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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
PENSACOLA, FLORIDA

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EFFECTS OF PULSED MICROWAVES AT 1.28 AND 5.62 GHz ON RHESUS MONKEYS (*Macaca mulatta*) PERFORMING AN EXERCISE TASK AT THREE LEVELS OF WORK

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SUMMARY PAGE*

THE PROBLEM

Microwaves are present-day components of the naval environment. Consequently, it is desirable to know the biological effects that working personnel undergo when in the vicinity of operational radar equipment. Previous research has shown that animals other than man can provide useful models for assessing microwave effects. The present experiment studies both behavioral and physiological consequences of exposing exercising rhesus monkeys to microwave radiation.

FINDINGS

In experiments using 1.28 and 5.62 GHz pulsed microwave irradiation, operantly conditioned male rhesus monkeys exercised at three different work levels while exposed to the microwaves.

At 1.28 GHz four of the monkeys were exposed to power densities of 25, 41, and 89 mW/cm^2. Response rate, heart rate and colonic temperature were correlated with work load and power density level. At the highest power density exercising animals consistently had a lower response rate, a higher heart rate, and a greater increase in colonic temperature. At lower power densities the effects were generally less evident and were idiosyncratic.

At 5.62 GHz five monkeys were exposed to power densities of 10 and 43 mW/cm^2. Differences from controls were found only at 43 mW/cm^2: (1) colonic temperature averaged +0.8 °C higher (N=2), (2) response rate decreased (N=5) when the heaviest work load occurred during the terminal third of the session, and (3) heart rate (N=2) was higher.

At 1.28 GHz and 41 mW/cm^2, when a heavy work load occurred during the last third of a session response rate decreased. If the heavy work load was at the start of a session there was no response rate drop. During both work load series at the 41-43 mW/cm^2 range, colonic temperature exceeded 1 °C. This confirms previous work reporting threshold colonic temperature derivatives.

Other behavioral measures (interresponse time and post-reinforcement pause time) demonstrated no appreciable differences between control and irradiation sessions at either microwave frequency.

These experiments demonstrate that microwaves will produce cardiovascular effects in addition to those produced by exercise alone and that body temperature induced by microwave energy does not seem to be further accelerated by exercise. The results also illustrate that monkeys working a physically arduous task are more likely to stop working when exposed to

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*The animals in this study were handled in accordance with the principles stated in the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council, DHEW, NIH Publication No. 80-23, 1980.

microwaves than when working a less arduous task. Finally, the results show that although heart rate is increased with increased work load the increment attributed to microwaves seems to be independent of the increment caused by exercise.

ACKNOWLEDGMENTS

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INTRODUCTION

Naval environments may occasionally expose personnel to electromagnetic radiation at microwave frequencies. It is possible that under various conditions the microwave exposures could present a safety problem. Current projects in our laboratory are investigating several specific aspects of the biological effects of microwaves, but all these studies are conducted with experimental animals operating at a low metabolic rate. However, it is possible that the combination of increased metabolic heat and heat from microwave radiation could produce a greater indication of biological effects than would be produced by the microwave irradiation alone.

Although recent research (1, 2, 17) on the biological effects of microwaves has appeared wherein behaving, highly active animals served as subjects, none of the studies have considered metabolic heat production as an important variable. Nevertheless, outside of environmental factors, the most important cause of increased body heat is strenuous exercise (11). With the exception of the work of Adair and Adams (3), it is surprising that metabolic heat production has been generally ignored, particularly since many investigators acknowledge the thermal nature of microwaves in their work. On the other hand, the difficulty associated with simultaneously measuring metabolic heat induced by strenuous body activity along with other biological or behavioral measures may account for reluctance of investigators to enter this area. Metabolic heat production and its potential interaction with electromagnetic radiation necessitate experimental studies of the relation between muscular activity in an organism and the effects of microwave exposure. A clarification of such a relationship should allow a more exact definition of exposure conditions consistent with a safe occupational environment.

Because it is inadvisable to use humans as subjects in microwave experiments, rhesus monkeys (Macaca mulatta) were chosen. Rhesus monkeys can be taught to exercise vigorously for at least thirty minute sessions while achieving a total work output of as much as 2,795 J (9, 16). Rhesus monkeys are also excellent subjects for comparison to man in microwave studies because of their many similarities, especially those regarding temperature regulation (12).

This article reports behavioral and physiological investigations using trained exercising rhesus monkeys exposed to microwave power densities between 10 and 89 mW/cm^2 at frequencies of 5.62 GHz, pulsed at 626 pulses per second (pps), and 1.28 GHz, pulsed at 370 pps. The higher frequency experiments were conducted first.

5.62 GHz EXPERIMENTS

METHOD

Subjects

Five laboratory produced (13) and experimentally naive male rhesus monkeys, Macaca mulatta, 18-22 months old at the beginning of their use were maintained during the experiment at about 90% of their base line weights. The beginning base line weights were means of a series of daily weighings while the monkeys were generously fed* twice each day: subject 1R, 3.04 kg; subject 2R, 2.98 kg; subject 9R, 3.09 kg; subject 15R, 3.23 kg; and subject 62N, 3.16 kg. They were individually caged with continuously available water in the laboratory's vivarium under the care of an Air Force veterinary staff (14). The vivarium cage room was kept at 24 °C and had a light-dark cycle of 12-12 (lights came on at 0600 hours and went off at 1800 hours).

Apparatus

The outside dimensions of the anechoic exposure chamber, schematically illustrated in Figure 1, measured 2.45 meters long, 1.94 meters wide, and 2.43 meters high. It was shielded with copper and then completely lined with 20.4 cm pyramidal absorber (AAP-8) obtained from Advanced Absorber Products, Amesbury, MA. A Styrofoam wall was placed anterior to the absorber near the wall opposite the radiation source to permit better ambient temperature control. The exposure chamber was equipped with a closed-circuit television camera to monitor the animal, speakers (one for white noise and the other for auditory stimuli), lights and an ambient temperature probe 30 cm above the animal's head.

A radar set, AN/SPS-4 (Raytheon Manufacturing Co., Waltham, MA), was the source of 5.62 GHz microwaves pulsed at a repetition rate of 662 pulses per second. The pulse width was either 0.5 or 2.0 µs. A waveguide connected to a standard gain antenna, Narda model 643 (Narda Microwave Corporation, Plainview, NY), was used to irradiate in the far field (E polarization) the animal's ventral surface while it was restrained in an upright seated position in a Styrofoam exercise chair. The animal's muzzle was 134.2 cm from the radiation horn (minimum far field = 132 cm from horn).

The exercise chair shown in Figure 2 has handles, bars, and pivoted connecting plates so arranged that a spring located on the chamber's outer back wall and attached by a cable to the lowest bar, could be pulled 0.17 m by the subject. Associated with completion of each rowing-like correct response on the exercise device (handles pulled all the way back 0.17 m and then returned all the way forward 0.17 m) was a discrete 1.8 kHz audible tone delivered from a speaker for 0.3 s. Partial responses had no consequencies. A feeding tube was connected to a styrene elbow on the top, near the front left side of the chair. The food reinforcer was a 750 mg Noyes Precision food pellet (The P. H. Noyes Company, Lancaster, NH) delivered by an automatic feeder through the feeding tube into a trough in front of the monkey. General illumination was provided by a 25 Watt overhead bulb when an experiment was not in progress, but when one was in progress a white 150 Watt light above the horn was used. The luminance inside the chamber was approximately 6.5 foot-candles as measured with a Gossen LUNA-PRO photometer with the experiment light on. When the radar equipment, ventilation fans and white noise were all on, the sound pressure level was 79 dB.

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* Each feeding (one at 0700 hours and the other at 1500 hours each day) consisted of 17 Wayne Monkey diet biscuits (produced by Allied Mills, Inc., Chicago, IL). A biscuit weighed, on the average, 4.1 grams and provided 3.22 kilocalories per gram.

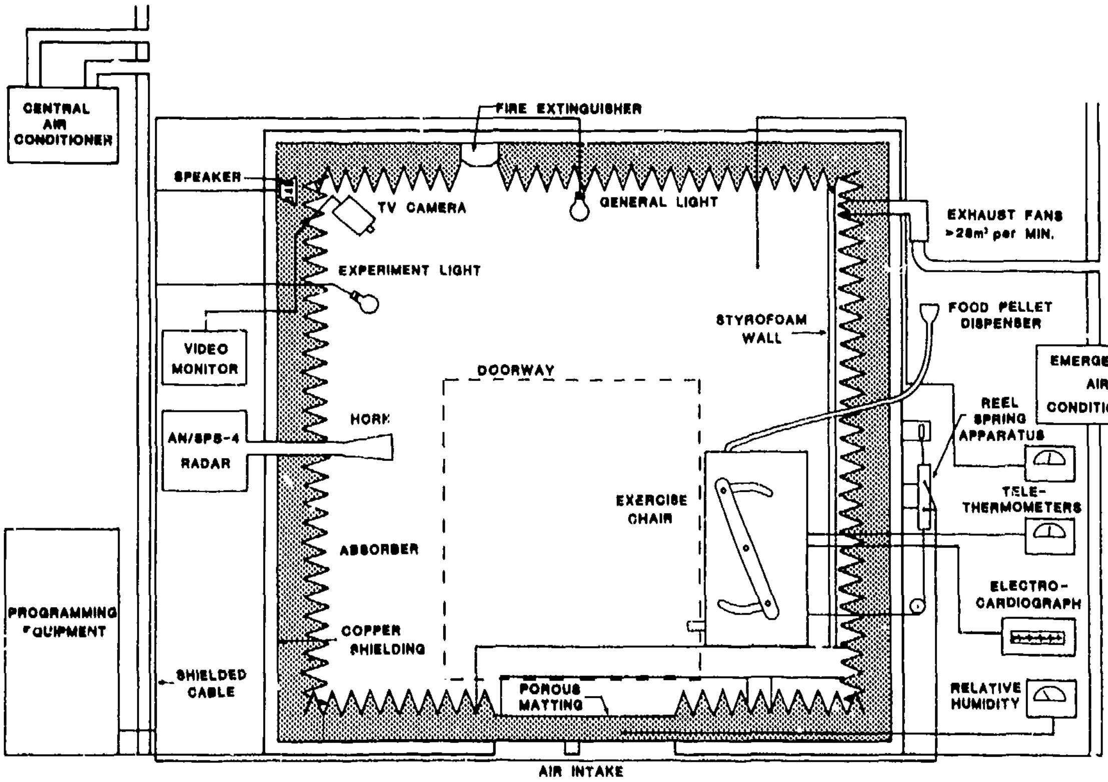

Figure 1

Diagram of the 5.62 GHz exposure chamber and ventilation system.

Animal colonic temperature was measured with a Yellow Springs Instrument tele-thermometer, model 46 TUC (Yellow Springs Instrument Company, Yellow Springs, OH) and a thermistor probe (Yellow Springs Instrument temperature probe number 401) inserted approximately 10 cm past the anal sphincter. The thermistor lead was taped to the base of the subject's tail.

