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THE THERMAL BASIS FOR DISRUPTION OF OPERANT BEHAVIOR BY MICROWAVES IN THREE ANIMAL SPECIES

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THE THERMAL BASIS Fo. DISRUPTION OF OPERANT BEHAVIOR BY MICROWAVES IN THREE ANIMAL SPECIES

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Naval Medical Research and Development Command
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SUMMARY PAGE

THE PROBLEM

A large variety of microwave producing devices are used in contemporary naval communications and weapons systems. Public and scientific concern about potential biological effects of microwave irradiation such as produced by these various devices requires documentation of such effects. Currently, the only well documented direct effect of microwaves is heating of the exposed organism. The present report is of a series of studies whose aim was to explore several microwave frequencies and their effect on performance and simultaneously to investigate the relationship to core heating in the exposed animals. Three different sized species of animals were used so that generalization to larger animals could be made.

FINDINGS

Rats, squirrel monkeys, and rhesus monkeys showed consistent effects of 60-minute exposures to microwaves when their body temperatures were increased at least 1 °C above baseline temperatures. Performance was not reliably affected when body temperatures remained below this level. Greater intensities of microwaves were required to influence the animals' temperature and behavior as the animal size increased. A direct relationship between frequency and power density was observed in the rhesus monkey; e. g., as the frequency of the microwaves increased, the power density needed to affect behavior and temperature also increased.

ACKNOWLEDGMENTS

Mr. C. S. Ezell was responsible for conducting most of the experiments in this study and for constructing associated equipment; great appreciation is expressed for his assistance. Appreciation is also extended to the Visual Aids Service for assistance in the preparation of figures. Especial appreciation is extended to Mrs. Roberts for her assistance in typing the manuscript.

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The experiments reported herein were conducted according to the principles set forth in the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council, DHEW, PUB. No. (NIH) 78-23.

INTRODUCTION

Several years ago research on the behavioral effects of microwave exposure was initiated in our laboratory. In the original work (2) rhesus monkeys were used because their thermoregulatory responses (11, 20) are similar to man's and because few investigators in this research area had studied the responses of primates. The overriding interest in using primates was caused by attempts to generalize data derived from animal research to man. As our research effort continued it became obvious that animals of different sizes exposed to different microwave frequencies would need to be examined if generalizations regarding larger animals were to be drawn. This realization resulted in selecting rats and squirrel monkeys and using three different microwave frequencies, all above the resonant frequency for these animals. The microwave frequencies, 1.3, 2.45, and 5.7 GHz, were chosen primarily because of availability and secondarily because they represented frequencies in use by the Navy.

Another key aspect of the program has been to choose a behavioral task on which all three species could be trained and that would generalize to human behavior without serious qualifications. An observing response task was chosen wherein an animal engages in operant behavior and obtains positive reinforcement (8). The task is similar to vigilance behavior and requires the sustained attention of the animal. For various reasons some of this work has utilized data from animals on other operant tasks (16, 19), but the primary data have been taken from a series of experiments measuring observing-response performance (2, 3, 5).

The behavioral literature reveals no unique behavior associated with microwaves other than the auditory phenomenon (7). Thus, the present approach has attempted to examine changes in operant behavior as a consequence of exposure to microwaves. Disruption of ongoing behavior is the effect on which this study was focused because it is the effect most commonly reported in the literature (10). Disruption of stable performance baselines typically is seen as a decreased rate of responding, although an increase in response rate has also been observed as a consequence of microwave irradiation (3). The present studies were not designed to evaluate an animal's detection of the microwaves nor were reinforcement contingencies associated with the presence of microwaves. Instead, the studies were designed to establish the lowest power density of microwaves that would disrupt ongoing behavior. On the observing-response task reinforcement was scheduled so that response-rate changes normally did not increase or decrease its frequency; that is, either random interval or variable interval schedules of reinforcement were used (1).

The approach is one of seeing how well an operant response can be maintained when the animal is confronted with a biophysical agent as pervasive as microwaves. This approach demonstrated that a well-controlled operant response was unassailable or immune to microwave disruption as long as the animal's body temperature did not rise at least 1 °Celsius above its baseline level.

PROCEDURE

SUBJECTS

The subjects were rats either of the Long Evans strain (5) or the Sprague-Dawley strain (19) obtained from the Charles River Colonies; squirrel monkeys, Saimiri sciureus, obtained from Columbia, South America; and rhesus monkeys, Macaca mulatta, produced in our own breeding colony. All of the subjects were males. The average body masses of the animals were 300-400 g for rats, 700 g for squirrel monkeys, and 4.7-5.1 kg for the rhesus.

All of the subjects were trained while food deprived and maintained at approximately 85 to 95% of their free-feeding body mass. In the long-duration studies with the rhesus the animals were periodically placed on free-feeding schedules for several weeks to establish new 100% free-feeding values.

APPARATUS

The microwave exposures typically occurred in chambers anechoic to the microwave energy. The chambers differed only in basic dimensions that depended upon the direction and frequency of the irradiation. A schematic of a chamber instrumented for a rat experiment is illustrated in Figure 1. The chambers have been previously described in detail in the various experiments providing material for the present report (2, 5, 19). In brief, each chamber was constructed of copper-faced wood and lined with microwave radiation absorber. The chambers were cooled with air conditioners and ventilation fans, and each was equipped with a closed circuit television camera and a white-noise auditory masking source of approximately 75 dB SPL. Equipment for presenting either visual or auditory stimuli was located in the chambers along with transducers for recording ambient relative humidity and temperature.

Various military and commercial radar sets were used to generate the microwaves at three different frequencies: 1.3, 2.45, and 5.7 GHz. The frequency of 5.7 GHz is an average value based upon the 5.62-GHz microwaves used for irradiating the rats and squirrel monkeys and the 5.8-GHz microwaves used in the rhesus monkey experiment. Incident power density and its distribution in the chamber were determined in each experiment in the absence of the subject, and the value measured at the location of the center of an animal's head was the value referred to as the power density to which the animal was exposed.

All of the experiments used Styrofoam restraint devices in the form of either a chair (17) or as an operant conditioning box (19). Manipulanda and food apertures were placed in one wall of these devices. The primate chairs allowed continuous monitoring of the colonic temperatures of the monkeys. Reference air temperature probes, external to the animals, were located near the colonic probes.

