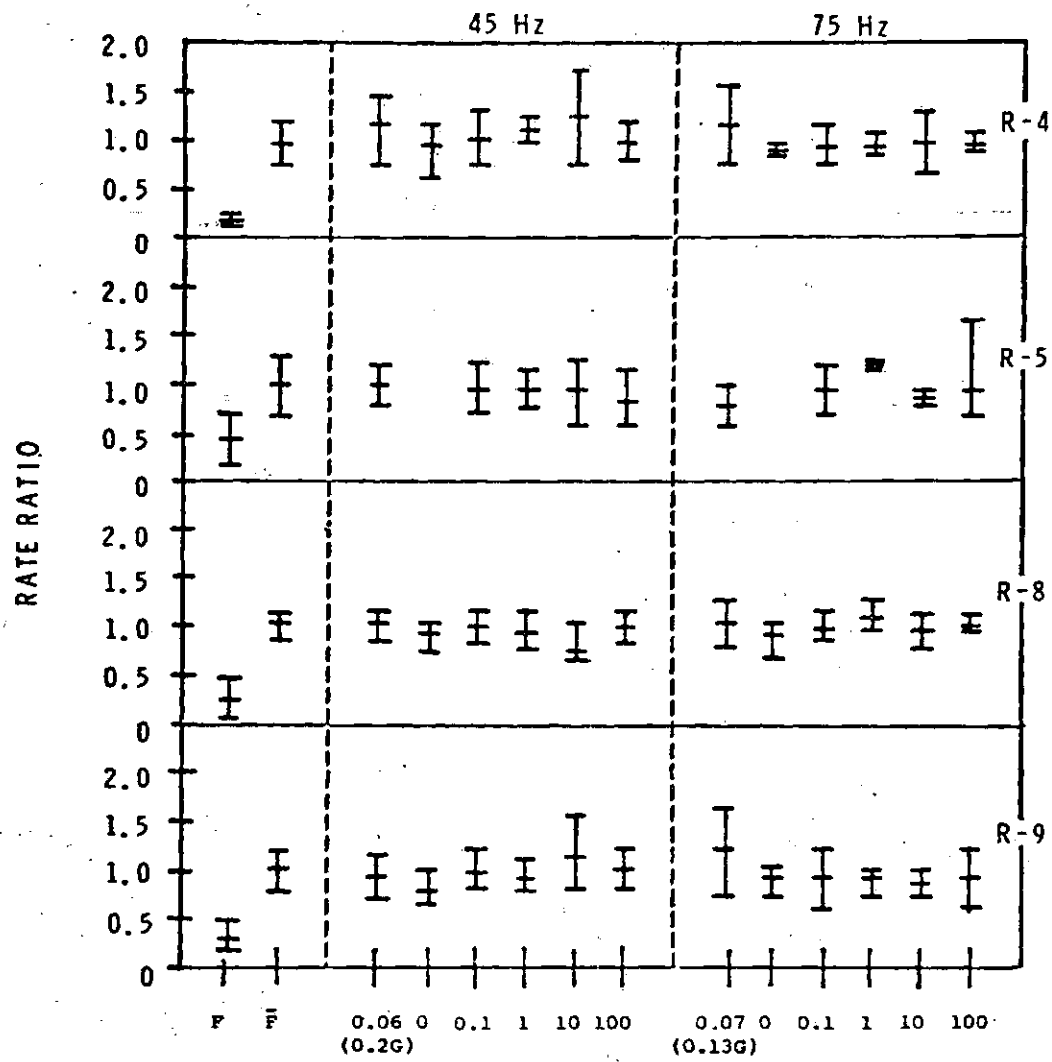

Figure 6. The Mean (± 99% Confidence Interval) Rate Ratio Per Session under Each Experimental and Control Condition for R-4, R-5, R-8, and R-9.

exposure times investigated, the ELF signals were not detectable by those subjects using those methods.