In a distal room solid state and electromechanical switching circuitry recorded responses and scheduled stimuli and response contingencies.

Air in the exposure chamber was circulated by fans at a rate exceeding 28 m^3 per minute. A Yellow Springs Instrument temperature probe number 405, located 4 cm above the subject's head, measured ambient temperature that varied between 23 °C and 25 °C, usually increasing during the day and, more so, when irradiating at a high power density. Humidity was measured at the start and end of each experimental day with an EL-TRONICS Model 106 hygrometer (Warren Components Division, EL-TRONICS, Inc., Warren, PA). The average humidity was 43% throughout the day.

Power density measurements were made with a Narda microline isotropic probe, model 8323, for the microwave incidence at the subject's muzzle which was 10 mW/cm^2 using the 0.5 μs pulse width and 43 mW/cm^2 with the 2.0 μs

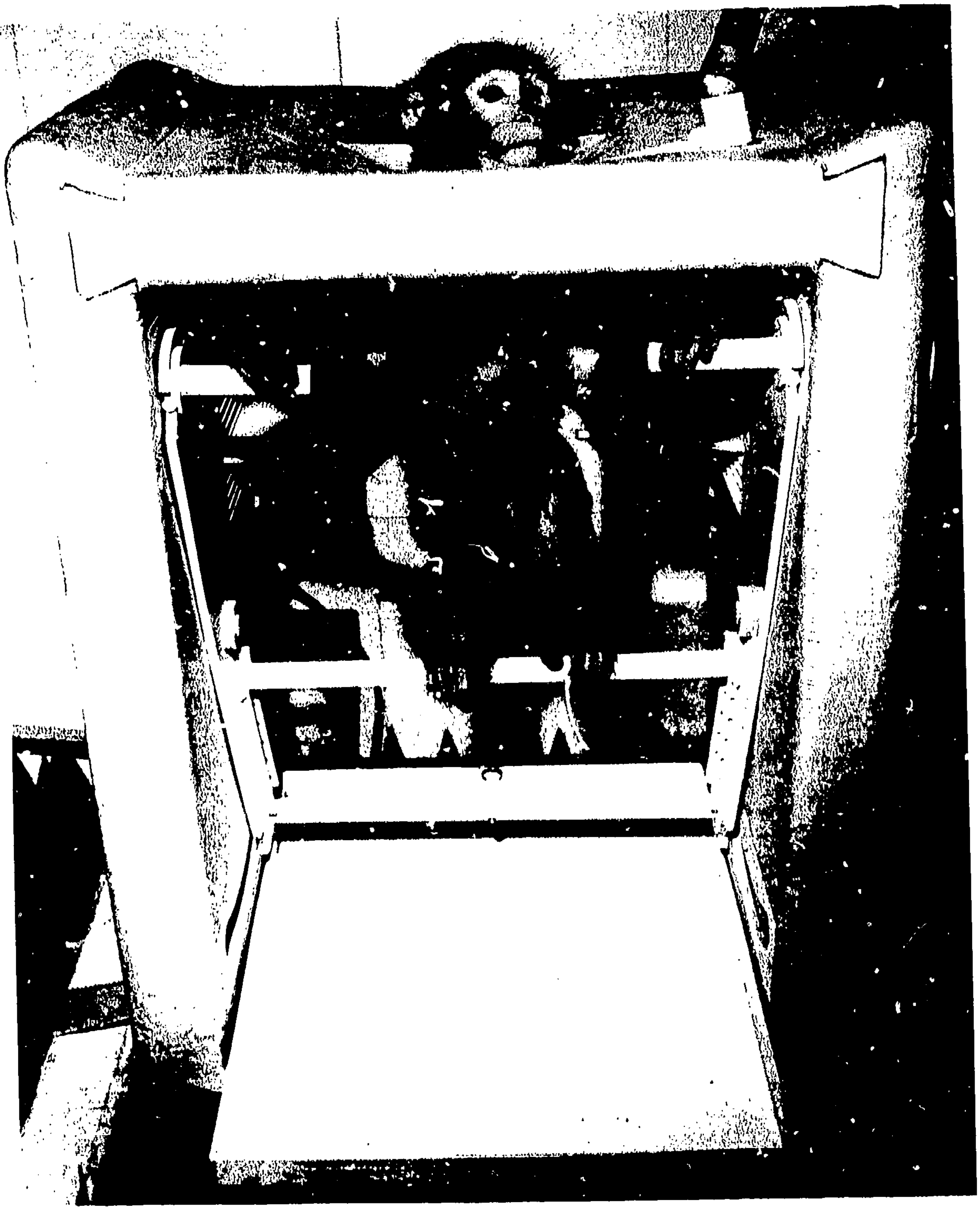

Figure 2. A male rhesus monkey sitting in a Styrofoam exercise chair equipped with handles and foot bar for pulling a reel spring attached to the chamber's outer wall and joined by cable to the chair's bottom bar. The food delivery tube is to the subject's left. The food pellet rolls into the trough before his mouth.

pulse width. All irradiations were in the far field of the horn. The formula, $2D^2/\lambda$, where D=diagonal of the horn opening and λ=radiation wave length, was used to define the minimum far field.

Procedures

Experiment I. Original training began with food deprived monkeys in a Plexiglas exercise chair and the animals were later moved into the microwave chamber in a Styrofoam chair. The goal of training prior to the microwave exposures was to have each subject physically exercise at three different response rates during an hour session and as a consequence receive food pellets equal to his daily nutrient need. Initally an attempt was made to accomplish this goal using a multiple random interval schedule (MRI) with 0.5, 1.0 and 2.0 minute intervals. The same work load was used for an entire session. However, it was found after 83 daily sessions that appropriate work response rates did not develop. Consequently, a multiple random ratio schedule (MRR) was introduced. This change produced differential response rates corresponding to three different work loads.

The MRR schedule required the subject to exercise during a session using the three different work loads and to receive a food pellet as reinforcement after making a random number of correct responses. The probability of food pellet delivery was programmed with two BRS-Foringer (Beltsville, MD) model PP-1 precision probability units connected in series (8). The probability-generator output unit was modified according to Clark and Hull (5) to prevent errors generated by incoming pulses and the unit's internal gating cycle.

After 50 daily sessions on the MRR 16 schedule (a mean ratio of 16 responses to each reinforcement), nine additional sessions were used to establish a base line. Then Experiment I, composed of 18 control and irradiation sessions, was conducted. Following that experiment, Experiment II was conducted with 15 intervening sessions for base line determination.

The final result of training was a subject that demonstrated three separate exercise rates during a behavioral session and each exercise rate directly correlated with a specific work load (using a spring constant of 0.6, 1.3, or 1.7 kg). Each 63-minute daily session was sub-divided into 1-minute pre-session, 54-minute behavioral session, and 8-minute post-session. Masking white noise was present during the entire session. The behavioral session was divided into a 15-minute exercise component followed by a 3-minute extinction component. The components were each repeated three times. During the pre-and post-sessions and extinction periods the levers were inoperative and the light was out. Spring work load was changed during each extinction component. The order of different work loads was changed each session so that no work load began or ended two consecutive sessions. Also the position (handles all the way forward or back) at which a correct response signal (audible tone) occurred was alternated each session. The tone was not operational during the extinction components. The sequential order of the spring work load series within a session was arranged in the following way and repeated throughout the course of Experiment I:

"G" series = 0.6 - 1.3 - 1.7 kg
"H" series = 1.7 - 0.6 - 1.3 kg
"I" series = 1.3 - 1.7 - 0.6 kg

After all subjects had finished the base line series, which was at the end of training session 142, 18 experimental sessions were conducted. Sessions were arranged so that a control session preceded and followed each microwave exposure session. A five-day work week was in effect; Monday, Wednesday, and Friday were control sessions, and microwave exposures were on Tuesday and Thursday. The work load sequence began with "G" and was repeated four times during the course of the experiment. Exposures began with a power density of 43 mW/cm^2 and alternated with 10 mW/cm^2 until an exposure to each power density occurred for each work load series. Consequently, data was obtained for each subject from three control sessions, one 10 mW/cm^2 session, and one 43 mW/cm^2 session for each work load series. Irradiation was always on during the exercise and extinction components of an irradiation session but not during pre-and post-session components. For control sessions the only difference was that the magnetron was not being pulsed.

During each experimental day, the rhesus monkeys were placed in the microwave exposure chamber in the same chronological order. About 35 minutes were required to remove one monkey from the chamber, return it to the vivarium and prepare another monkey. Total time devoted to a daily session with one animal was about 1.5 hours.

Conventional cumulative recordings of operant responding were obtained and a multi-styli recorder (Esterline-Angus Instrumental Company, Indianapolis, IN) registered moment-to-moment experiment events. Colonic and ambient temperatures were visually read and recorded, but only subject 15R was equipped with a colonic temperature probe.

Experiment II. A base line using only two work load series (increasing - "G" - 0.6, 1.3, 1.7 kg; decreasing - "K" - 1.7, 1.3, 0.6 kg) was established in sessions 161-176. Sessions were scheduled five days a week and repeated in the following sequence: G, G, K, K, G, K, K, G, G, K. Monday, Wednesday and Friday were control sessions; exposure sessions were on Tuesday and Thursday. All subjects were evaluated for acceptance and maintenance of a colonic temperature probe. Colonic temperatures were obtained from two monkeys, subjects 15R and 62N, during the session. Heart rates were determined in two other subjects, 1R and 2R.

A specific effort was made to keep the electrocardiography electrode sites out of direct microwave illumination and at the same time to have a non-invasive procedure. Two Holter monitoring disposable electrodes, part 18366P (Del Mar Avonics, Irvine, CA), were placed on the monkey in a 7-cm diameter area depilated in the middle back region and a 7-cm long portion depilated at the base of his tail. Depilation was accomplished with Neet (Whitehall Laboratories, New York, NY). It was found necessary to remove the hair from the electrode sites twice a week, at 0700 hours on Mondays and Wednesdays. After cleaning the area thoroughly with alcohol and allowing it to dry, electrically conductive gel (Spectra, 360 electrode gel, Parker Laboratories, Orange, NJ) was added to the Holter snap-lead type electrode and the electrode was secured to the electrode site with Elastikon elastic tape (Johnson & Johnson, New Brunick, NJ). Leads were attached to the electrodes before affixing them to the monkey (see Figure 3). The bipolar leads were connected to a Sanborn model 350-2700 high gain preamplifier (Hewlett-Packard, Sanborn Division, Waltham, MA) from which a signal was fed to a Sanborn Viso-Cardiette. Heart rate was measured from the electrocardiogram using a Valonics' heart rate per minute ruler (Valonics, Madison Heights, MI). Measures in heart beats per minute (BPM) were usually taken just after the subject had received a food pellet when the electrocardiogram was least erratic.

At the end of session 176 all five subjects had established reasonable stable behavioral and physiological base line measures. Consequently, Experiment II began with session 177 and continued for 34 sessions. The correct response tone always occurred on the arm backstroke. Control sessions separated the irradiation sessions. There were eight control and three each of 10 and 43 mW/cm^2 irradiation sessions for the increasing work load series and for the decreasing series nine control and three each of 10 and 43 mW/cm^2 sessions. Five additional sessions were required for subjects 2R, 15R, and 62N to compensate for sessions in which data were lost.