Colonic temperatures were not obtained from the rats used in these experiments but from animals of the same size and strain that had been

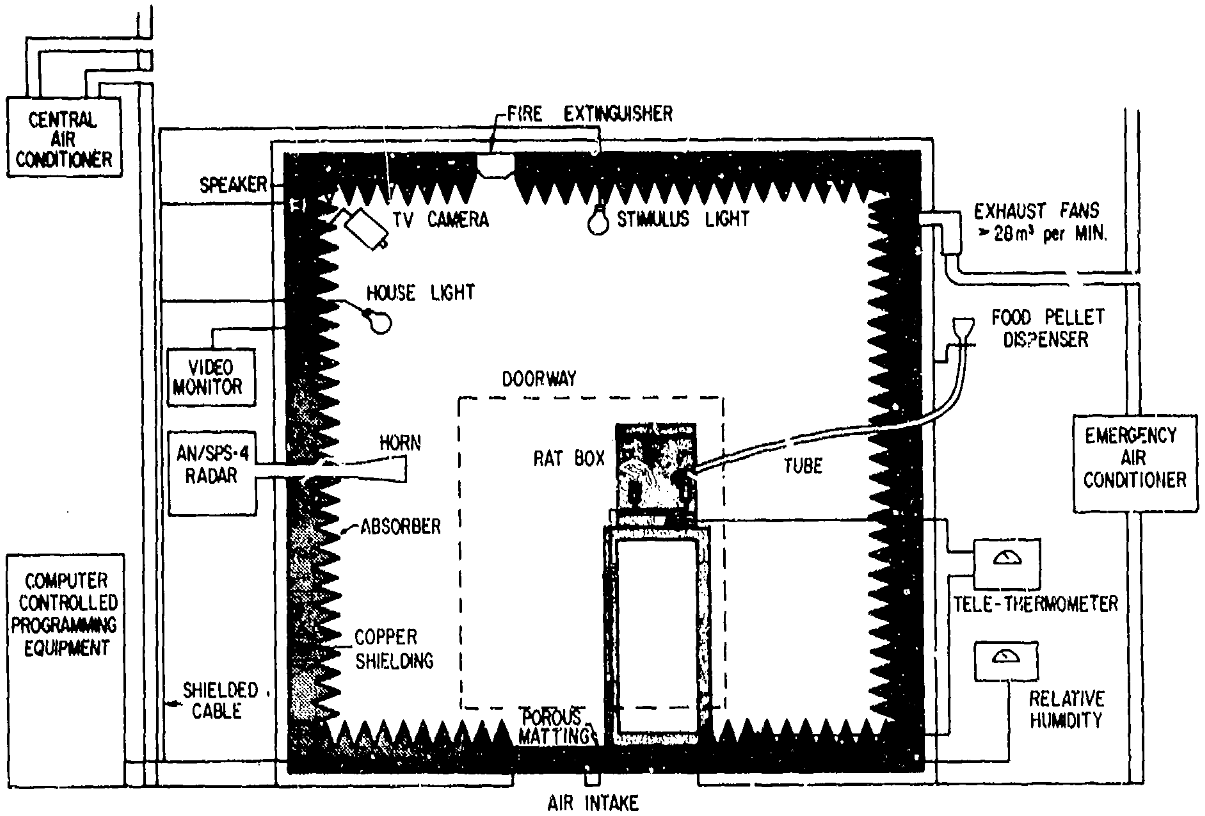

Figure 1

Diagram of an exposure chamber in which experiments at 5.6 to 5.8 GHz were conducted.

previously exposed in the same or similar chambers (9, 13). No colonic temperature data were available on rats exposed at 1.3 or 5.7 GHz. An estimate of the temperatures of rats exposed to 1.3 GHz was obtained from dosimetry data of de Lorge and Ezell (5) and a study by Merritt _et al_. (15) that used smaller rats at 1.6 GHz.

METHOD

The general approach of the entire study is summarized in Table I. At the left side of the table are indicated the three subject groups and at the top are the three microwave frequencies. The P refers to pulsed energy and CW refers to continuous wave. The operant task is shown in each cell as either an observing response with two levers, B1; a fixed interval schedule with one lever, B2; or a repeated acquisition task with three levers, B3. The upper-case T indicates that colonic temperature was continuously measured during the behavioral sessions and the lower-case t indicates that the colonic temperature was estimated. The orientation of the long axis of the subject to the electric field vector of the plane wave is

TABLE I

Characteristics of Contributing Experiments

	MICROWAVE FREQUENCY[a]		
Subject	1.3, P	2.45, CW	5.7, P
RAT	B_1 t	B_2 t	B_1
	X+Y, lateral	X+Y, dorsal	X+Y, lateral
SS		B_1 T	B_3 T
		Z+Y, dorsal	Y, frontal
RH	B_1 T	B_1 T	B_1 T
	Y, frontal	Y, frontal	Y, frontal

[a] Symbol Identification:

B_1= Observing Response

B_2= Fixed Interval

B_3= Repeated Acquisition

X,Y,Z= Long Axis Orientation to E Field

T= Colonic Temperature Measured

t= Colonic Temperature Estimated

P= Pulsed

CW= Continuous Wave

denoted by X, Y, and Z and whether the animal is facing the horn, frontal; below the horn, dorsal; or has its right side towards the horn, lateral.

Several variations in approach are evident in the Table I matrix. Squirrel monkeys were not irradiated at 1.3 GHz and all exposures were not orientated to the same polarization. Nevertheless, it will be shown that the distinctiveness and general lack of ambiguity in the overall results of these experiments question the relevance of these inconsistencies.

The specific procedure in each of these experiments was to train an animal on an operant task. The operant task most frequently used was an observing-response task; details of the procedure are provided in the experiment by de Lorge and Ezell (5). Details of the fixed-interval schedule experiment are found in Sanza and de Lorge (19), and similar information regarding the repeated acquisition task is found in Nelson (16) and de Lorge (4). Most of the daily food allotment was obtained during experimental sessions, and no water was available during the session.

The primary method of monitoring performance was with cumulative response recording. Response rate was the major index of performance, although other measures such as reaction time, errors of omission and commission, post-reinforcement pause, and response latency were also obtained. After within-session and between-session stable performance had developed (as determined by response-rate equivalency) the animal was exposed to the microwave field while performing the task. Typically, sham-exposure sessions (all of the radar equipment energized except the magnetron) preceded and followed exposure sessions by one day except that Friday sessions were followed by two days of no sessions and a sham-exposure session on Monday. With very few exceptions, each subject was exposed at least three times to each power density in every experiment and three to eight subjects participated in each experiment. The animals were trained on a specific operant task to manipulate one or more levers to obtain food. Exposure sessions were from 40 to 60 minutes. A power density threshold was determined by assessing the level where stable performance was disrupted. Disruption was most often seen as a response rate decrement. Simultaneously, in those studies where colonic temperature was measured, a body temperature was determined corresponding to the behavioral disruption threshold.

RESULTS

The response rate decrement as a consequence of microwave exposure is illustrated in Figure 2. This figure contains examples of cumulative observing-response records for a rat (R9) exposed at 5.62 GHz to power densities ranging from 0 to 48.5 mW/cm^2 (5).

Only selected power densities are shown in the figure because of space limitations. The numbers at the upper left of each record denote the power density (mW/cm^2) and C denotes a sham or control session. Each recording is from an entire 40-minute session, and each record for an exposure session is preceded by the sham session record. Sessions begin at the left with time increasing to the right. Each observing-response steps the record upwards. Hash marks on the response lines indicate the occurrence of a food lever response and hence reinforcement. The response pen resets after 280 responses or at the end of a session. At 26 mW/cm^2 this record (in Figure 2) shows a slight rate difference in the latter part of the session, at 31.5 mW/cm^2 a larger rate change with extensive pauses, and at 42 mW/cm^2 the rate change was greater and the pauses longer. These effects are typical of those observed throughout the study with all of the animals at all frequencies although exceptions did occur as illustrated in the behavior of a squirrel monkey in one experiment (3).