Figure 7 reveals the behavior of P-237 on the four conditions of the conditioned acceleration procedure. As in Figure 5, stepping pen deflections identify the signal interval when the stimulus is present (RL) or absent ($\overline{RL}$). The upward deflection, however, now represents the initiation of the 10-min TO period. Very few, if any, responses occurred during the TO (green keylight) interval. Similar to the conditioned suppression controls, the red keylight did not alter performance when presented without the TO ($\overline{TO}$). Thus the signal had no control on behavior before the conditioning procedure was initiated. Acceleration is clearly evident on RL-TO as responding markedly increases during the red keylight interval. Performance during field conditions was as undisturbed as during $\overline{RL}$-TO conditions. This lack of effect during the ELF-TO conditions signifies the inability of the ELF field (45 Hz, 10 V/m, 2 G) to control an increase in responding.

The conditioned acceleration response ratios were computed by dividing the rate of responding during the 1-min, pre-TO signal interval by the rate of responding during the 1-min interval previous to the signal presentation. For the acceleration procedure, however, the response rate increased during the pre-TO signal if the signal was detected. In this case, a ratio greater than unity would result if the signal was not detected. Thus detection of a stimulus under the conditioned

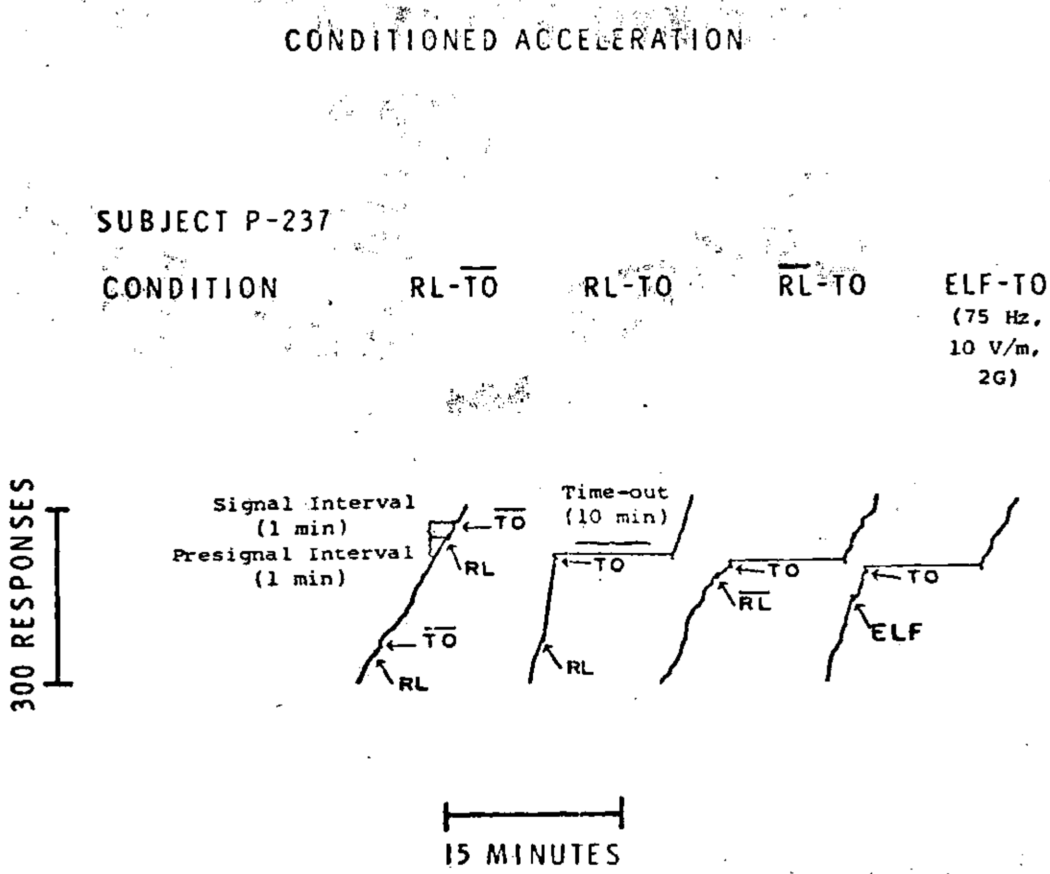

Figure 7. Behavior of P-237 on Four Conditions of the Conditioned Acceleration Procedure. The Arrows Point to the Onset of the Events (RL-Red Light, $\overline{RL}$-No Red Light, TO-Time-Out, and $\overline{TO}$-No Time-Out).