RESULTS AND DISCUSSION

Experiment I.

Figure 4 shows the relative effects of microwave power density on the five subjects' mean correct response rate under the three work load requirements. No microwave effects were obvious at 10 mW/cm^2 when using either the 0.6 kg and 1.3 kg work loads regardless of workload order. However, there was a microwave effect at 43 mW/cm^2 when exercising with the 1.7 kg work load. This effect was most evident when the 1.7 kg work load was being used in the terminal third of an experimental session. There was no difference evident between base line and control results.

Figure 5 contains a single subject's (62N) representative cumulative record results under all experimental conditions. The response rate difference between each work component is shown in this figure along with the rate decrease produced by the 43 mW/cm2 exposures. The effect of the higher power density is evident at each series when the 1.7 kg work load was used.

Figure 6 shows that subject 15R during control and 10 mW/cm^2 irradiation sessions had colonic temperatures approximately the same with elevations of about 0.5 °C. During the 43 mW/cm^2 sessions subject 15R's colonic temperature rose approximately 0.9 °C above control level. Note that his colonic temperature curves appear about the same regardless of work load series. Colonic temperature peaks usually occurred at the end of the terminal work load component.

General examination of the interresponse time data indicated no appreciable differences between control and irradiation session values.

Figure 3

Monkey fixed with electrodes for electrocardiography using bipolar leads. Note microwave irradiation absorbent material just in front of the tail.

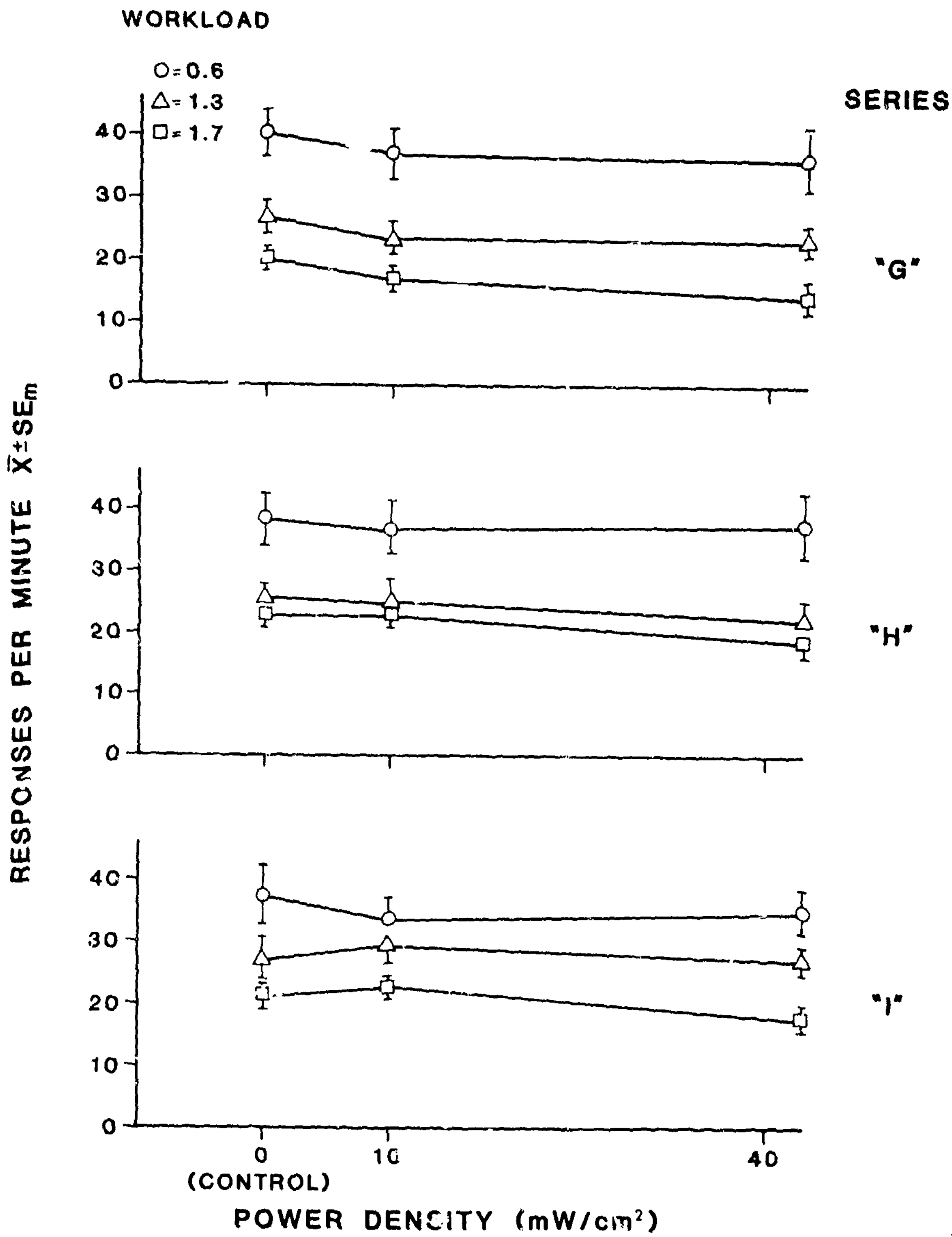

Figure 4. The mean and standard error of correct response rate from five male rhesus monkeys for each work load series under control and irradiation conditions. The N's for each subject's conditions were: control, N=3; 10 mW/cm^2, N=1; and 43 mW/cm^2, N=1.

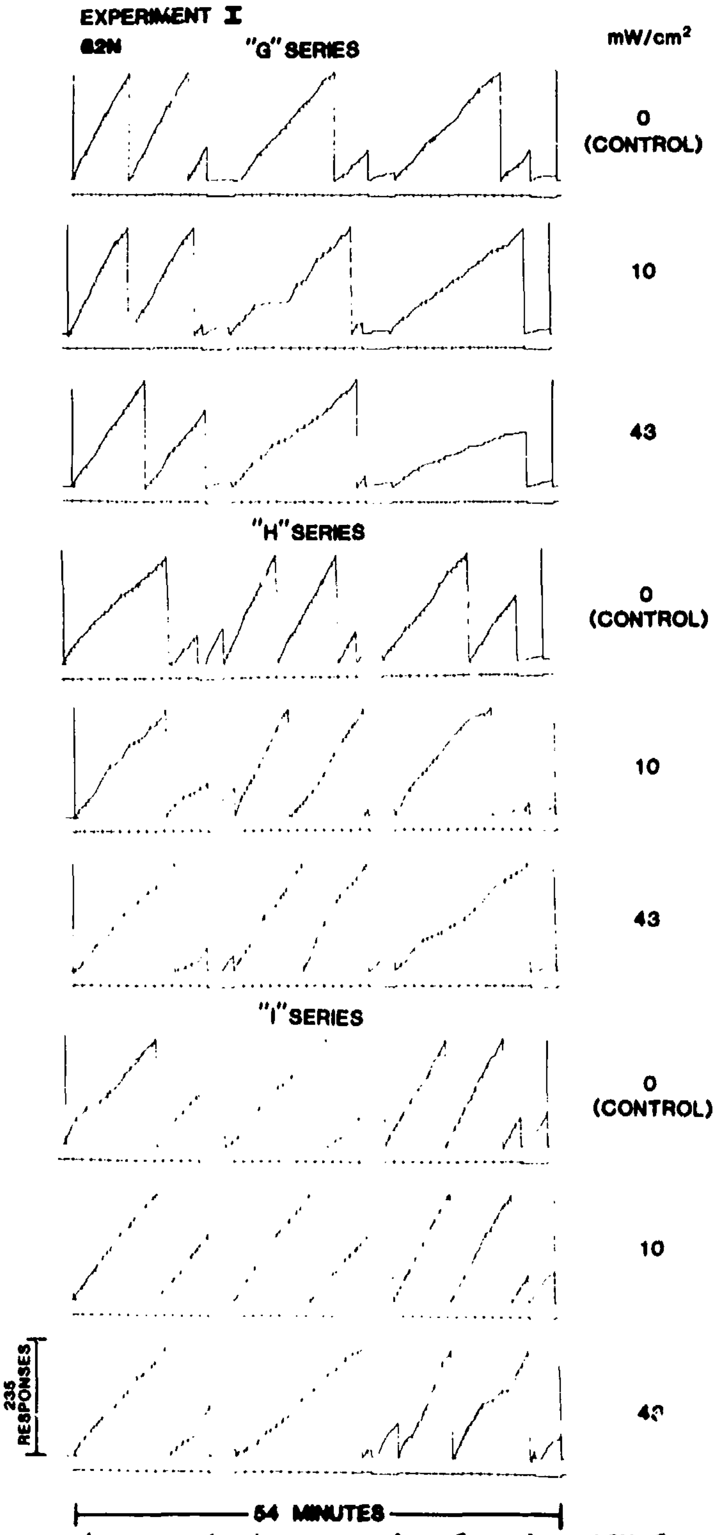

Figure 5. Representative cumulative records of monkey 62N for 5.62 GHz pulsed microwave experiment I series. Each record is a 54-minute exercise operant session. The response pen reset at the end of a component. The response pen was deflected with each food pellet delivery and stepped upwards with each correct response. The pen on the horizontal line below indicated with a vertical mark each minute of an exercise component and remained down during each extinction period.