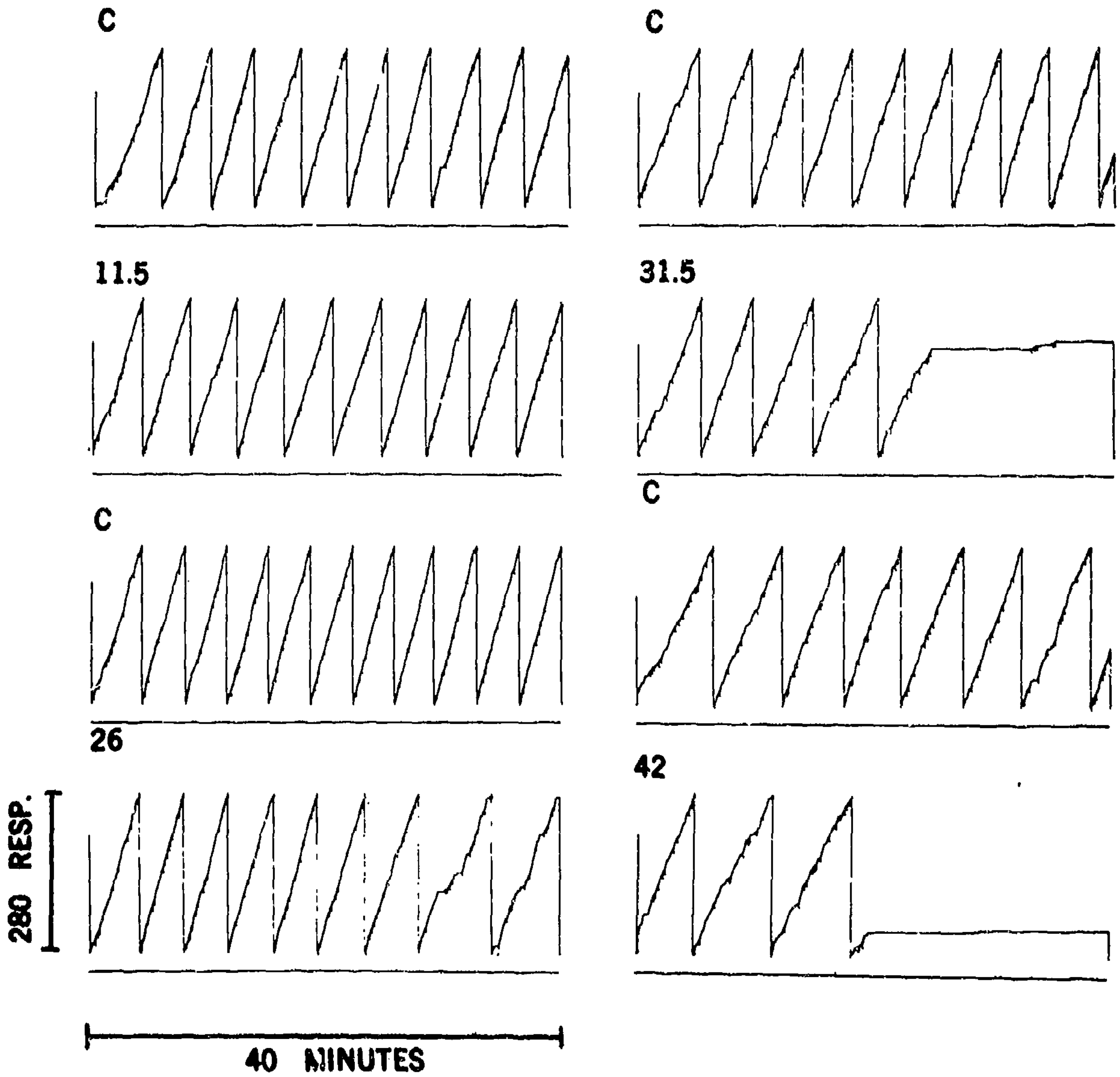

Figure 2

Cumulative records of observing-responses for a rat (R9) for sham (C) and exposure at 5.62 GHz. Power densities are indicated at the upper left of each record. An exposure session followed the sham session immediately above it. Responses are shown on the left and time is indicated at the bottom.

A similar record of observing-responses is shown in Figure 3 for a squirrel monkey. In addition, the colonic temperature of this animal is shown for the same exposure session (bottom record) as denoted on the left. Time is indicated at the bottom in consecutive minutes. The horizontal line below the cumulative response record indicates when the food available signal was present. In this experiment (3) the microwave exposure began 30 minutes (first arrow) into the session and lasted for 1 hour (second arrow). A slight rise in temperature occurred during the initial half hour followed by a more rapid rise during the exposure period. A decrement in response rate gradually developed during the microwave exposure. Several pauses occurred as irradiation continued and temperature increased. At the termination of irradiation the monkey stopped responding for several minutes and then gradually resumed pre-irradiation response rates. The rapid fall in colonic temperature after the microwaves were removed and the other characteristics of temperature and response changes were typical of this and similar experiments in the present report.

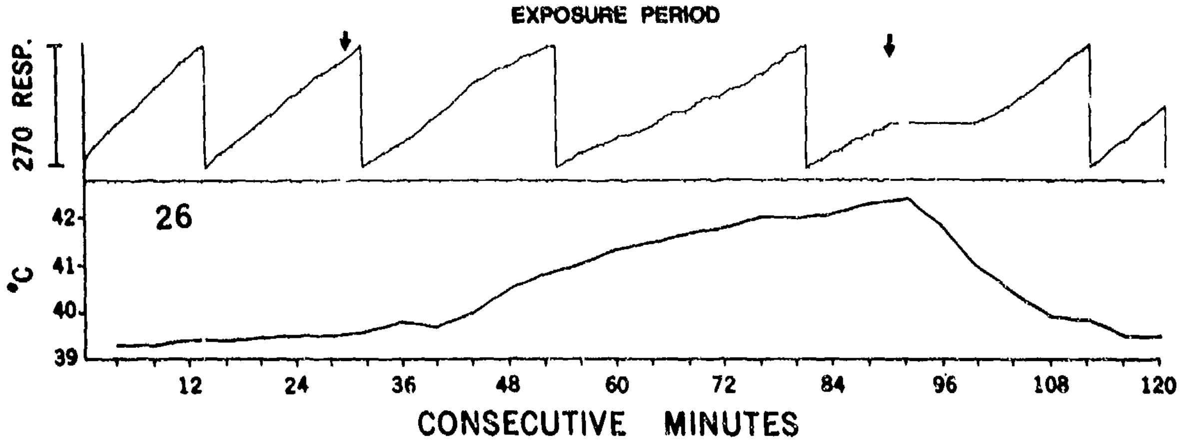

Figure 3

A cumulative record of observing-responses and rectal temperature for a squirrel monkey (26) exposed to 2.45 GHz microwaves. The response record is above and the temperature record is below. Irradiation began at 30 minutes and ended at 90 minutes as denoted by the arrows.

