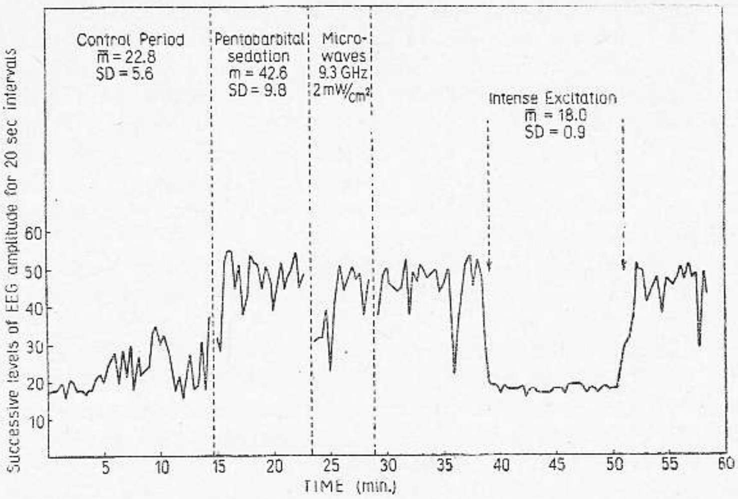

Fig. 3. Time-course changes in EEG amplitudes before, during and following microwave exposure.

ever, the difference is that with such drugs the hyperstimulation was sustained over long periods of time while with microwaves it waxed and waned.

The behavior of the animals during the periods of low EEG amplitude and variability was most unusual for rabbits, in that they exhibited repeated head movements, scratching, grooming, and uncoordinated locomotor activity. In fact, it was sometimes difficult to keep the animals in the chamber and some experiments had to be terminated early because the rabbits repeatedly unplugged the cable connecting the electrodes to the recorder by their violent jerking movements. In the example presented in Figure 3, the animal was in a catatonic-like state, with fixed gaze and a frozen posture.

Averaging the latencies for the occurrence of arousal did not reveal any significant relationship with the power density. However, the duration of arousal, computed by cumulating all the successive such periods for each experiment, indicates a possible dose-related increase. For 1.44 mW/cm^2 the duration of arousal was, on the average, of 240 ± 75 s while for 2.88 mW/cm^2, the duration was of 768 ± 78 s (nine experiments in each case; same total exposure time, namely 5 min.). In the absence of microwaves, the mean cumulated arousal time was 75 ± 12 s (12 experiments).

Although we have not been able to obtain direct measurements of the brain temperature during exposure, it seems doubtful that the EEG and behavioral effects could have resulted from a thermal change. In a number of published reports, it has been well demonstrated that with power densities of 0.7 to 2.8 mW/cm^2 there is no detectable increase in brain temperature. Furthermore, one of the most striking features of the microwave action has been the latent period following exposure, before over excitation. It is difficult to conceive of a delayed thermal effect. The same argument can be used as far as pain is concerned. If the excitatory effects result from a reaction to pain, one would have to account not only for the latency but also for the dose-related relationship. As a matter of fact, two experiments were run in which morphine sulfate (1 mg/kg) was substituted for pentobarbital: the microwave effect was as pronounced and as long lasting, with similar latent occurrence.

We do not have at present any direct indication of the mechanism (or mechanisms) of action of microwaves. However, there is a striking resemblance between the changes

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

observed after administration of microwaves and those produced by acute injection of naturally occurring compounds modified chemically to contain stable free radicals (1). With such compounds one finds a waxing and waning of excitation-sedation periods and also a latency between administration and appearance of the effect. This raises the possibility that microwave exposure produces or enhances the formation of free radicals from naturally occurring compounds in the brain. It is interesting that the effects of free radical compounds are present in spite of adrenergic blockade, depletion of catecholamines and serotonin, as well as cholinergic blockade (2), which suggests a mechanism different from the one existing under "classical" stimulatory actions.

In the course of the experiments reported, it was found that the microwave effects disappeared when the relative humidity reached or exceeded 40%. It may be that transmission of the waves through the fur is impaired in rabbits whose long hairs are known to adsorb water. Further experimentation is planned in which this environmental factor will be controlled.

Acknowledgments

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WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

PSYCHOGENIC STRESSORS ARE POTENT MEDIATORS OF THE THERMAL RESPONSE TO MICROWAVE IRRADIATION

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The data of several recent studies have confirmed observations of antiquity (3) that emotional arousal in mammals is paralleled by a rise of temperature in the core of the body. An elevation of colonic temperature to one degree Celsius or more appears to be an invariant reaction of the conscious animal to physically noxious stimuli (5), to physically benign stimuli that are novel to the organism (1, 2), or physically benign stimuli which have repeatedly been associated with a noxious event (4). The elevation of temperature appears within a few seconds and, if the evoking stimulus is of brief duration, usually dissipates within one to two minutes of time. We have given the label of Evoked Thermocolonic Response (ET_cR) to the reaction and are currently using it as an index of the ability of small mammals to detect microwave energy at low rms-densities.