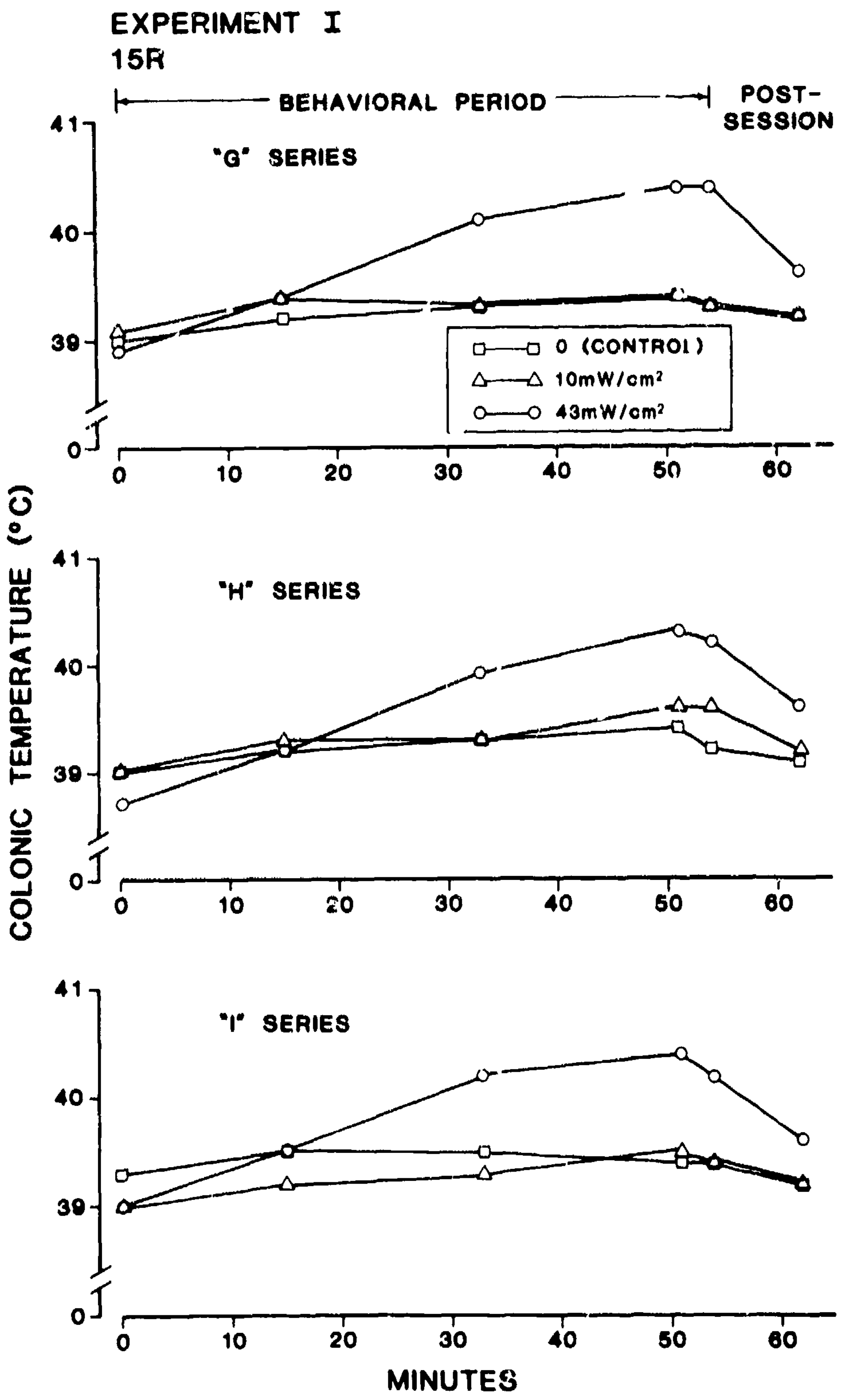

Figure 6. Colonic temperatures of subject 15R during Experiment I control (averaged) and 5.62 GHz microwave irradiation sessions.

The significant findings were that the greater work load (1.7 kg) in the presence of the 43 mW/cm^2 power density caused noticeable reduction in correct response rate, and, especially so when the heaviest load was at the end of the session ("G" or increasing series). Therefore, it was decided to investigate this phenomenon further by using the increasing work load series and a decreasing series of 1.7, 1.3, and 0.6 kg (a series not in Experiment I).

EXPERIMENT II.

Figure 7 presents the response rate data from the five subjects and the correct exercise response diminution effect is seen only at 43 mW/cm^2 when the work load increased during the experimental session. When the work load decreased there was no large response rate and power density interaction effect under any of the experimental conditions. Response curves similar to Figure 7 constructed for individual subjects reveal extremes of irradiation effects from none to a marked effect. The other subjects (9R, 15R, and 62N) have effects somewhere between.

Mean colonic temperature readings for subjects 15R and 62N under all conditions of the second series of experimental sessions are depicted in Figure 8. On the average there was no difference between colonic temperature changes taken under the control situation and those of 10 mW/cm^2. There was a mean difference in colonic temperature change of +0.8 °C when comparing control and 43 mW/cm^2 values. The graphs of Figure 8 revealed a slightly greater rate of increase in colonic temperature during the first fifteen minutes of the decreasing work load series.

Figure 9 gives average heart rates (BPM) and average exercise rates (responses per minute) measured at regular intervals during pre-, behavioral and post-session portions of a daily session for two subjects, 1R and 2R. A comparison of the graphs of both subjects reveals their idiosyncratic exercise heart rate and exercise response rate. Subject 1R had a higher heart rate during exercise (240-270 BPM) than subject 2R (190-210 BPM). Note that subject 1R's correct response rate was less than control rates during irradiation and he had corresponding heart rates below control measures during the decreasing series. On the other hand, subject 2R whose exercise rate was affected very little by irradiation, had heart rates throughout the irradiation session that were consistently higher than control values. For subject 2R the same relation of control and irradiation heart rate measures continued during the 3-minute extinction periods when he was not exercising and this was also true for subject 1R when he had worked in the previous exercise component. Note that in every instance for 2R the 43 mW/cm^2 irradiation heart rate values at the beginning of the post-session continued to be greater but after 7-8 minutes into the session these values were near control values.

CONCLUSIONS

From the results of Experiments I and II it is evident that three separate effects of 5.62 GHz pulsed microwave irradiation at 43 mW/cm^2 are present and that irradiation at 10 mW/cm^2 produced no large effect. The three effects at 43 mW/cm^2 were: (1) decrease from control values of

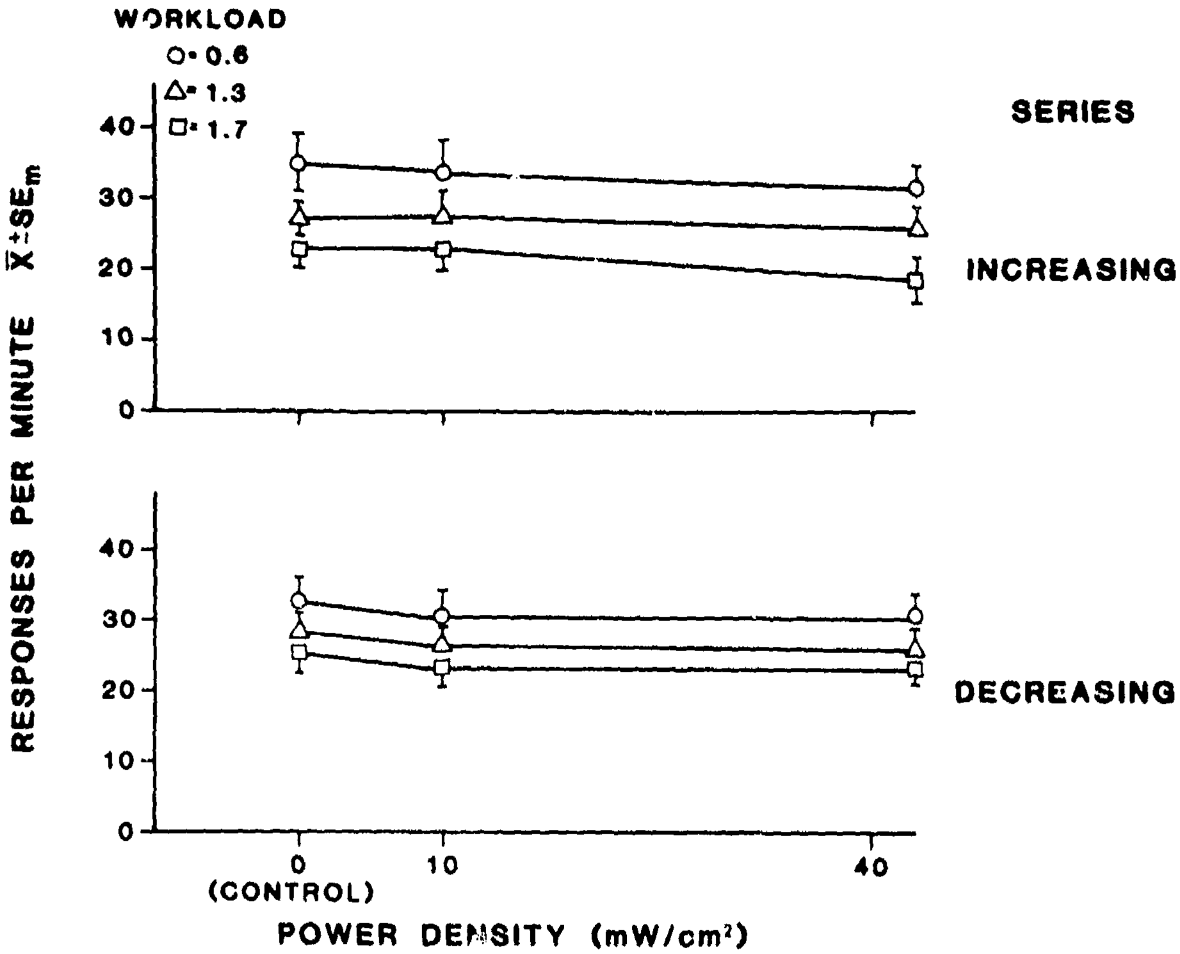

Figure 7

Graphs of the mean number of correct exercise response rate for a group of five male rhesus monkeys at each work load series (increasing-0.6, 1.3, 1.7 kg; decreasing-1.7, 1.3, 0.6 kg) under control and 5.62 GHz pulsed microwave irradiation conditions (10 mW/cm^2 and 43 mW/cm^2). The N's for each subjects' condition were: increasing control, N=8; decreasing control, N=9; 10 mW/cm^2, N=3; 43 mW/cm^2, N=3.

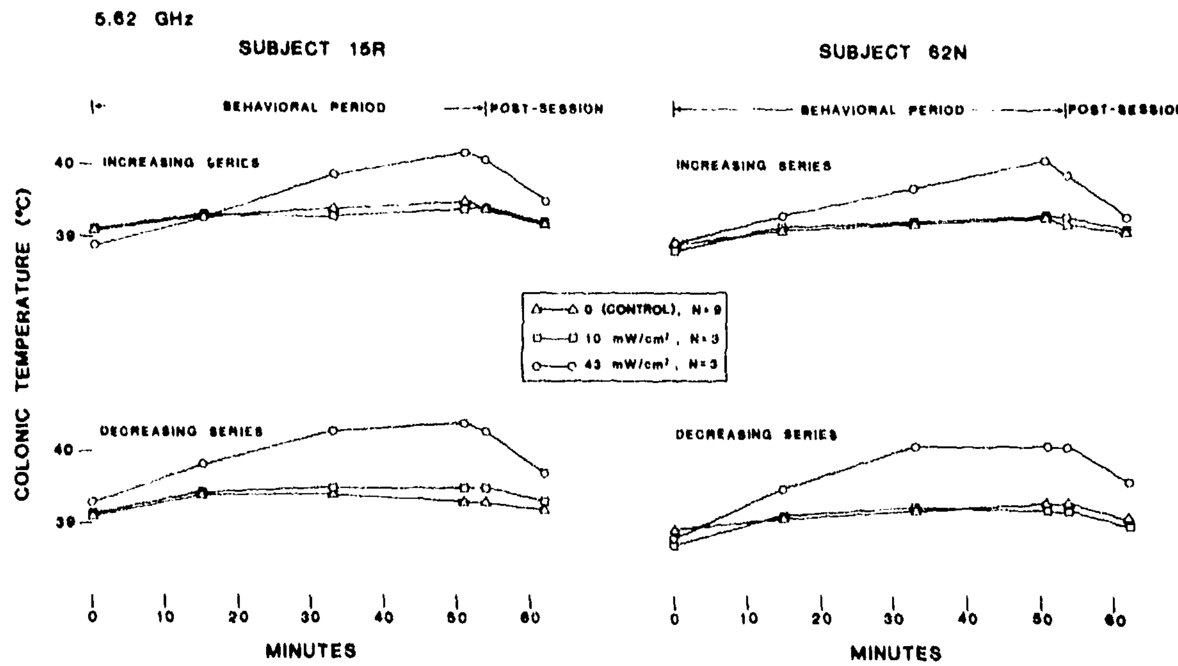

Figure 8

Mean colonic temperature graphs for subjects 15R and 62N during Experiment II (5.62 GHz) control (N=9) and microwave irradiation sessions (N=3 at 10 mW/cm^2, N=3 at 43 mW/cm^2.