The cumulative records provided an excellent method of assessing a microwave effect in action, but a quantitative assessment of this effect was achieved by comparing response rates in sham sessions with response rates during exposure sessions. An example of these ratios is illustrated in Figure 4 which summarizes the results of experiments on five rhesus monkeys exposed to 1.3 GHz microwaves during 1-hour observing-response sessions. The circles indicate the mean ratio as shown on the left and each mean is bracketed by the standard error of the mean. The horizontal line at a ratio of 1.0 denotes the same response rates during sham and exposure sessions. No large differences in responding at the various power densities were observed below 63 mW/cm^2. The slight increase at 45 mW/cm^2

was caused by an exceptionally high rate of responding by one animal. Omission of that animal's data produces a mean ratio of 1.01 and a corresponding smaller standard error. Ordinarily the decrement in response rate was correlated with increases in power density. An absolute threshold of 56 mW/cm^2 was chosen here. Similar graphs were plotted for all of the experiments, and thresholds were determined by choosing a level midway between the power density where an obvious effect was reliably observed and the one where no effect was seen.

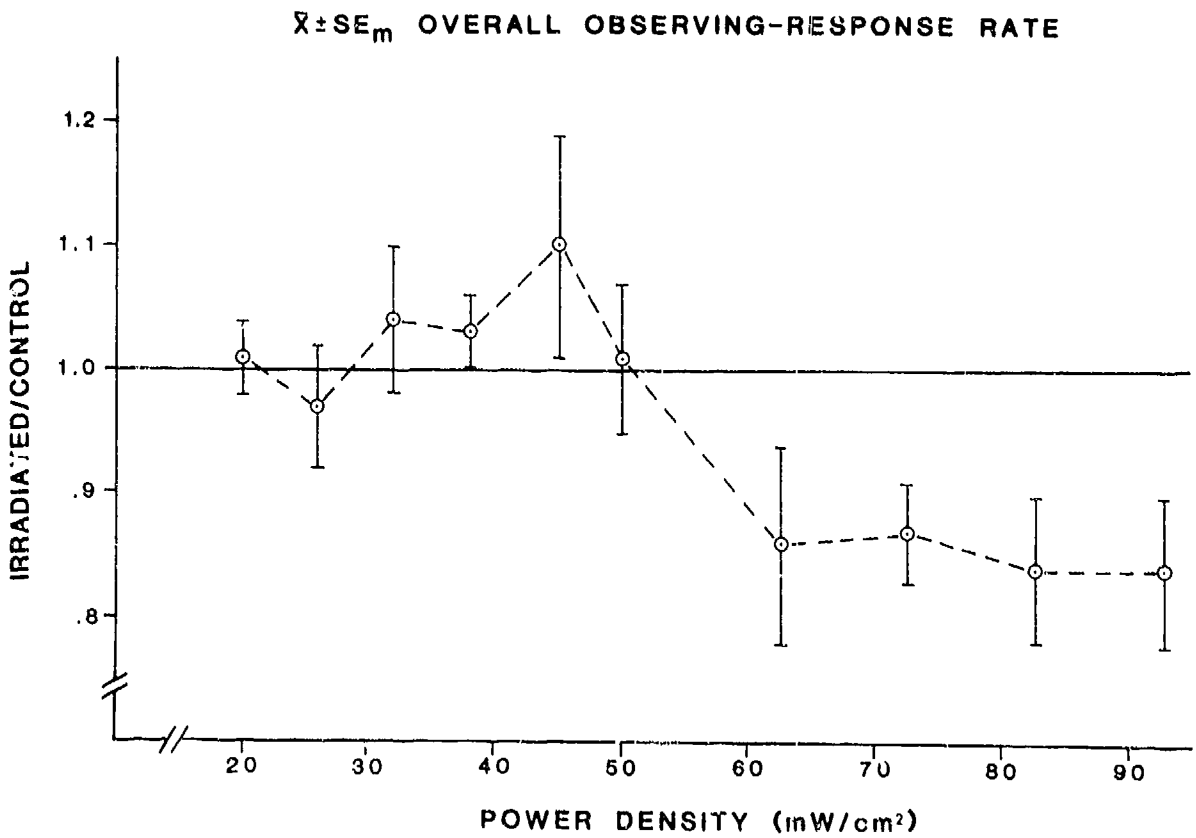

Figure 4

Observing-response rate plotted as a ratio of irradiated session means to sham (control) session means (including standard error of these ratios). Each point represents the mean of five animals (except at 93 mW/cm^2) when n=4).

The body temperature of the animals as indexed by colonic temperature is shown in Figure 5. A linear regression was calculated with these temperature data and 42 mW/cm^2 was estimated to be the power density at which a 1 °C body temperature increase above baseline would occur.

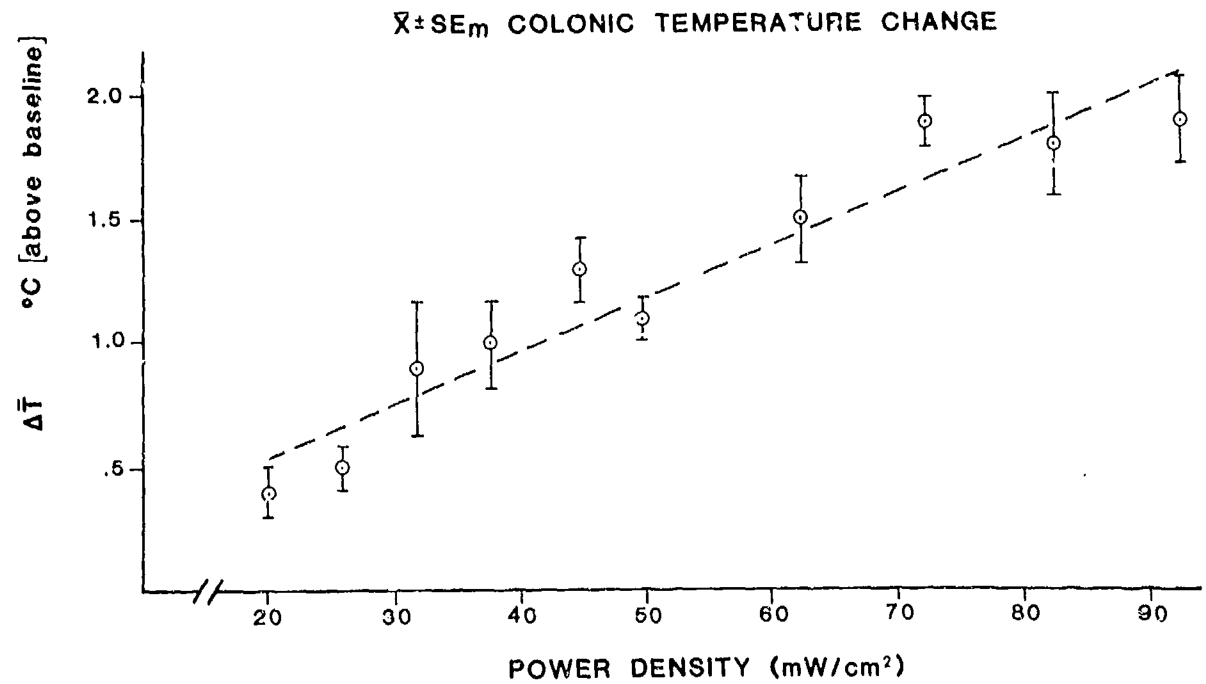

Figure 5

The mean ΔT in rectal temperature of five rhesus monkeys (n=4 at 93 mW/cm^2) exposed to microwaves at 1.3-GHz for 60 minutes. The rectal temperatures of the preceding sham session for each monkey served as a baseline at each power density.

