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Avoidance by Rats of Illumination with Low Power Nonionizing Electromagnetic Energy

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Rats spent more time in the halves of shuttle boxes that were shielded from illumination by 1.2 GHz microwave energy than in the unshielded. In Experiment 1, rats avoided the energy when it was presented as 30-μsec pulses with a pulse repetition rate of 100 pulses per second (pps). The average power density was about .6 mW/cm^2, and the peak power density was about 200 mW/cm^2. In Experiment 2, the energy was presented both continuously and in pulse-modulated form, i.e., .5-msec exponentially decaying pulses at a rate of 1,000 pps. The average power density of the continuous energy was 2.4 mW/cm^2, and the average power density of the pulse-modulated energy was .2 mW/cm^2. The peak power density of the modulated energy was 2.1 mW/cm^2. The rats avoided the pulsed energy, but not the continuous energy.

Human beings, cats, and rats perceive low power density pulse-modulated nonionizing electromagnetic energy (Frey, 1961, 1971; Frey & Messenger, 1973; Guy, in press; King, Justesen, Clarke, 1971). When human subjects are illuminated, they report that they "hear" buzzes, hisses, and other sounds, even though the energy transmitted is not acoustic but instead is electromagnetic (EM).

The EM energy spectrum encompasses the wavelengths from 3×10^7 m to .003 Å. The energy can propagate through a vacuum and, to varying degrees, through a number of media such as air and water. The very short wavelength EM energy is ionizing. The longer wavelength energy used in these studies is not ionizing; it occupies the radio frequency (RF) portion of the EM spectrum. The RF portion of the spectrum encompasses frequencies between 10^3 and 10^{11} Hz (wavelengths between 3×10^5 m and 3×10^{-3} m) and includes the energy broadcast by radio, radar, and microwave systems.

Electromagnetic energy is generated through a change in the state of motion of an electron, such change being accompanied by the emission or absorption of EM energy. The wavelength of the emitted EM energy is inversely proportional to the magnitude of the energy change. EM energy, for example, is emitted when electrons are caused to move to and fro along a conductor such as a radiotransmitting antenna. Visible light is an example of EM energy and is generated as electrons change energy level in moving from one orbit to another in atoms. Since cellular processes are electrochemical reactions that involve the movement of electrons, they are also associated with emission or absorption of EM energy (Fraser & Frey, 1968).

Propagating electromagnetic waves vary in space and time. The physically varying quantity is really a set of quantities: electric and magnetic field vectors. These are an electric field in space, defined by the force that is exerted on an electric charge placed in the field and a magnetic field in space, defined by the force exerted upon a small electric element. These vary at any point with time, but are not independent entities. They are perpendicular to each other, and they are both perpendicular to the direction of propagation. The energy can be polarized horizontally, vertically, or circularly, and the orientation of an illuminated object in the field, be it a mass of tissue or length of wire, affects the amount of energy absorbed. The energy that illuminates an object is scattered and absorbed by that object with the

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amount of energy absorbed being a complex function of many factors, such as the wavelength of the energy, size of the object, and electrical characteristics of the object.

One can illuminate biological objects with EM energy in what could be called the typical mode, i.e., in the free-field, far-field situation. This is essentially the exposure we get from the energy emitted by TV and radio stations. By free field, we mean that the energy propagates through space without significant reflection back upon the subject of interest. By far field, we mean that the subject is more than several wavelengths from the antenna so his exposure to the energy is where the EM energy is more or less organized and evenly distributed as it moves through space. One can also set up special situations such as a multimode cavity, e.g., a microwave oven, in which the energy exposure is quite different from free-field, far-field exposure. Details on multimode cavities can be found in a report by Justesen, Levinson, Clark, and King (1971).

Electromagnetic energy can be emitted continuously, or it can be modulated in various ways, e.g., sine wave, pulse, etc. This is significant from the biological standpoint, both in terms of effect obtained and in terms of measurement of the energy that illuminates the object of interest. For example, photic driving occurs with properly pulsed modulated light, but not with continuous light. Also, if the energy is modulated, then the average amount of energy in the field is less than the value of peak energy.

Typically the energy is measured in terms of average power density, i.e., mW/cm^2. Measurement of this energy is a difficult problem, because any object introduced into the energy field constitutes a discontinuity that results in errors of measurement. Directional effects, focusing effects, occurrence of spurious frequency modes, and other factors combine to make energy measurement in the free field difficult. Further, the processes by which tissues are affected by EM energy are not fully understood. These matters are discussed more fully elsewhere (Frey, 1965, 1971).