acceleration procedure can be represented as follows:

$$\text{DETECTION} \quad \frac{\text{RATE OF RESPONDING DURING THE 1-MIN, PRE-TO SIGNAL}}{\text{RATE OF RESPONDING 1-MIN PREVIOUS TO THE ONSET OF THE SIGNAL}} > 1$$

$$\text{NO DETECTION} \quad \frac{\text{RATE OF RESPONDING DURING THE 1-MIN, PRE-TO SIGNAL}}{\text{RATE OF RESPONDING 1-MIN PREVIOUS TO THE ONSET OF THE SIGNAL}} = 1$$

Rate ratios were calculated by sessions and by trials. Again the only rate ratio by sessions was reliable enough to use.

Figure 8 shows mean rate ratios per session enclosed by the 99% confidence interval. Using a red keylight (RL) as a pre-TO signal resulted in an average rate increase of 50%. When TO was unsignalled, $\overline{\text{RL}}$, the rate ratio remained near unity, i.e., no acceleration occurred. No reliable indications of acceleration for any subject occurred when an ELF signal preceded TO, indicating that at the parameter values and exposure times studied, these signals were undetected using these methods.

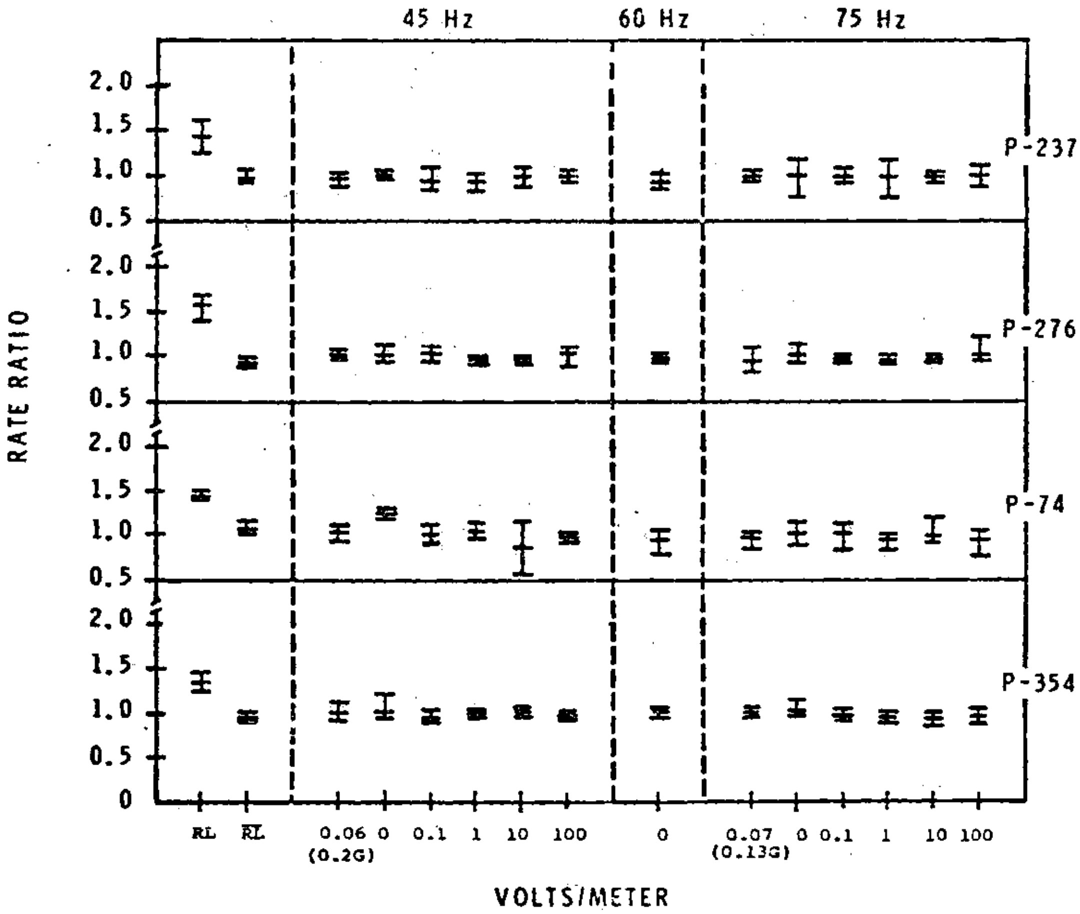

Figure 8. The Mean (± 99% Confidence Interval) Rate Ratio under Each Experimental and Control Condition for P-237, P-276, P-74, and P-354.

CHAPTER IV

CONCLUSIONS

No reliable effects of ELF electromagnetic fields at 45, 60, and 75 Hz, 0.13-2.0 G, and 0 to 100 V/m were found. These results suggest that these signals were undetected. The results do not imply, of course, that effects could not have been shown using other baselines, longer exposures, more subjects, different species, or other field parameters.

It should be noted that to prove statistically that detection did not occur is to prove the null hypothesis, which is logically impossible. Any study of this nature involves some risk taking. A desirable design should be one that procures favorable odds for a detection. This study did so by utilizing the following:

1. Three frequencies within the range of interest.
2. A series of intensities within the range of interest.
3. Subjects whose behavioral histories were familiar and manipulable.
4. Reliable and sensitive procedures.

Given the above provisions, however, by no means may one conclude that ELF electromagnetic radiation has been adequately investigated. This inadequacy becomes more apparent as one compares possible detection within the ELF spectrum with known detection within the visible light spectrum. Before doing so, it should be noted that this may be an unfair comparison in many ways due to the physical differences in these spectrums. The 300-Hz frequency range is much smaller than the 5×10^{14}-Hz frequency range of visible light. The wavelengths differ proportionally in that visible light wavelengths range from 400 nm (one-millionth of a meter) to 700 nm, and ELF wavelengths range from 10^6 to 10^7 meters. In