Because the ET_cR is a new concept from the standpoints of application, instrumentation, and measurement, some justification and qualification of its use are in order. By way of justification, we note, first, that the behavioral indicant of choice for determining perceptual sensitivity to exotic stimuli — the mix of methodologies from Pavlovian and Instrumental conditioning known as conditioned suppression — is extraordinarily laborious and time-consuming when large numbers of experimental subjects are to be studied. Second, the neurophysiological indicant of choice for scaling perceptual or emotional arousal, the electroencephalogram (EEG), has received an unfriendly welcome (and probably undeservedly so) to the radiobiological laboratory. However the possibility of passive and active interactions of microwave fields with the conductive leads that contact the skull or brain of an irradiated subject makes for a problem that is both persistent and real when animals are irradiated in the multi-mode cavity. The ET_cR, in contrast, is easily and quickly obtained. It makes use of a small, indwelling heat-sensor which can be isolated electrically from the animal, thus precluding stimulation of tissues by demodulated energy. The possibility of passive interactions still exists from injection of trapped energy into sensor-amplifying circuitry, but spurious readings of temperature can be avoided because the ET_cR is of sufficient duration that it can be observed well after irradiation of an experimental subject is terminated.

We shall qualify the ET_cR in terms of pertinent thermal characteristics of the species — the rat — to which we have given the most attention. The requisite background of parametric data is given in the first of two original experiments to be reported here; the other experiment involved comparison of ET_cR's as evoked by peripheral sensory stimulation and by microwave irradiation. In both experiments we utilized female albino rats of Sprague-Dawley lineage. The rat was selected for its economy, mass, and geometry; the female, because she lacks the elaborate arteriovenous shunt which serves as a thermoregulator in the male's testicular apparatus. The proximity of the apparatus to the large colon in the male could confound measurement of an ET_cR.

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

Experiment 1

Aims: 1) to determine the norm, range, and variability of the rat's nocturnally and acutely measured colonic temperature; 2) to determine whether averaged temperatures differ between animals which are manually handled only and those which are also concomitantly subjected to thermal measurement; and 3) to determine the rate at which a handling-evoked ET_cR is habituated during a series of handling treatments.

Procedure. Eighty rats which individually weighed between 250 and 300 g were obtained in a common shipment on 11 March from a local supplier. They were placed four to a cage (24 by 18 by 13 cm) in a windowless vivarium in which ambient temperatures and relative humidities were maintained, respectively, between 22 and 26°C, and 55 and 65%. While in their cages, the rats had unrestricted access to Purina Lab Chow and water. An automatically timed, 24-hour cycle of darkness and fluorescent illumination was maintained in the vivarium, the darkness occurring from 19 : 00 to 3 : 00 hours. Except for a daily change to a clean cage, for daily replenishment of food and water, and for punch-coding of the ears on 13 July, none of the rats was physically contacted by human beings until 20 July. After random division into two numerically equal groups, all 80 rats were individually handled by one of us (D.M.L.) for 45 to 50 seconds each day for six consecutive days. Handling was carried out between 7 : 30 and 9 : 00 hours during the rats' nocturnal period when they would normally be awake and active. Temperatures were measured each day in experimental animals but only during the first and sixth days in controls. It was necessary to illuminate the vivarium during the periods of handling so that the animals and recording apparatus could be visualized. Thermal measurement was made by picking up an animal in a gloved hand with the major axis of the animal's body held in a vertical position; a lubricated thermistor-probe (United Systems Model 406), which was held in the other hand, was then inserted past the animal's anal sphincter into the colon to a minimum depth of 6 cm. Each animal was held in the same, stationary position whether or not measurement of temperature was made. Stabilized readings of temperature after 30 seconds of insertion of the probe were independently read by the handler and by another investigator from the digital display of a precision electronic thermometer (United Systems Model 1502). After mutual concurrence about the reading had been reached, the second investigator recorded the values in a log book. One experimental animal and two controls had presented symptoms of pulmonary disease by the sixth day of treatment; although their temperatures were close to normal, their data were excluded from the analyses that followed.

Results and comment. Colonic temperatures of the 77 rats were persistently variable (Fig. 1), showing a range of more than 1.5°C on each occasion of measurement. The decline in averaged temperatures between the first and sixth days was smaller in experimental rats (0.74°C) than in controls (0.92°C), but not reliably so ($p > .05$), which confirmed our subjective impressions that the naive rat's distress upon being handled is not noticeably augmented by the concomitant probing of its anus and colon. The declines *per se* were highly reliable for both groups of rats (both $p \ll .01$). The large daily inter-individual differences of temperature notwithstanding, the high reliability of the declines indicates a marked degree of intra-individual stability of temperature in the downward trend across time.

