Thermographic and Behavioral Studies of Rats in the Near Field of 918-MHz Radiations

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Abstract—**Patterns of thermalized energy of rat carcasses exposed to 918-MHz CW radiation in the near zone have been determined using a computerized thermograph. Peak absorption of energy in the body was estimated to be 0.9 W/kg per mW/cm^2 of incident energy. Operant responses of irradiated rats to schedules of fixed-ratio (food) reinforcement under the same conditions as the dosimetric test were observed to occur at averaged power densities of 30–40 mW/cm^2. This range of densities corresponds to absorbed peaks of energy of 27–36 W/kg. No change in behavior was observed for incident power densities and peaks of absorbed energy to 20–30 mW/cm^2 and to 18–27 W/kg, respectively, and all changes at higher values were reversible.**

INTRODUCTION

THE ABUNDANT literature on biological effects of microwave radiation divides into two categories, one pertaining to well-defined thermal effects on living tissues at averaged power densities of radiation above 100 mW/cm^2, the other pertaining to "nonthermal" or "low-level" effects of CW or pulsed energy, usually at densities below 20 mW/cm^2. The effects at high densities are probably related to thermalization of tissues by absorbed microwave energy but concurrent nonthermal effects that might be masked or complexed by heating should not be ruled out. The mechanisms underlying low-level effects such as the RF hearing phenomenon [1] are unknown but probably are due to thermoelastic transduction. There are several reports [2]–[6], that confirm alteration of behaviors of small animals during or after exposure to low to moderate densities of microwave energy. Specifically, radiation has been found to facilitate the performance of rats in a Y maze [2], and to influence the spontaneous activity and emotionality of animals as well as their sensitivity to electroconvulsive shock [4]. A decrease in the frequency of bar pressing for food and lessened endurance as indicated by swimming tasks have also been found in irradiated animals [5]. In addition, birds have exhibited escape reactions when exposed to microwave fields [6]. Although these subtle behavioral changes may be produced by seemingly thermally insignificant fields, the lack of information on the spatial distribution of absorbed energy in the target animal makes a nonthermal interpretation somewhat suspect. Given fields of very low density (i.e., $< 500\ \mu$W/cm^2), there is still the possibility that concentrations of thermalized energy—"hot spots"—may conspire to produce thermal stimulation. For instance, it was demonstrated [7] that by granting the animals freedom of movement in a large, electrically shielded enclosure the behavioral changes observed at 0.1 mW/cm^2 averaged density of microwave energy were associated with peak absorptions of 140 W/kg in tissues of radiated animals. Thus free movement can seriously compromise control of exposure in a closed space or in the free field.

A specially designed apparatus that restricted the body movement of rats but permitted simultaneous exposure and monitoring of performances was assembled. Measures of incident and absorbed energy were made in an effort to determine levels that disrupt the operant behavior.

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EXPERIMENT

The subjects were 200 (± 25) gram female white rats (Sprague–Dawley). The animals were partially deprived of food until their body masses fell to 80 percent of those before deprivation. They were placed in a plastic body-movement restrainer and were then trained to perform a head-raising response for a food pellet. The criterion was 30 rapidly and regularly executed head movements for each food pellet (fixed ratio, or FR-30) during 30-min sessions. After stabilizing, the rats typically responded 2000 times during each session. Following measures of base-line performance, the animals were exposed to increasing levels of radiation while performance was monitored.

Behavior Task

The general arrangements for the behavioral test are shown in Fig. 1. The rat holder shown in Fig. 2 was designed to provide necessary restriction of body movement to facilitate determination of absorbed energy during experimentation while permitting sufficient movement of the animal's head and neck for collection of behavioral data. The holder is constructed of acrylic to reduce the amount of distortion of the incident microwave field. The spaced-bar construction provided adequate ventilation for control of the animal's surface temperature and permitted easy placement of the animal. After the first few sessions, the rats learned to position themselves in the holder by running into it and extending their heads through its opening. The holder

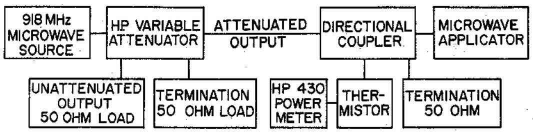

Fig. 1. Schematic of microwave exposure facilities for small animal behavioral investigation.