any case, according to Day (1969) the human observer can discriminate 128 colors when wavelength alone is varied. More important, however, is that he can discriminate between about 7,500,000 different colors when intensity, wavelength, and purity of light reaching the eye are varied conjointly. The potential for detection within the ELF spectrum should indeed be similarly related to frequency, intensity, and purity combinations.

Exposure effects should also be considered. The effects of high-energy ionizing radiation are inversely proportional to the length of their exposure durations. With the high-energy radiation-exposure intervals being as short as a few sec, ELF radiation might require many years for effects to occur.

The conclusions that one can draw from these data are limited by the number and species of the subjects used as well as the parameters investigated. A larger sample might have increased the probability of discovering a subject sensitive to the fields. Electric and microwave field studies reviewed earlier demonstrated the possibility that only a select sample of humans may be sensitive to auditory effects (Frey, 1963, 1965; Wieske, 1963). Other studies have clearly demonstrated that some species are more sensitive to electric fields. According to Presman (1970) some fish with electric organs can react to electric field pulses of very low strength (1×10^{-6} V/m). Electrosensitivity in fish seems to be a type of species-specific behavior, a process which may have no analog in other species, as is the case with other kinds of reception in animals, such as the perception of ultraviolet rays by the bee or infrared rays by the snake. ELF perception may be similarly species-specific.

The lack of observable ELF effects in the present study agrees with most of the previous findings reviewed in Chapter I. The nature of an effect, however, no doubt depends on the kind of animal, the type of higher nervous activity, the parameters of the acting electromagnetic field, and the exposure conditions. Since there are innumerable possibilities for these characteristics to be varied, the results of different studies cannot readily be related to each other.

Presently available data provide no suggestion of distinct effects on humans or on populations of other higher animals in ELF fields. However, subtle effects of ELF fields in individual organisms have been demonstrated for example by Gavalas et al. (1970) and Persinger and Foster (1970) and Reille (1968). These experimenters are working under the assumption that if the natural magnetic field is of significance to behavior, then one must postulate that organisms possess an organ capable of acting as a direct magnetometer, since field strengths and variations are of such low values that induced currents are negligible.