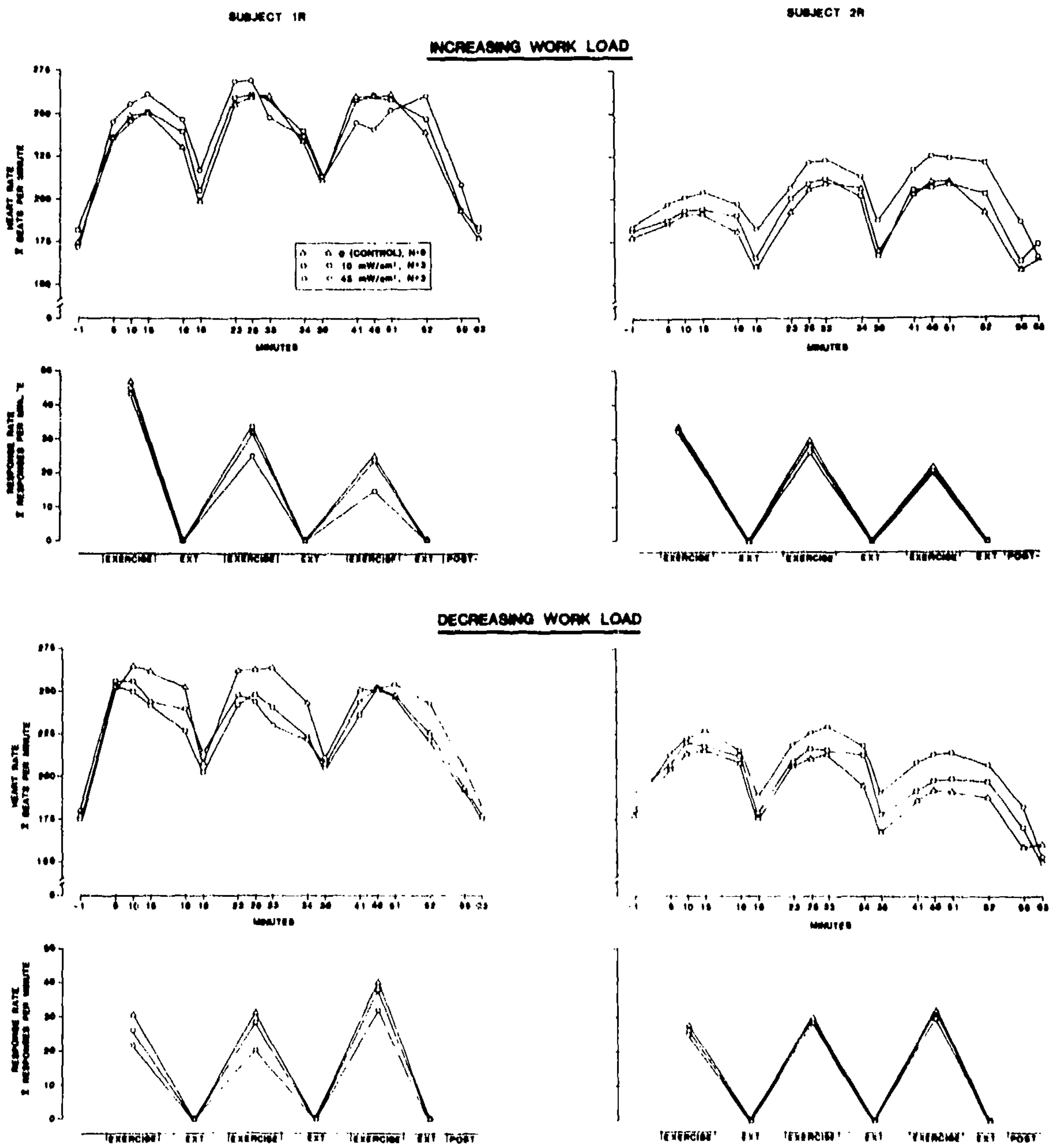

Figure 9

Averaged heart rate and correct exercise response rate graphs of subjects 1R and 2R during Experiment II (5.62 GHz). Each 15 min exercise component of the experimental session is broken into three 5-min portions. Each 3-min extinction (E) period is broken into a first and a third minute. The post-session values are for one minute after the end of the experiment session and 8 minutes later.

correct exercise response rate (N=5) only when the heaviest work load (1.7 kg) was being used and especially if it was the work load during the last component of the behavioral session; (2) a higher than control heart rate when exercising for one subject (2R); and (3) and an average 0.8 °C colonic temperature increase over control level (N=2).

1.28 GHz EXPERIMENT

METHOD

Subjects

Four of the five rhesus monkeys used in the 5.62 experiments were used as subjects at between 85 and 90% of their base line weights. At the start of this series new base line weights were established: Subject 1R, 3.90 kg; subject 2R, 3.77 kg; subject 15R, 3.77 kg; and subject 62N, 4.01 kg. Maintenance and handling of the subjects were the same as for the previous experiment.

Apparatus

The outside dimensions of the anechoic exposure chamber measured 3.40 m long, 2.20 m wide, and 2.35 m high, and it, too, was shielded with copper and then completely lined with 20.4 cm pyramidal absorber (AAP-8). A Styrofoam wall was placed anterior to the absorber near the wall opposite the radiation source to permit better ambient temperature control. The exposure chamber was equipped with a closed circuit television camera, speakers, lights and an ambient temperature.

A radar set AN/TPS-1G (Hazeltine Corporation, Little Neck, NY), was the source of 1.28 GHz microwaves pulsed at 370 pulses per second (pulse duration, 3 μs). A custom-made horn was connected with a coaxial transmission line to the radar. The ventral surface of the animal was irradiated (E polarization) while the animal was restrained in an upright seated position in a Styrofoam exercise chair. Power density measurements were made with a Narda Microline isotropic probe, model 8323, for the microwave incidence at the subject's muzzle. The measures were 25, 41, and 89 mW/cm^2. The 25 mW/cm^2 chair position was in the far field of the horn and the 41 and 89 mW/cm^2 positions were in the intermediate or near field (minimum far field = 169 cm from horn).

The exercise chair shown in Figure 2 was used. The food reinforcer and food delivery were the same as for the 5.62 GHz experiments. General illumination was provided by a white 25 Watt overhead bulb if an experiment was not in progress, but when one was active a white 60 Watt light above the horn was used. When the radar set, ventilation fans and white noise were all on the sound pressure level was 79 dB.

Computer-operated control and recording equipment were located in an adjoining room. Details of that system will be described in a later report.

Temperature, humidity and heart rate measurements were conducted just as for the 5.62 GHz experiments except the temperature and heart rate analogue data were converted to digital form for computer acquisition and storage. Electrode sites on the monkey were prepared as needed with a rotary razor.

Ambient temperature varied between 22 ° and 24 °C and the average humidity was 64% during the day.

Procedure

Following the 5.62 GHz experiments there was a 5-month interim for changing radar exposure chambers and developing computer control, recording, and data acquisition techniques. Subsequently, there were 12 sessions for adapting the monkeys to the new conditions.

The result of these training sessions was a subject who demonstrated three separate exercise rates during a multiple random ratio schedule of 16 responses per each reinforcement (MRR 16) and each exercise rate directly correlated with the animal's performance using a specific work load (0.6, 1.3, or 2.2 kg). Each 84-minute daily session was subdivided into 15-minute pre-session, 54-minute behavioral session, and 15-minute post-session. White noise was present during the entire session. The behavioral session was divided into the following components: 15-minute exercise; 3-minute extinction; 15-minute exercise; 3-minute extinction; 15-minute exercise; 3-minute extinction. During the pre-and post-sessions and extinction periods the levers were inoperative and the light was out.

Work load schedules and arrangements that follow were similar to those of the 5.62 GHz Experiment II except that a larger work load was used (increasing: "L" - 0.6, 1.3, 2.2 kg; decreasing: "M" - 2.2, 1.3, 0.6 kg). The experiment was conducted five days a week in the following sequence: L, L, M, M, L, M, M, L, L, M. All four subjects became adapted to colonic temperature probes and heart rate electrodes during the next 15 sessions. Electrocardiography (note Figure 3) and colonic temperature measurement were conducted in the same way as for the 5.62 GHz Experiment II except that the data was acquired by computer and stored for later analyses.

Following adaptation of the subjects to the temperature and heart rate hardware, there were 20 sessions of behavioral and physiological base line measures. Consequently, the 1.28 GHz experiment began at the end of the base line establishment and continued for 63 sessions. The correct response tone always occurred on the arm backstroke. Control sessions separated the irradiation sessions as before. There were 9 control and three each of 25, 41 and 89 mW/cm^2 exposure sessions, for both the increasing and the decreasing work load series.

RESULTS AND DISCUSSION

Table I shows that group mean colonic temperature differences between control and exposure sessions significantly increased and the differences were greater with each higher power density.

Table I

Means (N=4) of control (C) and exposure (E=1.28 GHz) sessions with their mean and percent mean differences ($\overline{\text{DIFF}}$). Increasing (INC) and decreasing (DEC) work load mean values (Mean ± SE).