Analytical reviews (Frey, 1971; Presman, 1970) of the biophysical response to EM energy illumination suggest that data on the RF hearing phenomena and other reported effects have implications for improving our understanding of transfer and storage of information in the nervous system. Yet no behavioral studies with animals in the free field have been reported with sufficient data to allow an evaluation of sensory and possible motivational properties. The few behavioral experiments that do provide adequate information on the parameters of energy exposure, e.g., King, Justesen, and Clark (1971), were done with rats in a multimode cavity. The marked differences between cavity and free-field exposures dictate caution in attempting to generalize between them. But we can note that in the former, evidence of perception of low densities of microwave energy by appetitively motivated rats did not appear. In the latter study, rats under aversive motivation readily discriminated the energy. Although the authors interpreted the discrepancy in terms of a presumed low saliency of the microwave stimulus, it is just as feasible to postulate that the stimulus of the microwave energy was itself aversive.

Prior work and a pilot study by us suggested that rats might perceive and avoid pulse-modulated energy in a shuttle box situation. The experiments reported here were designed to determine whether pulsed microwave energy illumination has reliable motivational properties at low average power densities.

Method

Experiment 1

The source of energy was a pulsed microwave triode generator adapted for our experimental work. The energy was conveyed by a Model 874 General Radio Co. air line and RG-8 cable to a model 11-1.1 Scientific Atlanta coaxial-to-waveguide adaptor and standard gain horn antenna. (Slayton, 1955). The antenna emitted the energy into an RF anechoic chamber that was constructed of Eccosorb FR-340 absorbing material that minimized spurious reflections so as to create an essentially free-field condition. The frequency of the energy was 1.2 GHz, the pulse width was 30 μsec, and the repetition rate was 100 pulses per second (pps). The emitted energy was horizontally polarized.

Energy densities were measured before and af-

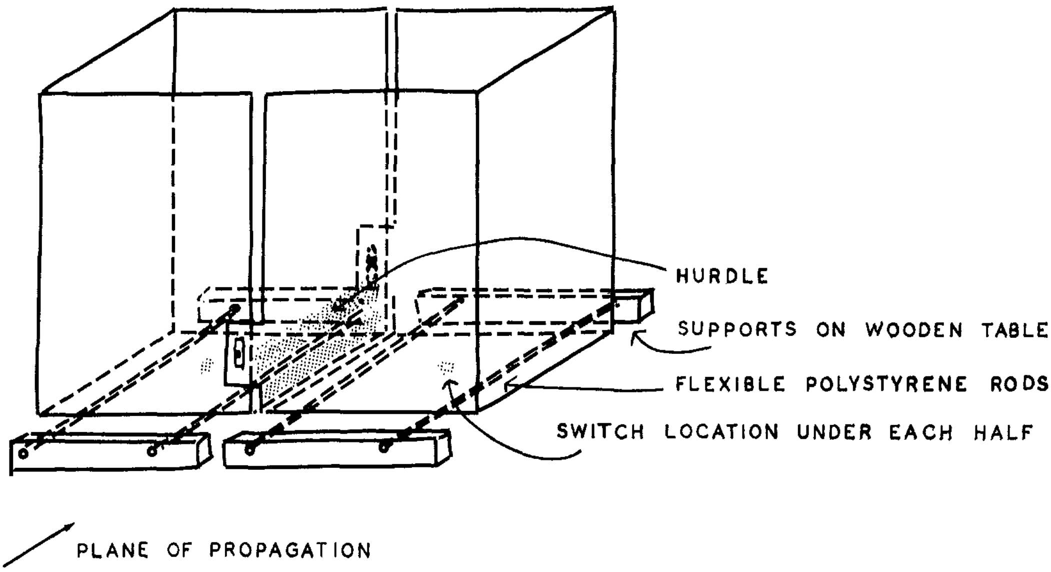

FIGURE 1. Shuttle boxes used in Experiment 1. (Each half was 22 × 21 × 30 cm. high. Two horizontal polystyrene rods near the top supported a perforated acrylic lid on each half.)

ter each session within each half of a shuttle box by a half-wave dipole antenna located 6 cm above the floor of the box. The dipole was connected by an RG-58 coaxial cable to a Microlab Model AF-20 attenuator that was located outside of the chamber. The cable within the chamber was oriented for minimum field perturbation during measurement. The attenuator was connected to a Hewlett-Packard Model 477B thermister mount and then to a Hewlett-Packard 430C power meter.