DISCUSSION AND CONCLUSIONS

After analyzing the empirical records to determine the power density thresholds necessary to produce a significant change in behavior, these data were used to generate three families of curve sets that show relationships among microwave field parameters and various anatomical indices. The first set is shown in Figure 6 which plots the behavioral thresholds as a function of body mass. Mass is plotted on the abscissa on a logarithmic scale and each curve corresponds to a specific microwave frequency. The ordinate is power density in mW/cm^2 at threshold. The three points corresponding to the heavier animals, the rhesus monkeys, are grouped at the right, the three data points derived from rats are at the left, and the two data points derived from squirrel monkeys are at the center of the figure. The plotted values are the means for all animals in the same species that were used to establish the thresholds. It is apparent that an increase in power density sufficient to cause an effect occurs as the microwave frequency and body mass increase. The relative increase in threshold power density at the high frequency for the rhesus is about the same as that for the other animals except that 2.45 GHz is the frequency requiring the most energy for an effect in the smaller animals.

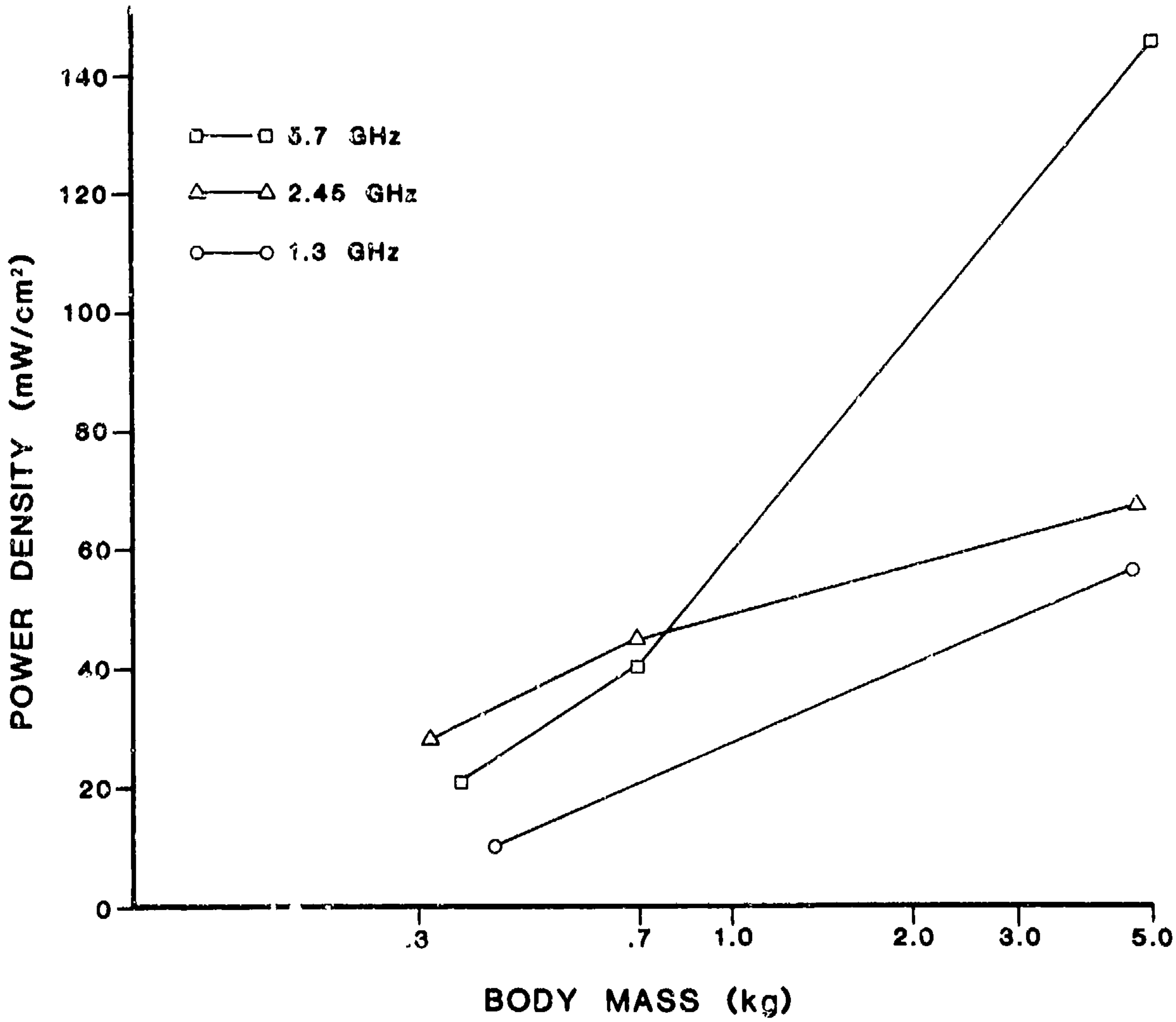

Figure 6

The thresholds of behavioral disruption on operant tasks for different sized animals as a function of power density (ordinate) and body mass (abscissa). The body mass is plotted on a logarithmic scale and the different curves correspond to different frequencies as shown in the upper left.

An animal's ability to generate or maintain body heat is often given as specific metabolic rate or metabolic heat production per unit body mass; therefore, the curves of Figure 6 might provide a basis for extrapolation to other sized animals and thus predict power densities where similar behavior would be disrupted. However, it is also likely that an animal's body surface area would be an important index for extrapolation. Body mass and body surface area are directly correlated (14) and curves based on one resemble curves based on the other. The same is true of body length and body mass (12). For example, in Figure 7 the same behavioral thresholds of power density that were previously shown are now plotted as a function of one half of the body surface area of the animals. This measure was used as a liberal estimate of the surface exposed to the microwave field.