POWER DENSITY		COLONIC TEMPERATURE (°C ± SE)				EXERCISE HEART RATE (BPM ± SE)				EXERCISE RESPONSE RATE (RPM ± SE)			
		INC		DEC		INC		DEC		INC		DEC	
		C	!	C	E	C	E	C	E	C	E	C	E
25 mW/cm²	S[‡]	38.28 ± .06	38.38 ± .12	38.18 ± .07	38.38 ± .10	192 ± 5.3	200 ± 5.3	189 ± 8.2	196 ± 7.4	33 ± 4.7	31 ± 2.9	33 ± 4.4	31 ± 4.5
	M	38.79 ± .07	39.17 ± .15	38.63 ± .09	39.12 ± .14								
$\overline{\text{DIFF}}$		0.28 ± .05*		0.33 ± .07**		7.75 ± 4.09		7.25 ± 3.35		-1.25 ± 1.89		-2.25 ± .75	
41 mW/cm²	S	38.28 ± .10	38.32 ± .13	38.40 ± .13	38.51 ± .06	194 ± 8.7	204 ± 6.8	198 ± 6.7	208 ± 10.0	31 ± 4.5	28 ± 3.4	32 ± 3.5	30 ± 3.8
	M	38.60 ± .18	39.26 ± .21	38.86 ± .09	39.55 ± .16								
$\overline{\text{DIFF}}$		0.57 ± .07*		0.58 ± .11*		10.00 ± 5.96		10.52 ± 5.32		-3.75 ± 1.49		-2.00 ± .71	
39 mW/cm²	S	38.34 ± .16	38.37 ± .10	38.44 ± .11	38.40 ± .09	196 ± 7.7	217 ± 12.0	189 ± 8.6	220 ± 11.3	33 ± 3.7	21 ± 2.6	33 ± 4.1	17 ± 0.7
	M	38.89 ± .20	40.32 ± .27	38.87 ± .15	40.43 ± .22								
$\overline{\text{DIFF}}$		1.43 ± .12*		1.61 ± .18*		21.00 ± 8.74		30.50 ± 10.14		-12.50 ± 1.19*		-16 ± 4.04**	

‡S=Start of session; M=maximum colonic temperature recorded during session.
* P=0.01
** P=0.05

Figure 10 graphically depicts rise of group (N=4) mean colonic temperature with exercise alone (control) and exercise plus irradiation. With only exercise there was an average 0.45 °C increase, with exercise plus 25 mW/cm^2 there was an average 0.8 °C increase, with exercise plus 41 mW/cm^2 there was an average 1.0 °C increase and at 89 mW/cm^2 there was an average 2 °C increase in colonic temperature due to microwave and exercise thermal loads. Note in Figure 10 that comparable mean colonic temperature curves for the group have both the same general configurations and rates of increase regardless of work load order. Figure 11 is a single subject's (15R) record of mean temperature that shows the similarity of an individual to the group (Figure 10).

Figure 12 is composed of group (N=4) mean heart rate and response curves for the 25 mW/cm^2 microwave exposure and control sessions. It is seen in Figure 12 that heart rate varies directly and mean responses vary indirectly with work load except for the heart rate during the exposed decreasing work load series. Heart rates during exposure were at times slightly greater than control but mean responses remained about the same. Table I gives group means of control and exposure session heart rates and responses per minute (RPM) for increasing and decreasing work loads. The Table I heart rate and response rate values for percent differences between control and exposure sessions reflect the small differences evident in Figure 12.

Figure 13 shows the control and exposure results for group mean heart rates and responses at 41 mW/cm^2. At this increased power density heart rate is about 5% greater than control and the average response rate is 8% less than control. Note in Figure 13 that during the terminal third of exposure in the increasing series there was a large reduction in mean response rate from control rate, although the corresponding heart rates were about the same.

Figure 14 contains the group (N=4) heart rate and response graphs for exposure and control sessions at 89 mW/cm^2. As shown by Table I the 41% response rate decrease from control rate at this power density was significant and heart rate increased an average of 13% over control rate.

As seen in Figures 12-14 mean heart rate ranged between 126 and 226 BPM and the usual pre-session resting heart rate was about 135 BPM. During the increasing work load series heart rate initially went from 130 to 180 BPM, an increase of 50 BPM. During the decreasing work load series it went initially from 125 to 200 BPM, an increase of 75 BPM. Once the mean heart rate had increased during exercise while exposed to microwaves, it remained at a higher than control rate even though the response rate was lower. Once the microwave exposure stopped, heart rate gradually approached the control rate. Heart rate decreased substantially during the extinction components of the session when there were only a few responses. As power density increased extinction heart rates of irradiated animals were greater than control values.

Individual variability was noted for all types of measurements, from no differences to highly significant differences between control and

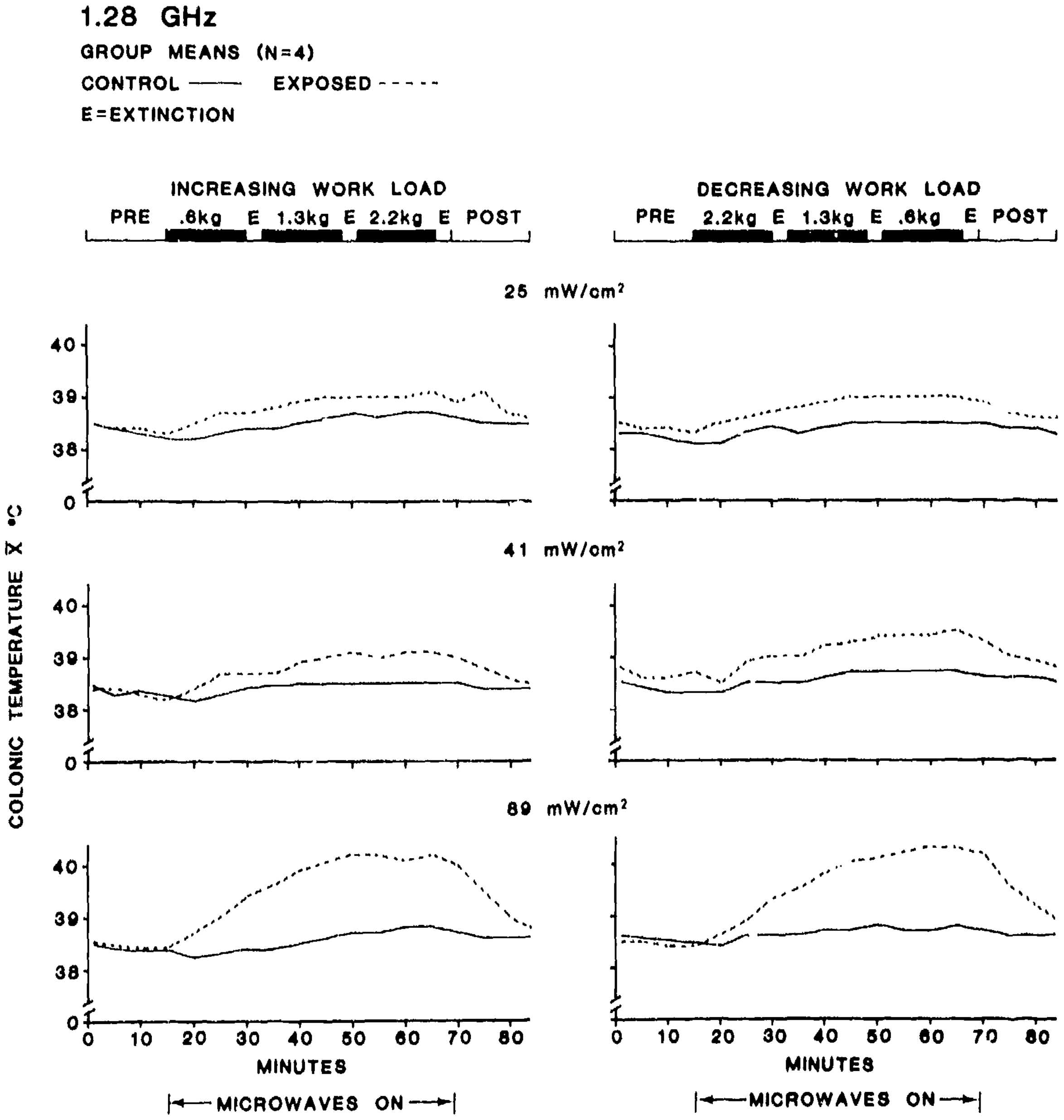

Figure 10

Group means (N=4) of colonic temperature recorded during start, each fifth minute, and end of an 84-minute experimental session; 1.28 GHz and 25 mW/cm^2, 41 mW/cm^2, and 89 mW/cm^2.

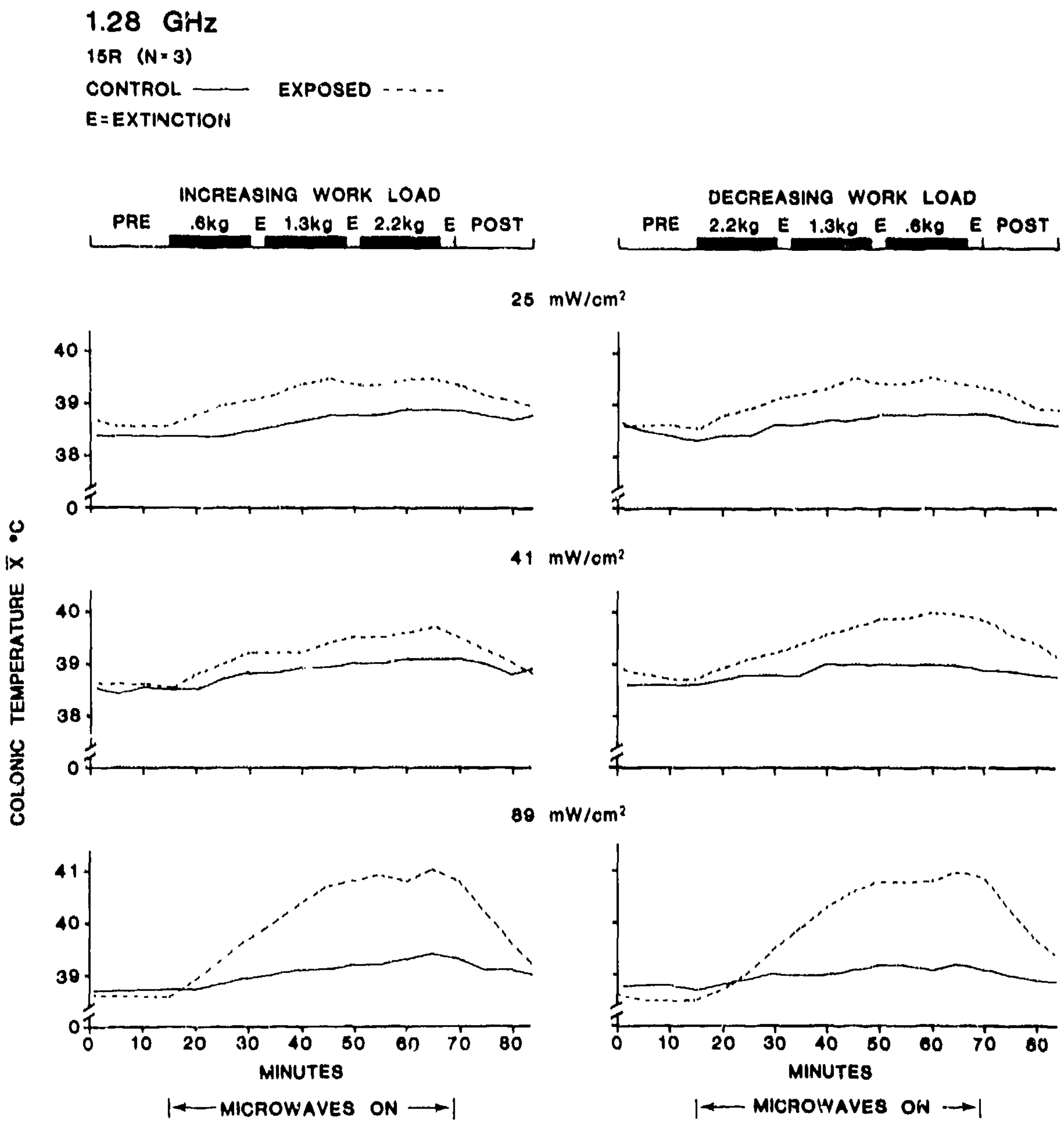

Figure 11

Subject 15R's means (N=3) of colonic temperature recorded during start, each fifth minute, and end of an 84-minute experimental session; 1.28 GHz and 25 mW/cm^2, 41 mW/cm^2, and 89 mW/cm^2.