A major implication of the data is that even the minimal and benign handling that was necessary to obtain an acute measurement of colonic temperature resulted during the initial treatment in an ET_cR of an averaged magnitude + 0.83°C — as extrapolated from the averaged 6-day decrements of both groups. While habituation of

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

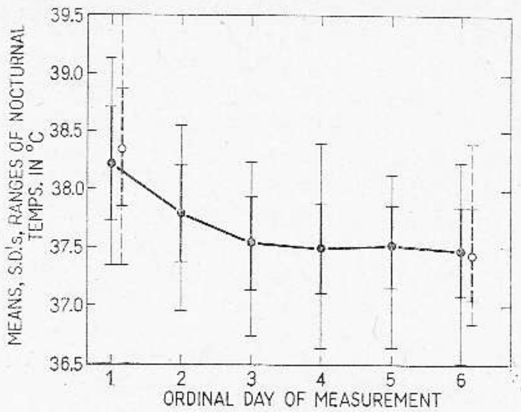

Fig. 1. Means (circles), plus-and-minus standard deviations (heavy vertical lines), and ranges (lighter vertical lines) of nocturnally measured colonic temperatures of 39 experimental (closed circles) and 38 control rats (open circles). Experimental and control rats were briefly handled each day for six consecutive days. Rats of the experimental group were concomitantly measured for temperature during all six days, control rats, on the first and sixth days only. Temperatures were measured when the rats were 4.5 to 6 hours into the 16-hour "dark" phase of an artificial 24-hour dark-light cycle. Ambient temperature at the center of the room where the rats were housed was 23.14±0.86°C during the periods when temperatures were measured.

the ET_cR to handling was rapid, occurring within the first three handling treatments in experimental animals, we discovered subsequently that the extinguished ET_cR is readily disinhibited. One week after the sixth handling treatment, the same 77 rats were wheeled in their cages from the vivarium to an adjacent laboratory approximately 45 meters away, but in the same building. Even though temperatures were measured as before and by the same handler, they averaged slightly more than 39°C. If one takes 37.5°C as the habituated nocturnal norm of our rats, it would appear that the novel complex of vestibular, visual, and acoustic stimuli that were occasioned by the move resulted in an ET_cR whose magnitude exceeded 1.5°C.

Experiment 2

Aims: In an earlier study (6), we had observed that a moderately thermalizing but non-lethal dose of microwave energy and a potent but non-lethal stressor (bodily restraint) were sometimes lethal for the rat when applied in combination. The results of the earlier study and of Experiment 1 led us to question whether smaller doses of microwave energy and a mildly aversive stimulus (faradic electrical stimulation of the feet) would: 1) evoke comparable ET_cR's; and 2) be additive when combined with respect to magnitude of the ET_cR.

Procedure. Forty-five experimentally naive rats, which averaged 303 g at the time of experimentation, were obtained from the local supplier and were housed in the vivarium, four to a cage. While in their cages the rats had continuous access to food and water. Each rat was handled for a minimum of 60 seconds by an ungloved investigator for a total of eight times during a period of four weeks. During the next four weeks, the rats were moved to the adjacent laboratory on three different occasions

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

where they were again handled and then concomitantly measured for temperature while they were allowed to explore within a multi-mode cavity (6) which was being operated on a "standby" basis (without injection of microwave energy into the cavity). The temperature was measured by a carefully calibrated thermistor which had been encased (except for its epoxy-covered extremity) along with its tightly twisted conductive leads within a 1-meter length of flexible polyethylene tubing (outside diameter: 2.4 mm). The thermistor-and-tubing assembly was inserted through a small hole in the grille of the door of the cavity; with the door unlatched, the thermistor was then inserted into the colon of an animal to a minimum depth of 6-cm. The thermistor was held in place by fastening the tubing to the tail of an animal by a small strip of paper masking tape. When the door to the cavity was latched, the animal within could be visualized through the grille. All of the animals during the period of habituation to the inert cavity and the subsequent period of experimentation were closely observed (while light tension was maintained on the tubing) to prevent them from chewing at the tube and interfering with thermal measurement. Within the cavity was a Plexiglas chamber (inside dimensions: 37 by 24 by 25 cm) with a floor-grid which was used to supply the faradic stimulation to the feet (7). Fresh air at 22 to 23°C and 50 to 60% relative humidity was continuously circulated through the chamber with an estimated flow-rate of 2.8 cubic meters per minute.

The nominal frequency of the magnetron-generated microwave energy that was injected into the cavity by a waveguide was 2.45 GHz. The energy was modulated as a half-wave sinusoid; pulses of approximately 8 ms each recurred at 60 Hz and were mechanically mixed by a four-bladed modal stirrer that rotated between the waveguide opening and the Plexiglas chamber at 3 Hz. Dosing estimates of absorbed energy, which was calorimetrically determined (6, 8), are given in this paper as averaged (rms) values, but maximum peak values as determined from oscillographic tracings of probe-detected demodulated energy were 20 times greater.

The 45 rats were randomly assorted in equal numbers of five each into the nine possible conditions that resulted from the factorial combination of three levels of microwave dosing with three levels of intensity of faradic foot shock. The three levels of microwave dosing, stated as total-energy doses in millijoules per gram (mJ/g) were 0, 360 ±18, and 1800 ±90 mJ/g. The three rms intensities of faradic current were measured at 0, 50, and 60 μA-rms with respective maximum peak-to-peak intensities of 0, 450, and 700 μA. The faradic current was of a "grey-noise" character with a dominant frequency near 1-kHz and negligible energy above 5-kHz. Each rat received a succession of three challenges, each of which included a 60-s period of sham or actual irradiation which overlapped a $^1/_2$-s period of sham or actual faradic stimulation. The latter period commenced 50 seconds after onset of the former. An aperiodic, 30- to 180-s interval occurred between challenges. The stabilized basal temperature of each rat was measured and recorded before challenges were begun and then the peak of temperature during the 30-s period that followed each period of challenge was observed and recorded.