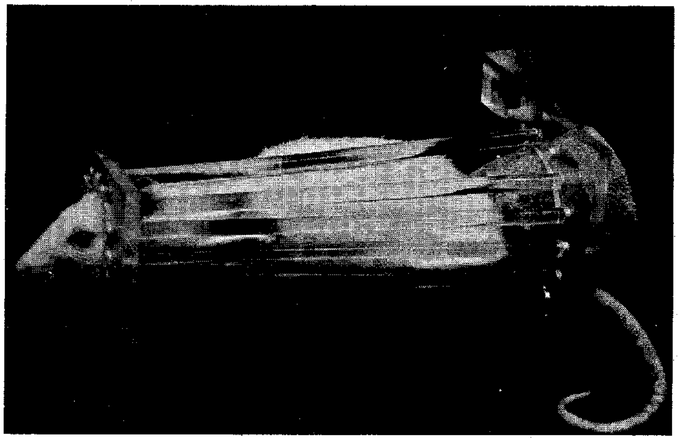

Fig. 2. Rat holder.

with the rat enclosed was then placed in a receiver as shown in Fig. 3. The holder and receiver were placed in a modified cooler chest that was lined with microwave absorbing material. In addition, a small fan attached to a wall at one end of the chest provided a forced flow of air to keep the environmental conditions within reasonable limits. The receiver positioned the rat in such a way that it allowed the rat to interrupt a light beam by moving its head in a short vertical arc. The small head movement, which interrupted the light beam, constituted the operant behavior. After 30 interruptions of the beam of light a switch closed leading to the delivery of food. An external feeder caused a small 45-mg food pellet to be delivered via a polyethylene tube to a receptacle, which was constructed of the same material as the holder, directly below the rat's head. The rat was able to eat the food pellet with only a slight downward movement of its head. This system provided a consistent means of investigating behavior that is adaptable to the special requirements of microwave radiation in the free field. Examples of baseline performances of animals in the apparatus are shown in Fig. 4. A slash on the cumulative records indicates that 30 head raises had been performed and that a food pellet had been delivered.

Exposure and Dosimetry

After base-line performances were established, the rats were exposed to four levels of 918-MHz radiation (0, 10, 20, and 40 mW/cm^2). The technique for exposing the animals is shown in Fig. 5. Microwave energy was emitted by a cavity-backed applicator with a square aperture. The maximum density of the radiated energy was directed toward the longitudinal midpoint of the rat's body. Immobilization of the tail was necessary to minimize a hot spot that developed near its point of attachment to the body and was observed during preliminary studies. The distance between the proximal surface of the animal's body and the radiator was 8 cm.

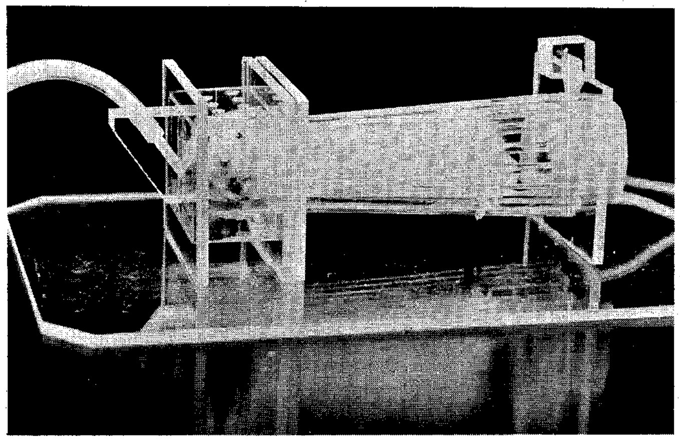

Fig. 3. Rat holder and receiver.

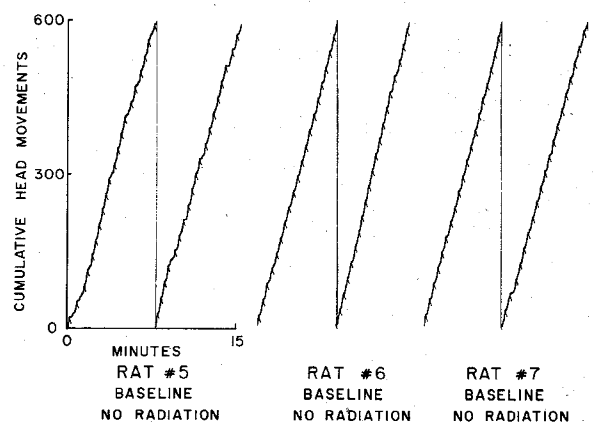

Fig. 4. Cumulative records of fixed-ratio performance of three animals during a pre-irradiation session.