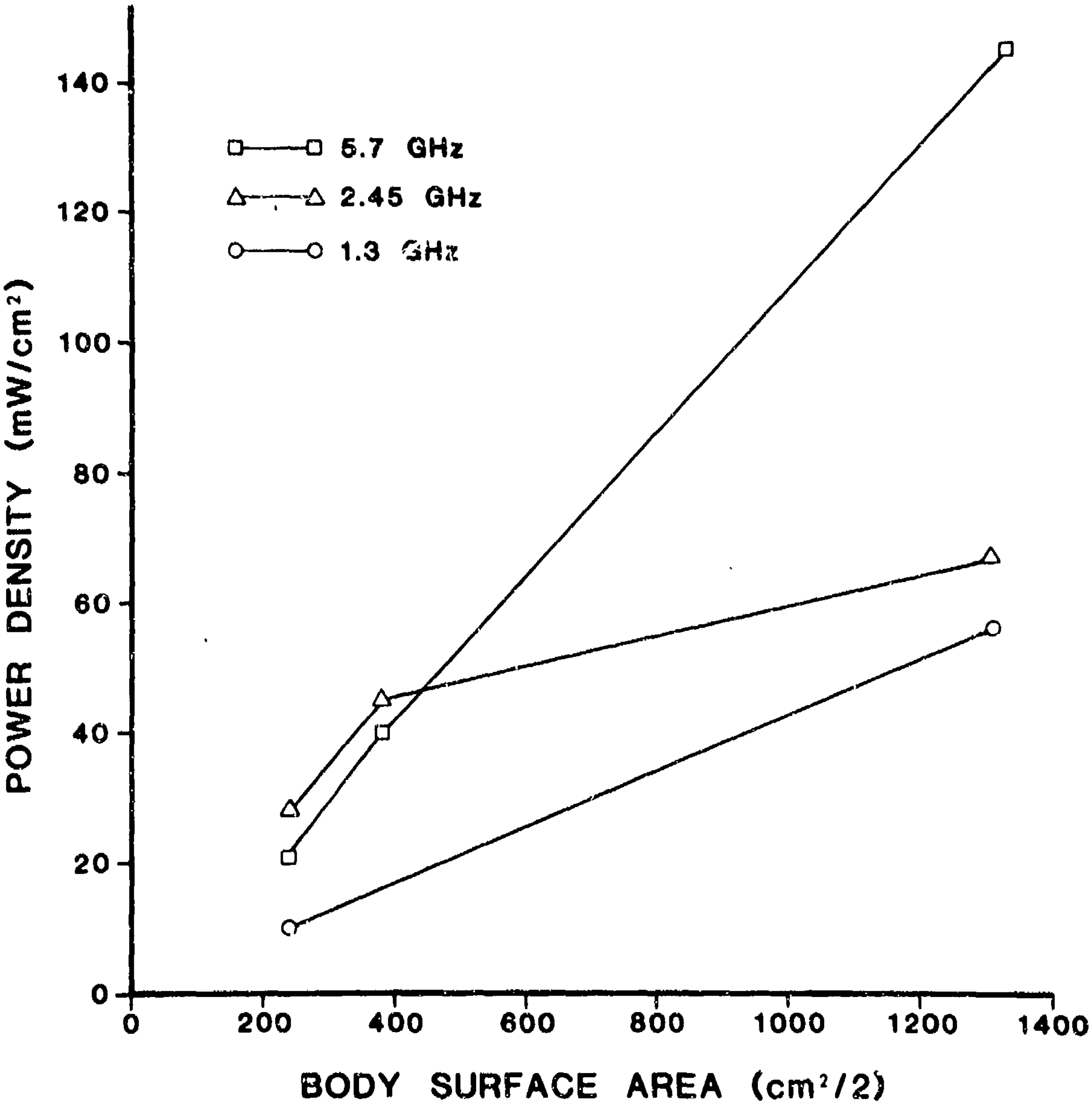

Figure 7

The thresholds of behavioral disruption on operant tasks at three frequencies shown as a function of estimated exposed body surface area (abscissa).

Instead of whole-body energy absorption as a predictive index of an animal's reaction to microwave irradiation, one might consider local energy absorption in specific anatomical structures. For example, the three species of animals in the present study all have different sized cranial cavities that may have unique relationships to the wavelengths of the three different microwave frequencies. In Figure 8 the behavioral thresholds shown in previous figures are illustrated as a function of the anterior-posterior length of the cranial cavity for a representative animal of each group of subjects. With the exception of the rhesus monkey at 5.7 GHz, this particular relationship is more linear than the previous relationships and might be a better index for predicting behavioral effects in animals with cranial cavities smaller than that of the rhesus.

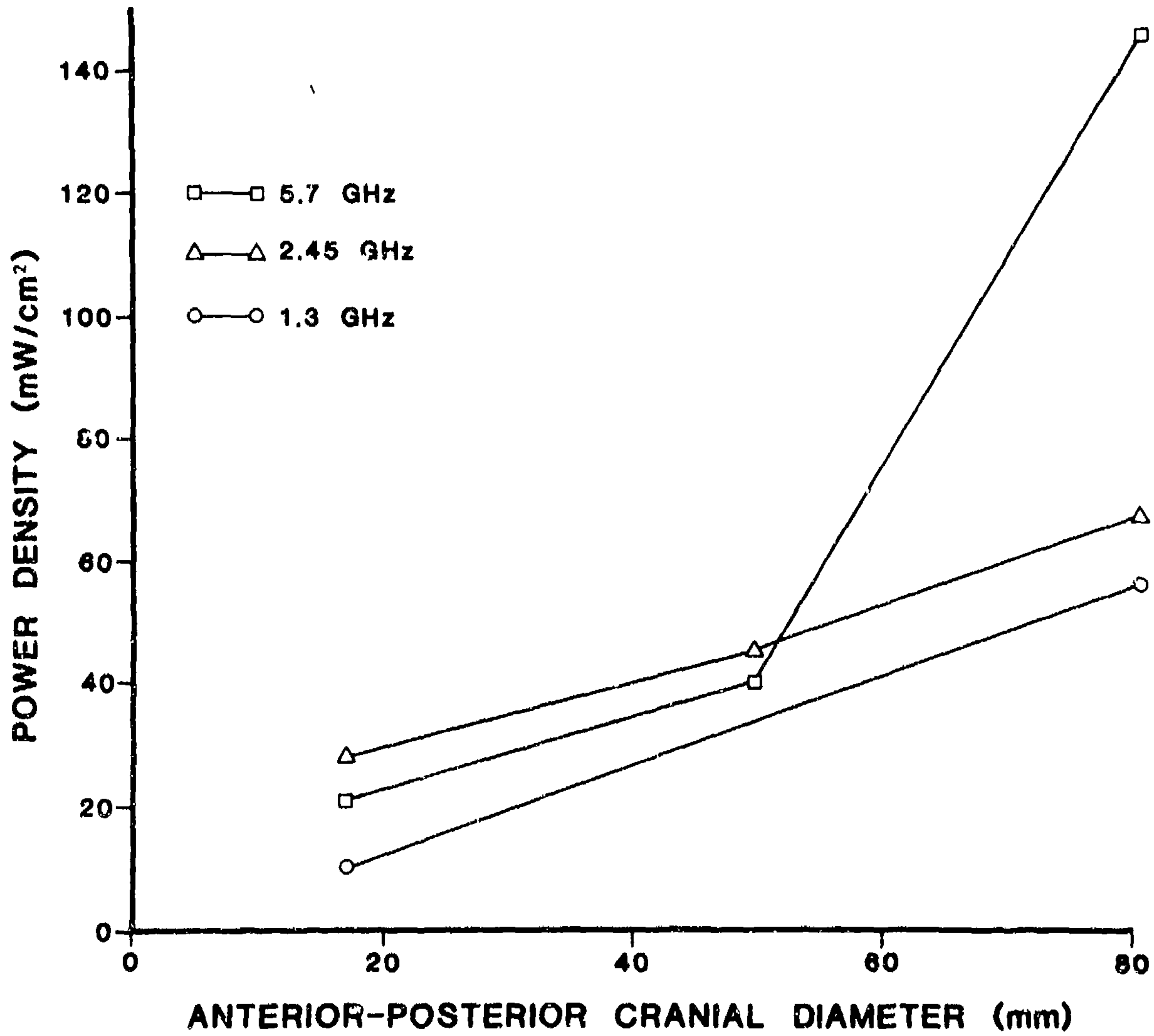

Figure 8

The thresholds of behavioral disruption at three frequencies shown as a function of the anterior-posterior cranial cavity diameter (abscissa).