The "lower" and "higher" (as opposed to zero-level) dosing values of microwave irradiation were based upon dose-rates of 2 and 10 milliwatts per gram (mW/g). The two dose-rates respectively correspond to threshold and highly salient energy levels when microwave energy is used as a sensory cue by rats in our cavity-system in measures of conditional suppression (7, 9). The "lower" and "higher" intensities of faradic current were based upon subjective reactions by us when the shock was administered for $^1/_2$-s through the finger tips; the lower intensity was just above

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

the absolute threshold for sensation while the higher, in spite of its modest increment of energy over the lower intensity, was decidedly "unpleasant."

Results and comment. Each of the three ET_cR's of each rat was calculated by subtracting the animal's basal temperature from its post-challenge peaks of temperature. For all except the rats of the control condition (zero radiation, zero foot shock), there was a virtually linear incrementing of magnitudes of the successive ET_cR's — each challenge

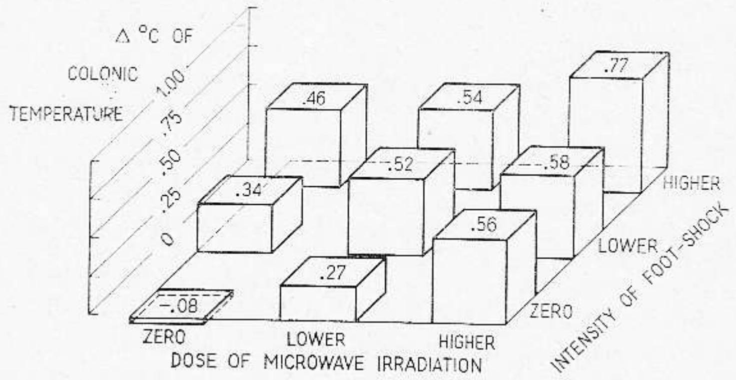

Fig. 2. Averaged elevations of colonic temperature over baseline values of nine groups of female rats which had been thrice exposed within a 7-min period for 60-s to 2.45 GHz microwave irradiation (0, 2, or 10 mW/g) and for 0.5-s to faradic foot shock (0, 50, or 60 μA-rms) in a factorially designed experiment. Anesthetized controls (data not shown) exhibited a maximum averaged elevation of +0.06 °C.

was followed with few exceptions by an additional increase of peak-temperature. To simplify the presentation of the data, we report the averaged magnitude of the ET_cR which occurred after the third (and final) challenge (Fig. 2). A factorial analysis of variance revealed that irradiation and foot shock, as independent sources of variation, were highly reliable triggers of the ET_cR (both F-ratios >8.5 at 2 and 36 d. f.; both $p \leq .01$). The interaction of irradiation and foot shock was nil (F-ratio $=$ 1.13 at 4 and 36 d. f.; $p > .05$), indicating that the two classes of "stimuli" in combination neither masked nor synergized but were simply additive with respect to controlling the magnitude of the ET_cR.

For purposes of providing additional control data another factorially controlled study was performed. Four additional groups of five rats each, all with a pre-experimental history comparable to that of the animals of Experiment 2 were given the sham and "higher" treatments of irradiation and foot shock. The treatment conditions replicated those of Experiment 2, except that the "lower" level of irradiation and of foot shock was omitted. Thirty minutes prior to the first challenge, each rat was dosed with a hypnotic, sodium pentobarbital (intraperitoneally: 35 mg/kg). None of the averaged ET_cR's of the four groups exceeded +0.06°C, a finding which supports our contention that the occurrence of an ET_cR is a cognitively mediated event. Without perception of a (potentially threatening or alien) stimulus, there will not occur that quickening of nervous activity that somehow leads to a rise of core-temperature.

Discussion. Our findings confirm and extend those of Livšic (10), who demonstrated that the cord-transected or sympathectomized mammal exhibits much less of a rise in body temperature than does the intact animal when each is illuminated by the same density of EM energy. We are not certain of the meaning of Livšic speculation that

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

"...direct action of UHF energy upon the higher nervous centers..." is implicated by his findings. If he means a specific effect not explicable in terms of thermalization of tissues, we would take a conservative and contrary view at the present time. We argue on grounds of parsimony for an explanation based upon non-specific (thermal) stimulation. Perhaps a faint sensation occurs in the irradiated animal that is attributive to or derivative from a slight or uneven warming of innervated tissues. If so, minuscule amounts of energy could be translated into a potent psychogenic stressor. The stressor could be, that is, a signal of peripheral origin that only secondarily stirs the central nervous system to increased activity and has the tertiary consequence of evoking the transient hyperthermia that we call the ET_cR.