Shuttle boxes were designed for use in a microwave energy field. In Experiment 1, two boxes (see Figure 1) were constructed of acrylic, since this plastic has been used frequently to expose animals to RF energy and, if well oriented, has little effect on an EM field. The two halves of each shuttle box were independently suspended on .2-cm-diam. flexible polystyrene rods. Each half measured 22 × 21 × 30 cm. The two halves were loosely connected on each side by a nylon bolt and nut which could slide in a vertical slot. Between the halves was a 6-cm-high acrylic hurdle, on the top of which was mounted a phenolic roller to keep the animals from standing on the hurdle. The sides and top of the box were perforated by .6-cm-diam. holes spaced 6 cm apart to allow for circulation of air. Two polystyrene rods supported each perforated acrylic lid, and a third rod on top secured the lid. A shield of Eccosorb material was placed between the emitting antenna and one half of each shuttle box. Optically opaque paper was attached to both halves of the box on the side toward the antenna so that the subject could not see the shield. A mercury switch, 1.3 cm × .6 cm, was attached to the underside of each half of each box to register the subject's location on an Esterline Angus event recorder. The switches were carefully oriented to minimize interactions with the RF field. Each switch activated a pen on the recorder so that a continuous record of the rat's location within a shuttle box was obtained.

The horn antenna's field pattern was sufficiently broad to permit two shuttle boxes to be illuminated simultaneously. The boxes were mounted on wooden tables for minimum disturbance of the field and were located in the far-field region of the RF anechoic chamber. The right half of Box A and the left half of Box B were shielded from the RF energy to control for a possible side preference by subjects. The average power density of the energy that illuminated the unshielded half of Box A was measured at .4 mW/cm^2; the peak power density was 133 mW/cm^2. The measured average power density of the energy in the shielded half of Box A was 2% of that in the unshielded half. The unshielded half of Box B was exposed to .9 mW/cm^2 average power density and 300 mW/cm^2 peak power density. The shielded half of Box B was exposed to 7% of the unshielded level.

Eight experimentally naive male Sprague-Dawley rats, approximately 125 days old and weighing approximately 250 g at the start of the experiment, were used. They were housed in plastic cages and had free access to food and water. The day/night cycle (12:12) was reversed. The animals were frequently handled by an experimenter for a minimum of a week after being obtained and were habituated to the home cages and shuttle boxes. A small amount of litter of the type used in the home cages was used in the shuttle boxes and was changed at the end of each animal's habituation session. At the end of the period of familiarization, animals were randomly assigned either to the experimental group (illumination by pulsed energy) or to the control group (sham illumination).

Testing was carried out in the RF anechoic chamber under dim lighting so that the animals would be active. Each animal had seven 90-min test sessions in the RF anechoic chamber. The assignment to one of the two shuttle boxes and the order and time of day of exposing each animal were randomized. Prior to each day's sessions, all equipment was turned on, tested, and adjusted. A rheostat on the energy source was turned up to emit RF energy into the anechoic chamber when the animals in the chamber were from the illuminated group. When controls (sham-illuminated animals) were used, the rheostat on the energy source was not turned up, and no energy was emitted into the RF anechoic chamber. Temperature readings were taken several times each day inside the shuttle boxes; they neither deviated from the normal room temperatures (approximately 22° C) found elsewhere in the laboratory, nor did they deviate in association with experimental and control conditions.

Experiment 2

The design of the shuttle box and the parameters of illumination were changed to permit the gathering of additional information. A new shuttle box was constructed of white polystyrene sheet which minimizes residual reflections of incident EM energy insofar as it is possible with practical materials. We also changed the suspension of the box so that the bottom was a single sheet of polystyrene balanced as a seesaw on a 2-cm-high wooden wedge which permitted limited travel (1 cm). The mercury switches were replaced with microswitches, one at each end of the box. Only one box was used in the chamber, and the shielding was varied randomly from side to side. The source of energy was a Microdot Model 411A power oscillator that was connected directly to the RG-8 cable. The oscillator permitted us to use three exposure conditions: pulsed illumination, continuous illumination (CW), and sham illumination.

The pulsed-illumination group was exposed to a peak power density of 2.1 mW/cm^2 and to an average power density of .2 mW/cm^2. The CW group was illuminated with an energy level of 2.4 mW/cm^2. Peak power was estimated by measurement of oscilloscope waveforms and was verified by extrapolation from measurements of average power. Each .5-msec pulse had a 1.0-μsec rise time and then decayed exponentially to less than 1/3 of the peak amplitude. Several experiments have indicated that rise time may be critical and that decay time is not (Frey & Messenger, 1973; Frey, unpublished data, 1965). The pulse repetition rate was 1,000 pps.