Similar correlations to those shown in Figures 6, 7, and 8 could be constructed by using power density levels required for a 1 °C colonic temperature rise instead of the behavior disruption thresholds. The coincidence between these relationships is strikingly illustrated in Figure 9. This figure shows the power density required for a 1 °C change in temperature and the power density threshold for a behavioral change, both plotted as a function of microwave frequency. Each group of subjects is represented by a set of connected lines. The triangles denote the levels where temperature increases of 1 °C occurred and the circles represent the levels where behavior was affected. Several conclusions can be drawn from Figure 9. The smaller the animal the greater the relative effect at all frequencies, although this is only a guess for the squirrel monkey at 1.3 GHz. Behavioral changes will probably occur with the +1 °C colonic temperature change or at slightly higher temperature changes in the rhesus monkey. As the animal size increases, higher power densities are required to affect either behavior or colonic temperature at the chosen frequencies. At the frequency of whole-body resonance it is expected that all of these animals will display greater sensitivity. It is also possible that some of these values for the squirrel monkeys and rats differ more because of body orientation with respect to the microwave field vectors than from the change in wavelength. For example, lateral irradiation of the rat may deposit more energy than dorsal irradiation at 2.45 GHz, and frontal irradiation of the sitting squirrel monkey may deposit more energy than dorsal irradiation at the same frequency.

In contrast to the relationships of earlier figures, Figure 9 suggests that data obtained from one animal species do not lend themselves very well to generalizations about other species. The results of the rat studies might lead one to draw completely different conclusions than those derived from the rhesus data. Only with several different species at very different body sizes as in the present study can one begin to gain a realistic assessment of microwave effects.

The general shape of these curves might be predicted from the specific absorption rate curves for these animals as described in Durney _et al_. (6). One major exception to this was the high power required at 5.8 GHz for the rhesus monkey. Much less power to produce effects at this frequency was predicted. The cause of this exception may lie in the fact that, at this frequency, it was necessary to position the animal at about 60 percent of the far-field distance from the horn to achieve high power densities in the area of the animal's head. This proximity to the horn resulted in a highly nonuniform distribution of power density across the ventral surface of the animal.

Specific absorption rates (SAR) calculated or measured in saline models at the various threshold values for different species showed no consistencies except at 2.45 GHz. At this frequency the SARs tended to average between 4 and 5 W/kg. The rat at 5.7 GHz and the rhesus at 1.3 GHz also absorbed between 4 and 5 W/kg at the behavioral thresholds. However, the squirrel and rhesus monkeys at 5.7 GHz absorbed higher levels of energy and the rat at 1.3 GHz absorbed less energy. Consequently, whole body estimates of energy absorption may not be the best data for predicting

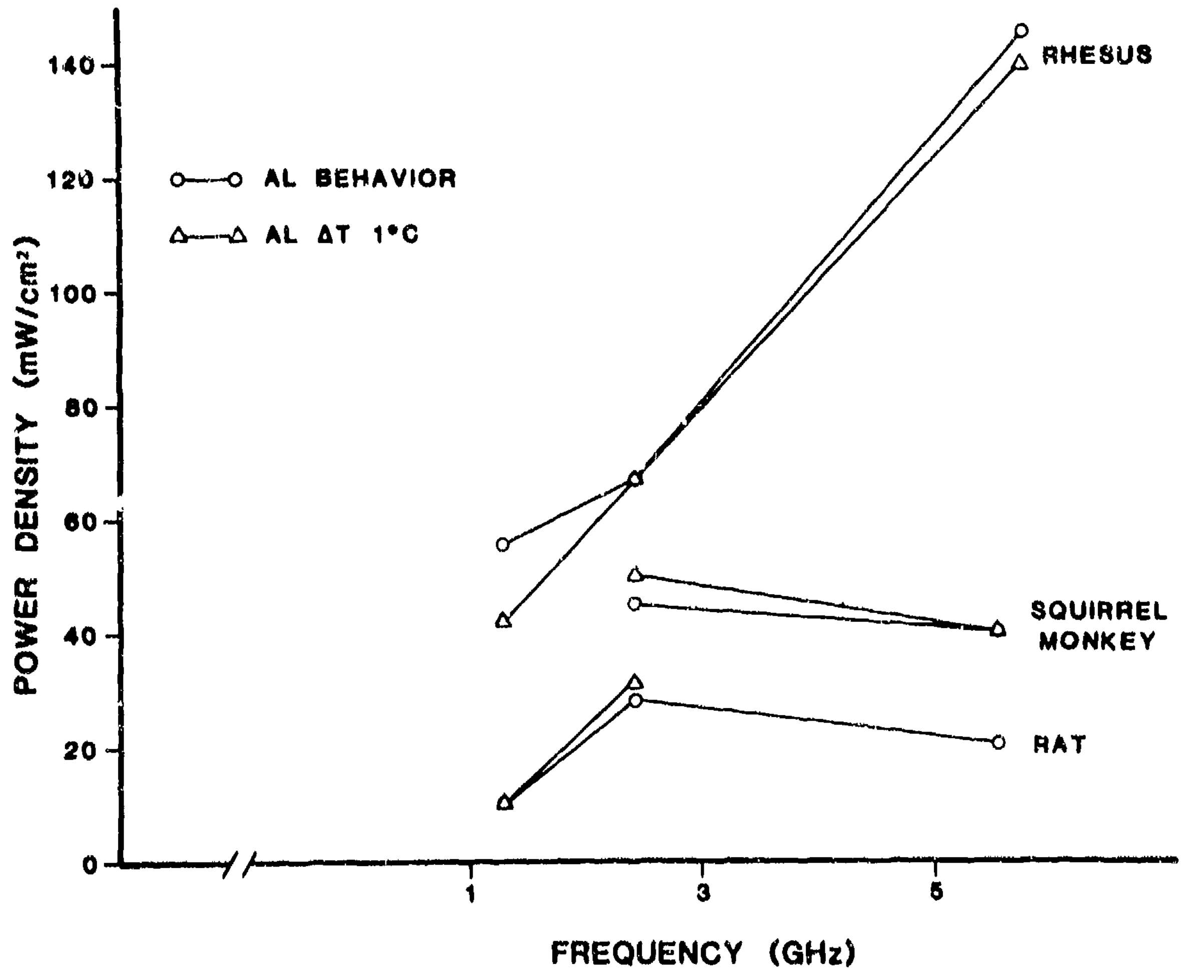

Figure 9

Thresholds (AL) of behavioral disruption of an operant task and of a 1 °C temperature increase above baseline for three different sized animals as a function of power density (ordinate) and frequency (abscissa).

behavioral effects across frequencies. Other aspects of microwave absorption such as distribution or local resonance might be more consistent parameters for predicting behavioral effects. Although the correlation between behavioral change and a 1 °C temperature rise is very useful for estimating disruption of behavior, the argument that the response is caused merely by a core temperature change is not very convincing. As indicated in Figure 8 the causal agent could be energy deposition in the brain or head area.