There is a widespread assumption, even among many biological scientists, that the body temperature of the mammal is largely invariant. While small variations are recognized as a normal accompaniment of circadian and ultradian rhythms, and larger variations, the result of pathological conditions, relatively little attention has been given to the factors of individual differences and cognitive interactions. The data of Experiment 1 revealed that mammalian body temperatures — at least those of rats — are quite variable from animal to animal, even in a controlled environment. The data of Experiments 1 and 2 also revealed that body temperature is reliably elevated by seemingly physically benign events — by handling, by change of surroundings, by tactile stimulation, by a weak faradic current, and by irradiation by low average densities of microwave energy. The finding that the combined application of microwave irradiation and novel tactile stimulation is additive with respect to the magnitude of the ET_cR should be a caveat to the radiobiologist. While he is grappling with problems of physical artifact, he must come to understand that they are compounded by those of psychogenic origin. The antidote for both problems is rigorous, well conceived, and well controlled experimentation in which monitoring of temperatures of intact animal subjects is no longer a nicety but an imperative.

* * *

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WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

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WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

SOME EFFECTS OF VARIOUS PULSED FIELDS ON ANIMALS WITH AUDIOGENIC EPILEPSY

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The problem of biological effects of pulsed modulated waves has not been dealt with consistently in the literature. It is not clear, for example, what is the significance of rapidly occuring, short-lasting, but pronounced changes in the momentary high peak value of the proper SHF-carrier wave. In other words, the question arises, to what extent the carrier modulation contributes to greater biological effectiveness of pulsed fields.

We attempted to solve the problem by comparing the effects of electrostatic pulsed fields, microwave pulsed fields and continuous fields. Changes in rats and mice with an inherited predisposition to epileptic seizures after sound stimulation (bell) were investigated in chronic experiments. In the first series the animals were exposed to a pulsed electrostatic field.

The present communication presents results of the second series of experiments in which animals were submitted to the action of a pulsed electromagnetic field. The amplitude of the electric component of the field corresponded to the experimental conditions in the first series.

METHODS

Experiments were performed on 40 rats reacting with epileptic seizures to a sound stimulus. 24 animals were irradiated and 16 served as controls. Starting with the second day after birth, the rats were submitted for 4 h to the action of a pulsed electromagnetic field daily for 10 weeks excluding Saturdays and Sundays.

The rats were placed in the field of electromagnetic radiation in perforated Perspex boxes. The position of individual rats during consecutive exposures was changed stepwise in such manner as to irradiate the animals evenly.

During irradiation the temperature was recorded continuously in two fixed boxes.

Weighing of the animals was done weekly starting with the 4th postnatal week. Testing by means of a bell was performed also from the 4th week of life onwards once a week, 6 times altogether. If after 60 s of uninterrupted ringing there was no change in behavior, for this particular examination the reaction of the rat was considered as "zero".

In animals which reacted to sound stimulation with motor reaction which ended, as a rule, in convulsions, the interval between the initiation of ringing and the onset of seizures was recorded. Neither the duration of seizures nor the length of the recovery phase was assessed.

We manipulated the control group similarly, including transfer to experimental premises but without irradiation.

The generator of pulsed electromagnetic radiation emitted waves at 2850 MHz fre-

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

quency. Pulse duration was 2.7 μsec and repetition frequency 357 Hz. The average power density within the area of exposure amounted to 30 mW/cm².

A constant temperature of approximately 23°C was maintained in the animal house. During experiments, i.e. from 8 a.m. till 12 noon, the temperature in the experimental room increased from 23°C to 26°C, while that in the Perspex boxes varied from 24.7°C to 27.8°C.

During the experiments we paid attention to changes in body weight, the interval from sound signal to the onset of the seizure, and the percentage of null reactions in irradiated and control animals. In addition we recorded the number of animals which died. Results are expressed in percentages and evaluated by means of the t-test.

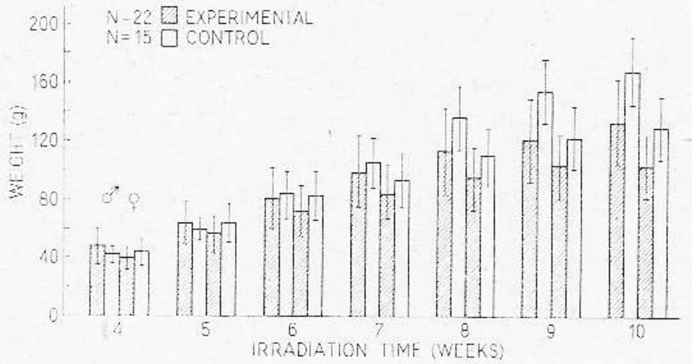

Fig. 1. For explanation, see text.

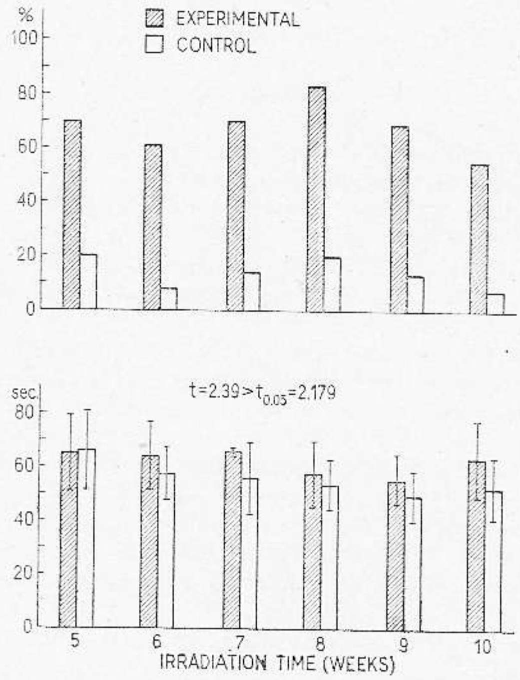

Fig. 2. For explanation, see text.