Two principal methods were used for estimating absorbed energy: 1) the energy density at the same position as the axis of the rat's body inside the holder in the empty exposure chamber and directly under the center of the radiator was calibrated by a National Bureau of Standards electric energy density meter; 2) thermographic measurements were made of the patterns of thermalized energy in exposed rat carcasses as described previously [8]. The animal was killed by an overdose of Nembutal, was subsequently frozen in the holder, was cast in a polyfoam block, and was then dissected along with its holder. After return to room temperature, the reassembled rat carcass and the holder were then taken to the exposure chamber and were radiated for 30 s at high power (1500 mW/cm^2) under the same geometrical arrangement as during the session of behavioral testing. The thermographically recorded temperature patterns over the midsagital plane of the rat were processed digitally using a Honeywell DDP 516 computer to obtain isothermal contours. The tissue properties were assumed to be homogeneous and equal to that of muscle material.

The isothermal contours inside the rat along the midsagital plane are shown in Fig. 6. Observable peaks of absorbed energy occurred both in the body and in the tail. The peak absorption at the tail corresponds to 0.9 W/kg per 1 mW/cm^2 of incident energy while the value for the body is 0.8 W/kg. The position of the tail had considerable influence

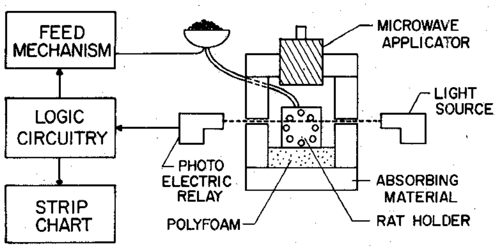

Fig. 5. Block diagram for irradiation of rats undergoing behavioral tests.

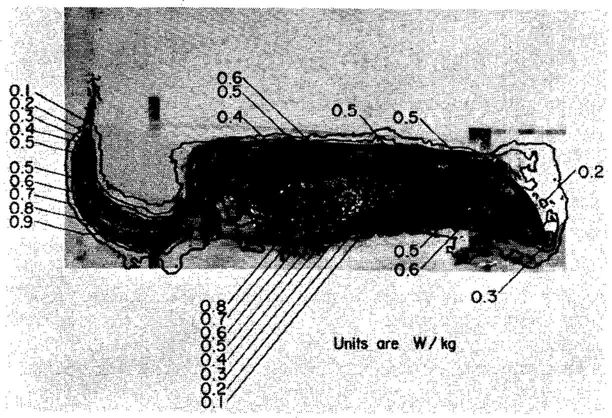

Fig. 6. Absorbed energy patterns (midsagittal plane) in a rat exposed to 918-MHz radiation at 8 cm; values are for 1 mW/cm^2 applied power.

on the absorbed energy. Prior dosimetric studies of phantom models of the rat indicated that absorbed energy at the base of the tail could increase by an order of magnitude when it was extended straight back [9]. Enhanced absorption was presumably due to an increase of current density that resulted from sharp changes in the cross-sectional area of the tail and a standing-wave maximum that resulted from resonance, since the rat model used in the previous study [9] was approximately one wavelength long.

Both visual inspection of cumulative records and measures of total responses across sessions revealed no noticeable effects of exposure until the incident energy power at densities of 40 mW/cm^2 was applied (Fig. 7). At this level the animal showed physiological changes, i.e., panting, fatigue, and foaming of the mouth, which are indicative of general hyperthermia (heat stress). Rat no. 5 was exposed during each of five consecutive days in order to observe gross cumulative effects of irradiation and to provide some control for unobserved sources of variability. Rat no. 6 was exposed on alternate days, Monday, Wednesday, and Friday. Rat no. 7 was sham-exposed. Recovery of the base-line performance for both exposed animals on the first day following exposure at 40 mW/cm^2 is readily observed in Fig. 7.