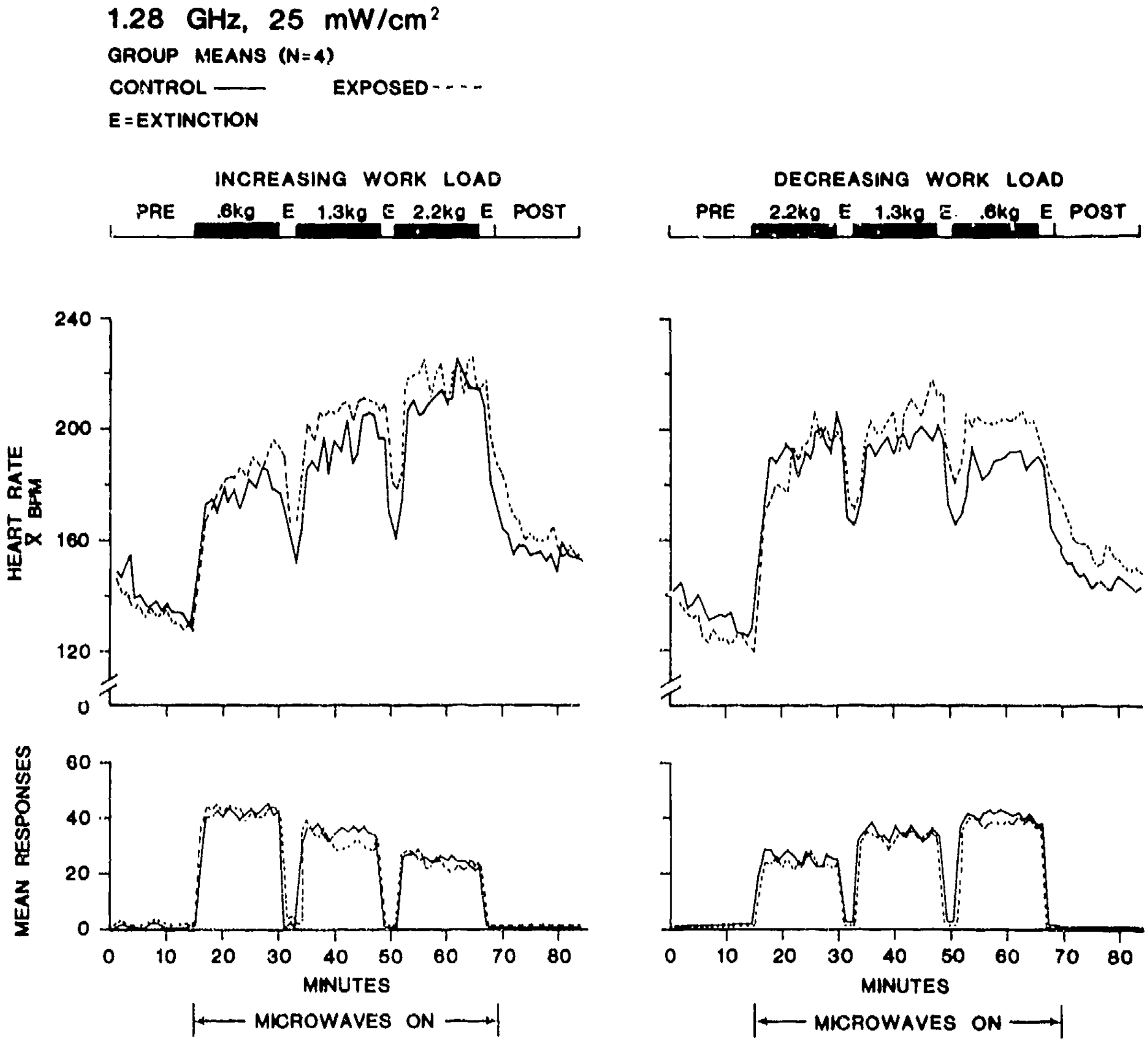

Figure 12

Group means (N=4) of heart rate and correct exercise responses during consecutive minutes of an 84-minute experimental session; 1.28 GHz, 25 mW/cm^2.

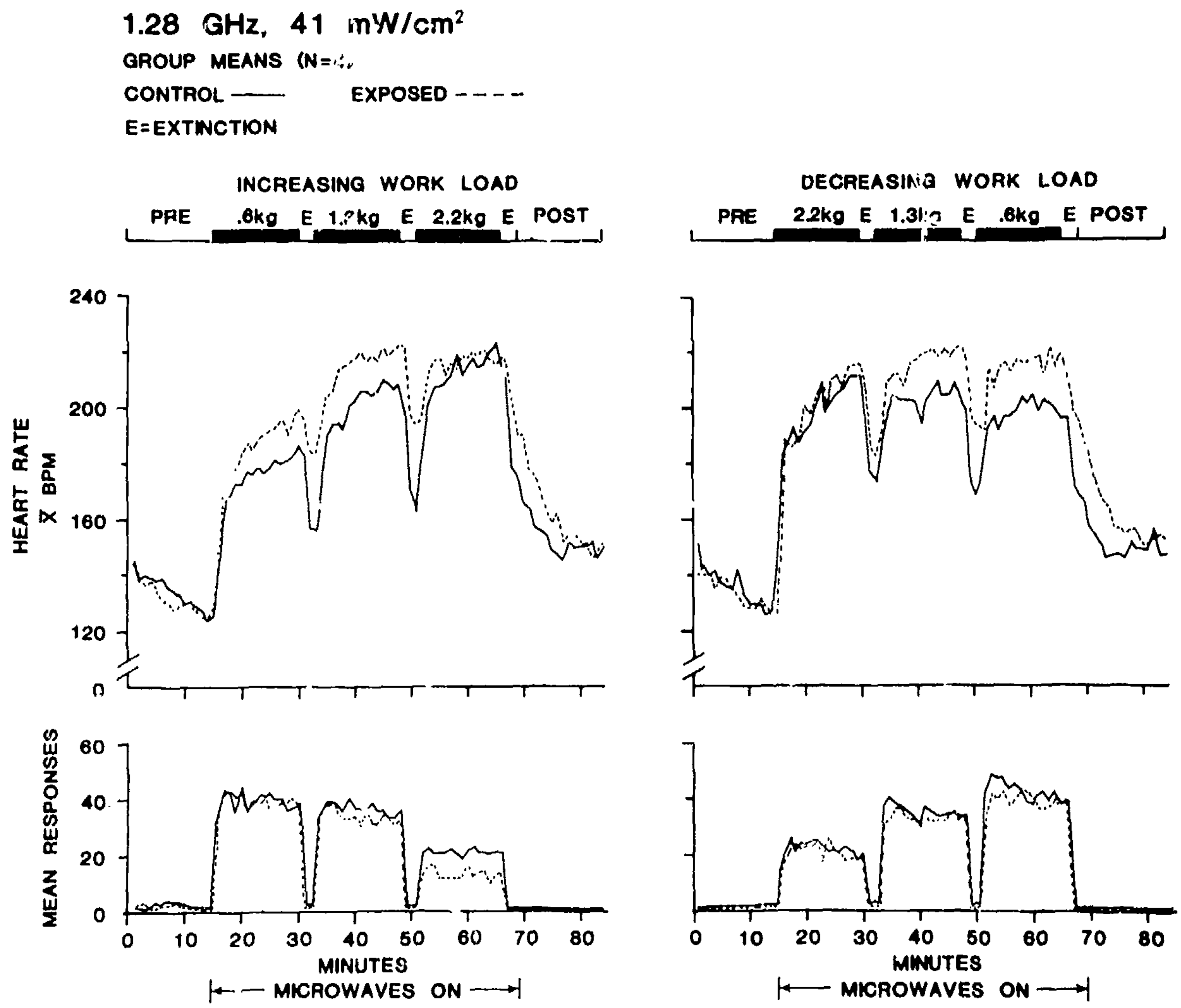

Figure 13

Group means (N=4) of heart rate and correct exercise responses during consecutive minutes of an 84-minute experimental session, 1.28 GHz, 41 mW/cm^2.

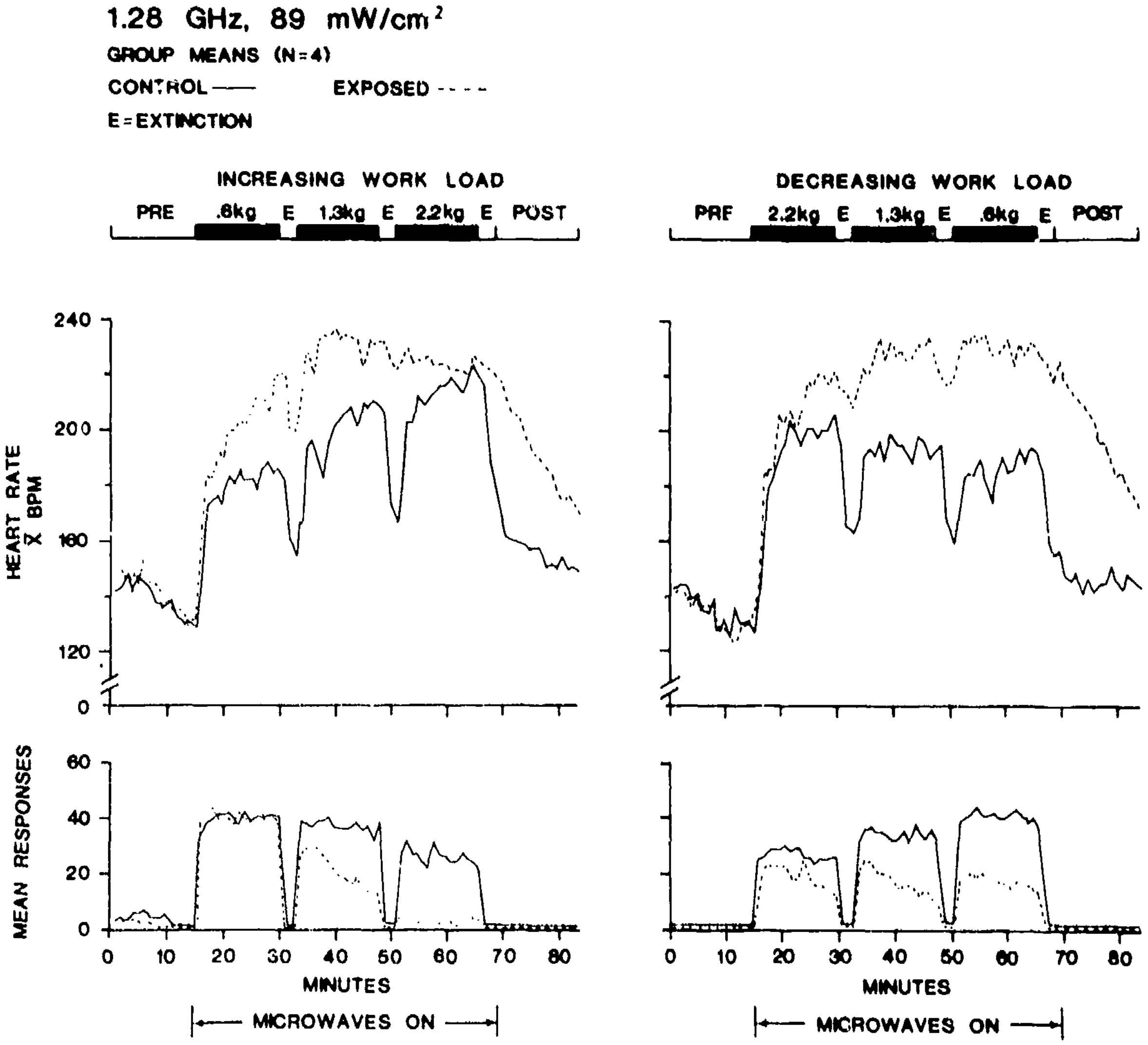

Figure 14

Group means (N=4) of heart rate and correct exercise responses during consecutive minutes of an 84-minute experimental session; 1.28 GHz, 89 mW/cm^2.

exposure values. Subject 15R demonstrated (a) the most signficant differences between control and exposure sessions for mean colonic temperature and mean heart rate and (b) least mean response rate change differences.