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

RESULTS

Figure 1 shows changes in weight of irradiated animals of both sexes and of controls. From the 4th to the 10th week of life the body weight tended to increase in all animals, more in males than in females. The body weight of irradiated animals was insignificantly lower than that of controls.

The upper half of Figure 2 illustrates the occurrence of null reactions in rats. The hatched columns represent the frequency of such reactions in irradiated animals, and the plain ones their frequency in control rats.

The null reaction occurred in approximately 70% of animals in the irradiated group and in 20% of the controls (percentages relate to the number of animals in separate groups).

The bottom section of the graph compares mean intervals between the start of ringing and the onset of seizures in irradiated and control animals. The hatched columns relate to irradiated animals and the plain ones to controls. In all cases the mean time preceding the onset of seizures is longer in irradiated than in control animals. The results obtained during the sixth week of experimental observations were significantly different at the 5% level; the remaining differences were statistically insignificant.

One control and 2 irradiated rats died during the first 4 weeks. No further deaths occurred during the remaining six weeks of irradiation and tests.

DISCUSSION

The results presented above form part of a long-term, multi-stage study aimed at characterization of pulsed fields of various types by means of investigating responses of the nervous system of rats with audiogenic epilepsy to sound irritation. The separate stages involve irradiation with a pulsed electrostatic field, a pulsed electromagnetic field and a continuous field.

Results obtained with a pulsed electrostatic field (pulse duration, 10 μsec; amplitude, 800 V; repetition rate, 769.2 Hz; field gradient, approximately 130 V/cm) (4) showed that irradiation of rats with audiogenic epilepsy (starting with the 4th day after birth, 4 h daily for 10 weeks) led to prolongation of the interval from the beginning of sound stimulation to the onset of seizures. In addition, a higher number of null reactions expressed in percentages occurred in irradiated animals.

In both cases results of 10 weeks' irradiation show a tendency to lowered sensitivity to sound stimulation of audiogenic rats and more frequent occurrence of null reactions.

It has been known from the literature that Soviet authors have investigated exposure of rats with audiogenic epilepsy submitted to a pulsed electromagnetic field (1, 2, 3). They obtained similar results although their methods differed. Also different was the mean power density (10 mW/cm^2).

In conclusion it could be noted that a pulsed electrostatic field and a pulsed electromagnetic field within the microwave range, when applied to rats sensitive to sound signals in methodologically identical experiments, resulted in lowered sensitivity and a significantly increased number of null reactions. In this stage of experiments the results show a possibility that modulation influences the biologic effects of pulsed electromagnetic fields.

We plan to examine the effects of a continuous microwave field by means of the same methods in the next stage of this long-term experiment. Then, detailed analysis of all results obtained so far will be conducted.

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

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WHO - BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

INTERACTION OF ELECTROMAGNETIC FIELDS AND LIVING SYSTEMS

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INTRODUCTION

There is an increasing need to master one of the most basic life processes, namely the interaction of electromagnetic fields from within and without tissue. This interaction occurs at all levels of complexity from the cell to the organism and plays a vital role in the maintenance of life itself.

The authors have been working for more than a decade on the basic phenomena underlying electromagnetic interaction. This report presents a review of their work together with a conceptual viewpoint of the emerging laws that govern such interactions.

EXPERIMENTAL FINDINGS ON INTERACTION EFFECTS

The findings obtained earlier were published as indicated in the reference list. To avoid repetitions only the general topics which were the subject of these investigations, will be indicated. Escape reactions of birds (42, 43), patterns of escape behavior (44), changes in egg of chickens in a very-low intensity microwave field (29), changes in EEG and EMG patterns in domestic fowl (30, 48), feathers as sensory detectors of microwave fields (45), and the interaction of these fields with feathers (4—7, 31), interaction of microwave fields with parakeets in flight (32) and the effect on feeding behavior of Leghorn hens (46) were studied. Gross effects on plants were also examined (33, 46).

Another series of experiments concerned effects on peripheral nerves of rats (13, 22, 24, 34—36), acceleration of the process of wound healing (14, 15, 17, 19, 23, 37) and changes in the diffusion rate of aqueous solutions of electrolytes through membranes (8, 9) as well as effects on the rate of flow and mass flux of liquids flowing along tubes of small diameter (10).

BIOLOGIC CONSIDERATIONS OF MICROWAVE RADIATION*

Extensive but inconclusive and controversial studies have been conducted in this area. An excellent source of references up to 1965 is Pressman. Since then, many other publications on this subject have appeared including our own contributions.

The interaction of microwaves with living systems is a subject of extreme complexity,

* References: 1, 2, 11, 12, 16, 18, 20, 21, 24, 25, 26, 27, 28, 38, 40, 41, 47.