Another experiment in which the incident power densities were raised in 3-mW/cm^2 increments indicated a slight decrease in responding during exposures to densities of 32 mW/cm^2 (Fig. 8). The corresponding peak in the rate of absorbed energy was 29 W/kg. Immediately after irradiation, the rat exhibited symptoms similar to the rat exposed to densities of 40 mW/cm^2. As shown in Fig. 8, the deterioration of responding did not occur in this animal until 20 min after initiation of exposure. In contrast, the response of

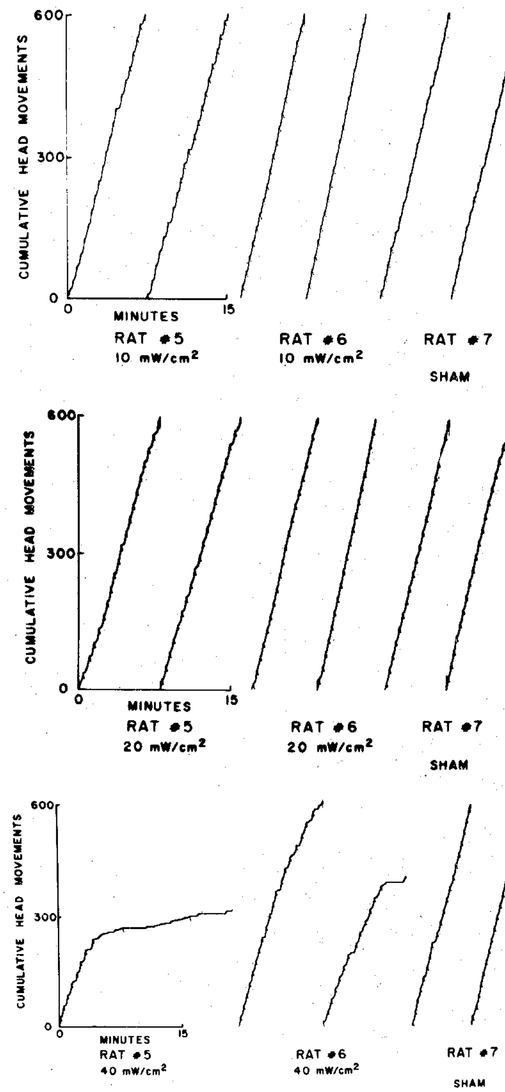

Fig. 7. Cumulative records of FR-30 responding during a microwave irradiation session.

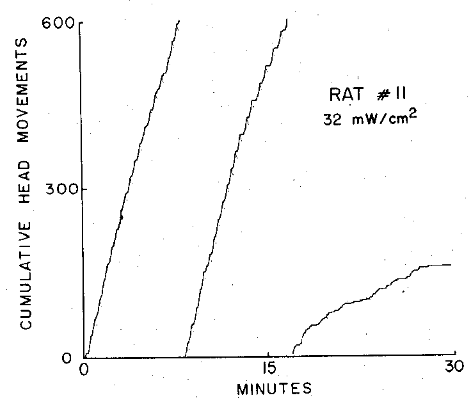

Fig. 8. Response record of a rat exposed to 32-mW/cm^2 indicent power density with a peak rate of absorbed energy of 28.8 W/kg.

animal no. 5 exposed to 40 mW/cm^2 decreased dramatically only 5 min into the period of irradiation. These data clearly point to a thermal loading mechanism of interaction.

Summary

These preliminary studies with reasonably accurate determinations of incident and absorbed energy suggest that incident CW microwaves at power densities of 20–30 mW/cm^2 and averaged rates of energy absorption in the body of 18–27 W/kg, after 30-min exposures, do not have significant effects on the fixed ratio behavior of the rat. Control performances one day after exposure to fairly high densities of energy (40 mW/cm^2) indicated that behavioral disruption, when occurring, is reversible.

It should be noted that the bodily dimensions of the rat should render it a resonant structure to 918 MHz of energy. Based on mass-equivalent muscle spheres, theoretical calculations show maximum peak absorption occurring in a body the size of a rat to have peak and averaged rates of absorbed energy equal to 0.85 and 0.21 W/kg, respectively, per 1 mW/cm^2 of incident energy. This indicates that energy at an incident power density of 40 mW/cm^2 is associated with a peak absorption of 34 W/kg and an averaged absorption of 8.4 W/kg. The measured peak-absorption rate for the rats exposed to 40 mW/cm^2 was 36 W/kg. The 8.4-W/kg rate of absorbed energy is particularly significant in light of the reported depressions in general activity of rats immediately following exposure to far-zone 2450-MHz microwaves that resulted in an average absorption rate of 8.0 W/kg [10].

It should also be mentioned that this study indicates that animals (at least the rat) can be trained to accept immobilization and nonetheless to perform well on an appetitively motivated operant task. Thus dose-determinate behavioral studies of the rat can take place in almost any kind of exposure environment if proper precautions are taken to habituate the animals to restraint.

Acknowledgment

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