It might be that at certain frequencies surface irradiation literally causes the animal to move away from a location so that another surface is illuminated or causes it to become less active and reduce metabolic rate

(18). Such responses, compatible with reduced energy capture but incompatible with ongoing responding, could explain the results of several studies using both restrained and unrestrained animals. In addition, other characteristics of microwaves such as novel stimulation, affective tone, auditory stimulation, and even the body temperature decrease that occurs with the removal of microwave irradiation, should not be dismissed.

Our experiments raise only questions relating to the behavioral effects of microwaves at frequencies above resonance for these specific animals. A different set of relationships may exist at resonant and below resonant frequencies although this investigator would hazard a guess that the power density threshold would continue to decrease for all three animal sizes at resonant frequencies and then increase again at frequencies below resonance. The utility of any of the specific relationships, e.g., that in Figure 8, at any range of frequencies will have to be empirically determined. To help resolve the issue a study should be conducted with a single behavioral task in a species of animals where a large variation in body size occurs in adults of that species (the canine, for example). Microwave parameters could be determined that would allow a representative series of wavelengths below resonance, at resonance, and above resonance for each body size. Holding constant the species variable while allowing body and brain sizes to vary should provide definitive answers to many questions elicited by the present study.

REFERENCES

1. Catania, A. C., Contemporary Research in Operant Behavior. New York: Scott, Foresman and Company, 1968.

2. de Lorge, J. O., The effects of microwave radiation on behavior and temperature in rhesus monkeys. In: Johnson, C. C., and Shore, M. L. (Eds.), Biological Effects of Electromagnetic Waves, Selected Papers of the USNC/URSI Annual Meeting, Boulder, CO, October 20-23, 1975. (Vol. 1). Washington, DC: U. S. Dept. of Health, Education and Welfare, Publication No. (FDA) 77-8010.

3. de Lorge, J. O., Operant behavior and colonic temperature of squirrel monkeys during microwave irradiation. Radio Science, 14(6S): 217-226, 1979.

4. de Lorge, J. O., The effects of microwaves on animal behavior. In: Berteaud, A. S., Ondes Electromagnetique et Biologie. Jouy en Josas, France: URSI, CNFRS, 1980. P 171.

5. de Lorge, J. O., and Ezell, C. S., Observing-responses of rats exposed to 1.28- and 5.62-GHz microwaves. Bioelectromagnetics, 1:183-198, 1980.

6. Durney, C. H., Johnson, C. C., Barber, P. W., Massoudi, H., Iskander, M. F., Lords, J. L., Ryser, D. K., Allen, S. J, and Mitchell, J. C., Radio-frequency radiation dosimetry handbook. Second Ed. SAM-TR-78-22. Brooks Air Force Base, Texas: USAF School of Aerospace Medicine, 1978.

7. Frey, A. H., and Messenger, R. Jr., Human perception of illumination with pulsed ultra-high frequency electromagnetic energy. Science, 181:356-358, 1973.

8. Holland, J. G., Technique for behavioral analysis of human observing. Science, 125:348-350, 1957.

9. Houk, W. M., and Michaelson, S. M., Metabolic and thermoregulatory responses to microwave radiation in young male rats. In: Preprints of 1974 Scientific Program Aerospace Medical Association, 45th Annual Scientific Meeting, Washington, DC, May 6-9, 1974, P 174.

10. Justesen, D. R., and King, N. W., Behavioral effects of low level microwave irradiation in the closed space situation. In: Biological Effects and Health Implications of Microwaves. Report BRH/DBE 70-2. Washington, DC: Bureau of Radiological Health, 1970. P 154.

11. Kenshalo, D. R., and Hall, E. C., Thermal thresholds of the rhesus monkey. J. Appl. Physiol., 36:902-910, 1974.

12. Liu, C. T., and Higbee, G. A., Determination of body surface area in the rhesus monkey. J. Appl. Physiol., 40:101-104, 1976.

13. Lotz, W. G., and Michaelson, S. M., Temperature and corticosterone relationships in microwave-exposed rats. J. Appl. Physiol., 44:438-445, 1978.

14. McMahon, T., Size and shape in biology. Science, 179:1201-1204, 1973.

15. Merritt, J. H., Chamness, A. F., Hartzell, R. H., and Allen, S. J., Orientation effects on microwave-induced hyperthermia and neurochemical correlates. J. Microwave Power, 12:167-172, 1977.

16. Nelson, T. D., Behavioral effects of microwave irradiation on squirrel monkeys (Saimiri sciureus) performance of a repeated acquisition task. NAMRL-1245. Pensacola, FL: Naval Aerospace Medical Research Laboratory, 1978.

17. Reno, V. R., and de Lorge, J. O., A primate restraint device for use in microwave biological research. IEEE Trans. Biomed. Eng., BME-24:201-203, 1977.

18. Roberts, W. W., Mooney, R. D., and Martin, J. R., Thermoregulatory behaviors of laboratory rodents. J. Comp. Physiol. Psychol., 86:693-699, 1974.

19. Sanza, J. N., and de Lorge, J., Fixed interval behavior of rats exposed to microwaves at low power densities. Radio Science, 12(6S): 273-277, 1977.

20. Smiles, K. A., Elizondo, R. S., and Barney, C. C., Sweating responses during changes of hypothalamic temperature in the rhesus monkeys. J. Appl. Physiol., 40:653-657, 1976.

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Microwave Effects
Vigilance
Operant Behavior
Colonic Temperature
rhesus monkey

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A large variety of microwave producing devices are used in contemporary naval communications and weapons systems. Public and scientific concern about potential biological effects of microwave irradiation such as produced by these various devices requires documentation of such effects. Currently, the only well documented direct effect of microwaves is heating of the exposed organism. The present report is of a series of studies whose aim was to explore several microwave frequencies and their effect on performance and

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) simultaneously to investigate the relationship to core heating in the exposed animals. Three different species of animals were used so that generalization to larger animals could be made.

Rats, squirrel monkeys, and rhesus monkeys showed consistent effects of 60-minute exposures to microwaves when their body temperatures were increased at least 1 °C above baseline temperatures. Performance was not reliably affected when body temperatures remained below this level. Greater intensities of microwaves were required to influence the animals' temperature and behavior as the animal size increased. A direct relationship between frequency and power density was observed in the rhesus monkey; e. g., as the frequency of the microwaves increased, the power density needed to affect behavior and temperature also increased.