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

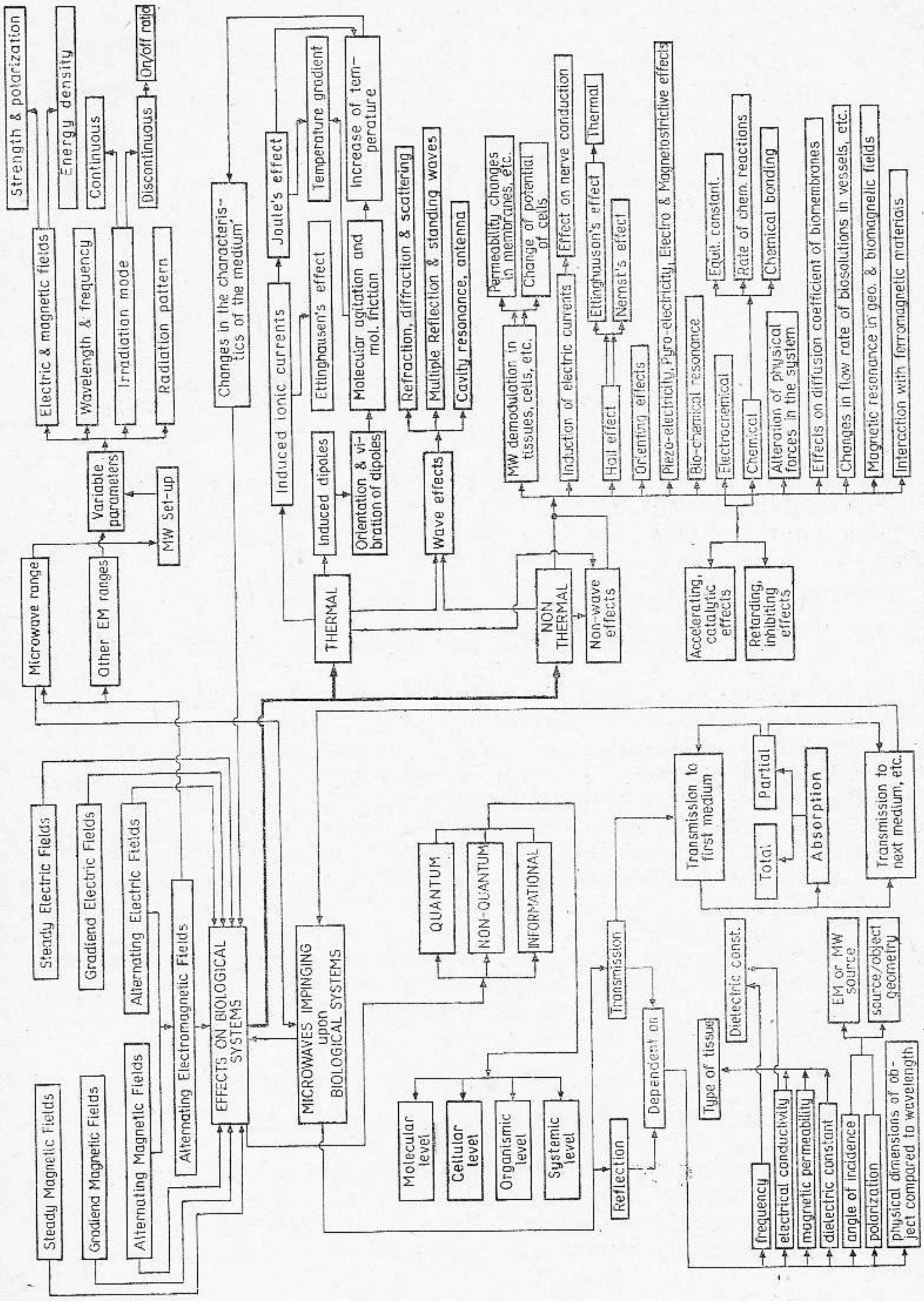

Fig. 1. Interaction of MW fields with biosystems.

WHO - BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

as depicted by the block diagram of Figure 1. In this diagram an arbitrary division has been made between wave and non-wave effects in order to point out some of the wave effects common to all electromagnetic radiation. Some of these interactions can be correlated with the biological effects elicited. However, a considerable amount of work has yet to be done in this field to elucidate the subtleties that would lead to an understanding of the observed effects at very low intensity radiation levels.

Biological effects can be divided into three categories (see Tab 1):

Table 1

Microwave field intensity ranges corresponding to the identifiable biological effects

Non-thermal	1 μW—100 μW
Thermal, non-heating	100 μW— 10 mW
Heating	10 mW and above

1. Heating effects.
2. Thermal, non-heating effects.
3. Non-thermal effects.

This division requires some clarification. Thermal, non-heating effects are effects identified with changes in temperature and heat balance not attributable to the direct conversion of MW energy to heat in tissue. Numbers are allocated to the intensity levels in Table 1 but it should be borne in mind that these are subject to gross variation when individual differences between living systems are taken into account. The same applies when the host of environmental parameters that profoundly influence the biological effects of microwave radiation are taken into account.

Irradiation intensities below 100 μW/cm² are considered non-thermal for both pulsed and CW beams, either with general or local irradiation of humans and animals. At a power level of 10 mW/cm², the energy transformed into heat in the body is roughly equal to the heat loss per square centimeter of body surface of humans and warm-blooded animals under normal environmental conditions. On this basis power levels between 100 μW and 10 mW are non-heating although thermal mechanisms may be involved.