Neither mean interresponse time nor mean post-reinforcement pause time measures were remarkably changed from control values by exposures to 1.28 GHz pulsed microwaves.

Figure 15 presents the plots of 1.28 GHz exposed heart rate and response rate deviations from control values according to each power density and work load series. An ordinate value of 1.0 indicates no difference between exposed and control values, greater than 1.0 an increase above control and less than 1.0 a decrease below control. Note in Figure 15 the increasing work load series behavioral effect at 41 mW/cm^2 that is not evident in the decreasing series.

Since there appeared to be a real interaction between power level, response rate, heart rate and work load order, an attempt was made to determine the degree of significance of that observation. Because the 1.28 GHz data of Figures 12-14 indicated that with increasing power density and work load there was greater than control heart rate increase and response rate decrease, the ratio of heart rate/response rate was used as the dependent variable in an analysis of variance (ANOVA). The data was analyzed using a three factor analysis of variance (10, 18) in which power density level, order of work loads, and work load value were the factors. This design resulted in a 3 X 2 X 3 X 4 factorial ANOVA with the last factor as the subject factor. All heart rate/response rate ratios of all factors were sampled for each subject. The subject factor interaction with the other factors constituted the error variance. The ANOVA showed that increasing power density had a significant effect on heart rate and response rate changes in exercising rhesus monkeys ($F=7.5$; d.f.=3&9; $p = < .01$) and that the amount of change was significantly dependent upon work load ($F=9.41$; d.f.=2&6; $p = < .025$).

GENERAL DISCUSSION

Work load order did not seemingly affect the rate of colonic temperature increase. Maximum colonic temperature was usually obtained during the middle or terminal third of the behavioral period. Metabolic heat generated by exercising (control) caused a mean +0.45 °C colonic temperature change during a session (see Table I). Table II shows the mean colonic temperature increase caused by microwave irradiation at the frequencies and power levels used in these experiments.

Note in Tables I and II that during both work load series at the 41-43 mW/cm^2 range, combined exercise and microwave thermal loads exceeded 1 °C. Exposures of subjects at this power density range showed greater behavioral sensitivity during the increasing work load series than the decreasing series. The increasing series results appear to substantiate previous work reporting behavioral effects at these colonic temperature increases (6, 7). The decreasing work load series results do not show a significant decrease in response rate at the 41-43 mW/cm^2 level even though there is a

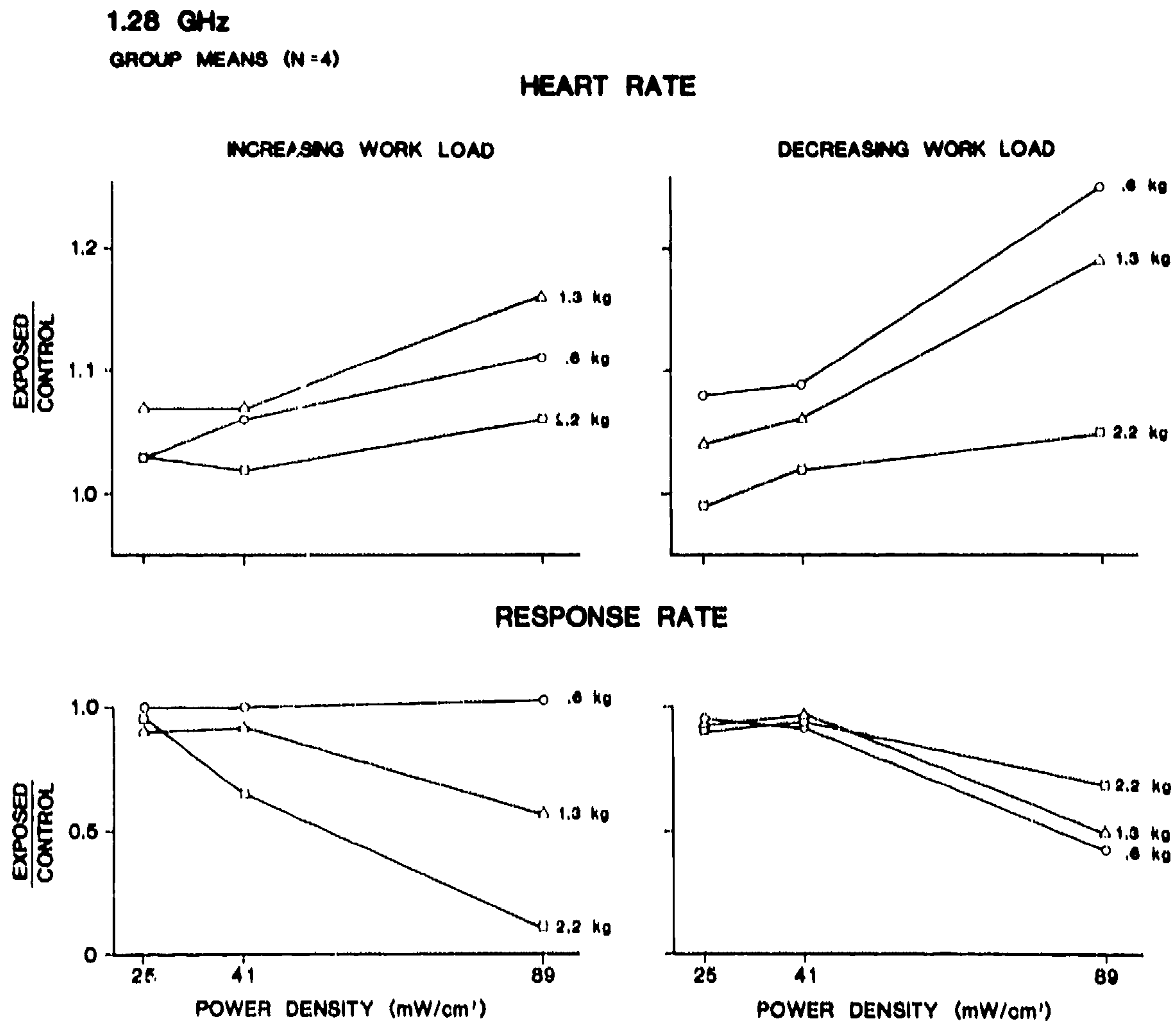

Figure 15

Plots of mean exposed/control heart rate and response rate ratios (N=4) for each work load and power density (1.28 GHz).

TABLE II

Mean temperature increase above control during irradiation of exercising rhesus monkeys. The exercise alone caused mean colonic temperature increase of 0.45 °C.

POWER DENSITY (mW/cm^2)	1.28 GHz (N=4)	5.62 GHz (N=2)
10		none
25	0.3 °C	
41	0.6 °C	
43		0.8 °C
89	1.5 °C	

1 °C difference between presession and exposure. This may indicate a possible relative beneficial behavioral effect of a relatively heavy work load when starting to exercise, or work, in a microwave field. This finding suggests that strenuous work under those conditions may promote improvement of thermoregulatory efficiency (heat acclimatization) as mentioned in a literature review by Cabanac (4) from his evaluation of a study by Marcus using human subjects (15).

These experiments demonstrate that microwaves will produce cardiovascular effects in addition to those produced by exercise alone and that body temperature induced by microwave energy does not seem to be further accelerated by exercise. The results also illustrate that monkeys working a physically arduous task are more likely to stop working when exposed to microwaves than when working a less arduous task. Finally, the results show that although heart rate is increased with increased work load the increment attributed to microwaves seems to be independent of the increment caused by exercise.

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Microwaves are present-day components of the naval environment. Consequently, it is desirable to know the biological effects that working personnel undergo when in the vicinity of operational radar equipment. Previous research has shown that animals other than man can provide useful models for assessing microwave effects. The present experiment studies both behavioral and physiological consequences of exposing exercising rhesus monkeys to microwave radiation.

In experiments using 1.28 and 5.62 GHz pulsed microwave irradiation,

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) operantly conditioned male rhesus monkeys exercised at three different work levels while exposed to the microwaves.

At 1.28 GHz four of the monkeys were exposed to power densities of 25, 41, and 89 mW/cm^2. Response rate, heart rate and colonic temperature were correlated with work load and power density level. At the highest power density exercising animals consistently had a lower response rate, a higher heart rate, and a greater increase in colonic temperature. At lower power densities the effects were generally less and idiosyncratic.

At 5.62 GHz five monkeys were exposed to power densities of 10 and 43 mW/cm^2. Differences from controls were found only at 43 mW/cm^2: (1) colonic temperature averaged +0.8 °C higher (N=2), (2) response rate decreased (N=5) when the heaviest work load occurred during the terminal third of the session, and (3) heart rate (N=2) was higher.

At 1.28 GHz and 41 mW/cm^2, when a heavy work load occurred during the last third of a session response rate decreased. If the heavy work load was at the start of a session there was no response rate drop. During both work load series at the 41-43 mW/cm^2 range, combined exercise and microwave thermal loads exceeded 1 °C. This confirms previous work reporting threshold colonic temperature derivatives.

Other behavioral measures (interresponse time and post-reinforcement pause time) demonstrated no appreciable differences between control and irradiation sessions at either microwave frequency.

These experiments demonstrate that microwaves will produce cardiovascular effects in addition to those produced by exercise alone and that body temperature induced by microwave energy does not seem to be further accelerated by exercise. The results also illustrate that monkeys working a physically arduous task are more likely to stop working when exposed to microwaves than when working a less arduous task. Finally, the results show that although heart rate is increased with increased work load the increment attributed to microwaves seems to be independent of the increment caused by exercise.