Traditionally the auditory and visual systems have been distinguished in part by the belief that the two systems respond to different types of energy, acoustic and electromagnetic, respectively. Frey's work (1963, 1965) not only indicates that the human auditory system can respond to electromagnetic energy, in at least a portion of the radio frequency spectrum, but also suggests a possible magnetometer.

A second possibility is that organisms might be sensitive to ELF fields without possessing a sole receptor system responsible for receiving electromagnetic radiation, converting it, and transmitting it on to an efferent system. The behavior under the influence of ELF low-energy fields may well be a result of a slow-acting, generalized body response--one which is not detected at one specific physiological location or by one specific mechanism.

This is conducive to Brown's external timer hypothesis for biological clocks. From his studies with plants and lower animals, Brown (1970) concludes that the orientation of the animals normally includes a true response to the earth's magnetic field and proposes that every cell of the body contains the perceptive capacity for magnetic fields.

A third possibility proposed by this author is as follows: ELF fields may affect higher animals through synaptic modifications which would change nerve cell excitabilities throughout the central nervous system. The effects of exposure to ELF radiation would be similar to those observed in many higher animals, including man, under the influence of alcohol and barbituates. Many animals can be trained while not drugged to perform a response different from the one learned while drugged (e.g., left turn in a maze instead of right turn). After training, the response performed will depend upon the state of the organism. Thus many learned behaviors can be conditioned to the drug-state during acquisition. Such behaviors are said to be state-dependent and exemplify dissociated learning. In a recent review of the literature, Overton (1971) has described state-dependent learning as a general phenomenon that occurs in a variety of tasks, in a variety of animals, including man, and is produced by many centrally acting drugs like barbituates and curare. Most relevant to the ELF-field literature is that sensory cues do not appear to be involved in dissociated learning, that it appears to be totally a central nervous system response to the drug. One mechanism explained by Overton not only provides a good example of how dissociated learning could conceivably be produced but also suggests how an ELF effect might occur. Overton describes a model originally proposed by Girden in 1940. Girden postulated that learning takes place in the cortex and that subcortical regions retain the ability to be conditioned. Under normal (undrugged) conditions these regions are inhibited by the neocortex, but under drugged conditions the cortex is inactivated, cortical inhibition disappears, and subcortical structures are allowed to acquire the conditioned response. Response learned under the drug, however, is dissociated and can be performed only while the animal is drugged. Without the drug the cortex suppresses the subcortical regions. Meanwhile, a different response to the same stimulus may be acquired by the cortex under undrugged conditions, and this response will be observed unless the animal is drugged, at which time the subcortical response will reappear.

The author admits that the only support for his proposal that a similar mechanism might result under ELF exposure is a number of physiological studies described by Presman (1970). After examining EEG records from a variety of animals, some experimenters report a recurring main reaction and a secondary reaction that are similar to the changes which are observed during sleep and anesthesia. From these studies, Presman concluded that radio-frequency electromagnetic radiation of athermal power densities may have an inhibiting effect on brain structures. Additional supporting evidence can be found in studies on electroanesthesia recently reviewed by Herin (1968). Electroanesthesia is anesthesia produced by applying 1-mA to 10-mA, 1-Hz to 10-kHz currents to the nervous system. Persinger et al. (1973) reported that the anesthesia induced by transtemporal electric currents can be potentiated by 5-Hz pulses and that 0.1-Hz pulses more readily potentiated the effect than 10-Hz or 100-Hz pulses.

It is clear that the identification of those variables or combinations of variables which determine the occurrence of behavioral effects of ELF fields requires and merits much more research. The future of this field of study, however, depends upon the type of research. What is needed is well-planned and well-reported experimentation by patient, dedicated scientists. The use of unsystematic, unspecified field conditions along with unreported or nonexistent measurement techniques and experimental procedures, will be of doubtful value in the advancement of this area of research. The absence of profound psychological hazards in the literature so far should not limit the interest in this field to those searching for exciting and rapid developments. Lastly, there is a need for more correlational studies between environmental, geophysical parameters and life processes as a source of stimulation and guidance for future experimental exploratory studies.

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