The interaction between EM fields and living systems is dependent on three groups of factors:

Group A — Characteristics of the radiation.
Group B — Characteristics of the environment.
Group C — Characteristics of the biological receptors.

In essence, (i) all these factors must be thoroughly understood and measured if one is to predict the effect of any kind of non-ionizing electromagnetic radiation and (ii) it is important to note that there is interplay between the groups of factors. This interplay is depicted in Figure 2 as the intersection of the sides of a triangle representing the three groups of factors. A sample set of parameters is tabulated in Table 2.

Because of the dramatic effects produced by thermal MW levels resulting in permanent damage and/or death of the biological specimen under irradiation, the short-term thermal level combination has been the most fruitful area of experimentation. Little work has been done on the short-term, non-thermal and long-term, non-thermal modes of MW radiation.

Since it is reasonably easy to detect and monitor high radiation levels we emphasize the importance of the last two irradiation modes. From these we consider the long-term

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION 1974

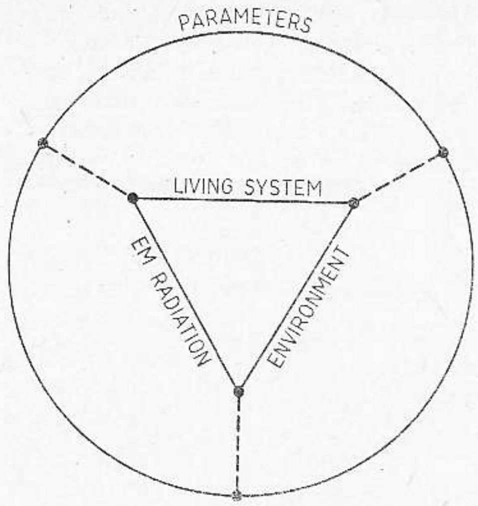

Fig. 2. Schematic presentation of the interaction of living systems with EM radiation and the environment.

Table 2

Sample table of parameters

Living system	EM Radiation	Environment
Type Species Age Sex Metabolic state Stress etc.	Duration (Long-term, short-term) Frequency Power flux density Modulation Far field Near field etc.	Temperature Pressure Humidity Atmospheric composition Light intensity Particulate matter Air velocity EM radiation (natural sources) Sound level Vibration etc.

non-thermal combination as being of the utmost importance because of the present-day proliferation of MW systems.

MECHANISM OF INTERACTION

The interaction of electromagnetic fields with living systems is a highly complex subject and can be viewed in the light of the many mechanisms potentially involved — see Figure 1.

Because heat is usually involved in the interaction of a MW field with the biosample, effects were originally observed at MW levels that produced a measurable increase in

WHO – BIOLOGIC EFFECTS & HEALTH HAZARDS OF MICROWAVE RADIATION
1974

the temperature of the specimens. Tissue and biological fluids being lossy materials of relative high electrical conductivity, high ohmic losses occur in them which are proportional to E^2. Thus the effect of an electric field (or its magnitude squared) has predominance over the magnetic field.

In the region where the predominant effect is heating of tissue it is obvious that the electric field plays a key role. In this region subtle non-thermal effects may be obscured. The question arises as to what happens in the non-thermal region. How are the electric and magnetic fields related to a specific non-thermal effect and what interaction takes place on a molecular or macroscopic level? It is important to note that very little attention has been given as yet to the effect that the magnetic field associated with the MW may have on a biological system.

In the light of the strong EM interaction between glial and neuronal cells and in the light of the pattern of interaction between EM fields and the organism, the emerging laws of interaction appear to be as follows:

1. Electromagnetic fields imposed on a living system modify the electromagnetic interaction that exists between glial and neuronal cells inside a nervous structure.
2. To predict the consequences of any interaction, all the parameters that characterize, (i) the electromagnetic field, (ii) the environment and (iii) the subject radiated, must be quantified and integrated.
3. Electromagnetic fields interact with living systems triggering a set of interactive biophysical phenomena.
4. The unstable sequence of events triggered by electromagnetic fields impinging on living systems may be stabilized at the level of the cell, tissue, organ or organism affected.

NAVIGATIONAL ORIENTATION IN BIRD MIGRATION

Since feathers have been shown to occupy a sensory role, functioning as receiving antenna arrays in electromagnetic fields, it follows that birds could conceivably use their feathers to obtain directional information. Migratory birds are affected by temperature and humidity to the point of triggering the migratory process. It is known that these two parameters modulate the sensitivity of feathers as antennas. Therefore it may be hypothesised that synchronization of the two corresponding biological processes provides the stimulus to the animal to seek a particular flight path in its continuing search for an optimal equilibrium.

Supporting evidence exists in the well-known phenomenon of disorientation and confusion that occurs with birds held captive for a short time during migration. A period of captivity introduces a discontinuity in the birds' spatial and temporal perception of the minute gradients in temperature, humidity and electromagnetic field. During this period changes occur in these parameters and when the birds are released they are confronted with a new environmental pattern and a new set of gradients from which to derive directional information. The inevitable result is disorientation.

This same concept can be applied to other migratory species. In the case of fish, for example, the appropriate biological receptors would be the scales.

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1974