Each of 18 female Sprague-Dawley rats was randomly assigned to one of the three exposure groups. There were four exposure sessions for each animal, and each session was 30 min in duration. Order of exposing subjects and the side of the shuttle box that was shielded during each session were randomized.

Results

During Experiment 1, most of the animal's activity occurred during the first 30 min in the shuttle boxes. Thus, in Experiment 2, the length of the test sessions was 30 min.

The first 30 min of data were evaluated by use of the Mann-Whitney U test. In Experiment 1, the animals in the pulse-illuminated group averaged 29% of their time in the unshielded half of the shuttle box compared with 57% for rats of the sham-illuminated group. The difference is significant ($U = 0$, $p = .014$). An aversive effect was apparent within 15 min, since the respective proportions of time spent in the illuminated side within the first 15 min were 32% and 54% for experimental and control groups, respectively ($U = 1$, $p = .029$). The effect was consistent over 7 days of testing, and the animals responded similarly in Boxes A and B, even though the boxes' unshielded halves differed in the amount of energy that illuminated them.

The mean number of hurdle crossings was seven per session for experimental subjects and 15 for controls ($U = 0$, $p = .014$). Fecal boluses were counted in each half of each box after each session as crude measure of emotionality. When the time spent in each half of the box was taken into account, the two groups did not differ. There were no significant differences between groups on means of final weight or amounts of weight gained.

In Experiment 2, the power density was reduced to what we believed would be near threshold levels. Three groups were used: pulse illuminated, CW illuminated, and sham illuminated. We expected that avoidance would not appear as soon as it did with the higher power levels used in Experiment 1. This may be noted by comparing the three exposure groups during the first two sessions and comparing them again during the last two sessions of the four-session sequence. The data for the first two of the four sessions show that the pulse-illuminated group, the continuous-illuminated group, and the sham-illuminated group of animals averaged, respectively, 60%, 64%, and 58% of their time in the unshielded half of the shuttle box. The differences are not significant (pulse vs. CW: $U = 15$, $p > .05$; pulse vs. sham: $U = 18$, $p > .05$; sham vs. CW: $U = 18$, $p > .05$). In contrast, the data for the last two sessions show that the pulse-illuminated group, the CW-illuminated group, and the sham-illuminated group of animals averaged, respectively, 30%, 64%, and 52% of their time in the unshielded half of the shuttle box. The difference between the pulse and CW groups is significant ($U = 4$, $p = .013$) as is the difference between the pulse and sham groups ($U = 4$, $p = .013$). There was no significant difference between the CW and sham groups ($U = 13$, $p > .05$). A Wilcoxon matched-pairs signed-ranks test showed that the slight difference between the means of the first two and last two sessions of the sham-illuminated group was not significant.

Discussion

The data reveal that rats tend to avoid low-intensity pulse-modulated EM energy in the free field. The data obtained in Experiment 1 suggest that less than 130 mW/cm^2 peak power density and less than .4 mW/cm^2 average power density are needed to produce aversion. The data of Experiment 2 indicate that energy at 2.1 mW/cm^2 peak and .2 mW/cm^2 average power density is also avoided and may be approaching a perceptual or motivational threshold. Continuous illumination did not appear to influence the shuttle box behavior of the animals, even though the average power density was higher than that avoided by pulse-illuminated subjects.

It was noted in the introduction that King et al. (1971) used the special situation of the multimode cavity with rats. They found conditioning of suppression to energy exposure, but were not able to produce an appetitively motivated discrimination in the rat. Frey (1965) reports avoidance conditioning of the cat in the free field with this energy. With the data reported here on avoidance of illumination by rats, the possible relationship between free-field illumination and cavity exposure would seem to be worth exploring. Determination of the reason for the effectiveness of this energy in the avoidance situation but not in the appetitive situation may be of considerable significance. The results we report here that show avoidance of the energy under several different exposure conditions provide a means to approach the question of the mechanism of RF energy's effect on behavior and the biophysical basis for the behavior. Frey, Feld, and Frey (in press), using this approach found, with the energy parameters described in Experiment 2, that pulsed energy significantly affected fluorescent dye-protein complex penetrability of the brain barriers of the diencephalon, whereas CW energy only slightly affected penetration. Thus, we have correlated findings at the physiological and behavioral levels of observation. Such approaches may well lead to an identification of mechanism.

There are many possible mechanisms for RF energy effects on the nervous system and behavior (Frey, 1971). The writers would hesitate to go beyond the foregoing suggestion of association in speculating on mechanisms. We would rather minimize speculation and emphasize that we provide here a verified behavioral approach to the question of mechanism.

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