MICROWAVE INTERACTION WITH THE AUDITORY SYSTEMS OF HUMANS AND CATS

Arthur W. Guy, Eugene M. Taylor, Bonnie Ashleman and James C. Lin
Department of Rehabilitation Medicine
University of Washington School of Medicine
Seattle, Washington 98195

Abstract

Recordings from elements of the auditory system of cats in response to pulsed microwaves, as well as determinations of thresholds of audibility of humans to the pulses indicate that an auditory sensation may be elicited by pulse energies >20 $\mu J/cm^2$, regardless of average or peak power.

Summary

Introduction

There have been numerous reports of microwaves eliciting an auditory sensation [1, 2, 3], although the neural substratum for the sensation remains obscure. In this paper we wish to describe the responses of certain elements of the auditory system to pulsed microwave radiation. The recording of cochlear microphonics, auditory nerve responses, and thalamic-evoked potentials from the cat in response to stimulation by both acoustic energy and microwave energy indicate that the microwave pulses are eliciting authentic auditory activity. The threshold of audibility of the microwave pulses to both cats and humans was determined as a function of pulse characteristics.

Results

Microwave pulses in both the UHF and microwave bands evoke activity in the medial geniculate nucleus of the cat. As is seen in the lower portion of FIG. 1, the radiation-evoked activity from the nucleus, which is involved in auditory mechanisms, is very similar to that evoked by a conventional click stimulus from a pulsed loudspeaker. The late slow wave in another brain area of the same cat (in the general somatosensory thalamic region) is the same for both pulsed microwave stimulation and conventional acoustic input (FIG. 2). That both acoustic and microwave energy are eliciting similar responses in parts of the CNS other than auditory areas indicates that the microwave input is not merely generating an artifact in either the preparation or the recording equipment.

A high-resistance carbon electrode, transparent to microwaves, applied to the round window of the cochlea of the cat was used to record activity in response to both a conventional click stimulus and microwaves in the UHF and microwave bands (FIGs. 1, 3). Both acoustic stimuli and microwave pulses elicit activity at the round window that includes the cochlear microphonic and/or the N_1 and N_2 response of the auditory nerve. There is a strong indication that the microwave pulse is producing N_1 and N_2 activity with little or no microphonic activity. The microphonic in the microwave case is either extremely brief and lost in the microwave artifact, greatly attenuated, or absent. Frey [4] has discounted the role of the cochlea in microwave acoustic effects, partly on the basis of not observing a microphonic in either cats of guinea pigs. We think, on the basis of our own observations, that this question deserves careful examination, particularly as we did observe a nearly classic N_1 and N_2 response as supported by latency characteristics and by response to anoxia as indicated in FIG. 4.

The round window responses suggest intriguing questions regarding the mechanism of action of microwave radiation of the auditory system. As shown in FIG. 3, microwave pulses at 2450 MHz yield potentials at the round window which, while having the same periodicity as acoustically evoked signals, have components whose amplitudes are dependent on the orientation of the radiation source with respect to the cat's head. Of particular interest is the observation that round-window responses elicited by radiation directly over the inferior temporal area have the same form as those elicited by the acoustic click stimulus. On the other hand, by positioning the applicator at a variety of sites removed from the immediate auditory area, a unique series of potentials with increasing amplitudes is obtained. As can be seen, these potentials are produced by radiation in the X as well as the S band. The pulse characteristics for eliciting auditory effects are given in parts a, b and c of TABLE I for three different frequencies for the cat. The pulsed microwaves were also audible to the co-investigators with the pulse characteristics shown in part d of TABLE I. The data clearly indicate that the threshold is a function of the energy per pulse rather than the average or peak power. It is significant to note that the threshold energy for detection by one subject with normal hearing reflected by the audiogram in FIG. 5 was approximately one-third to one-fourth that required for another subject with sensori-neural hearing impairment shown by the audiogram of Subject 2. Each individual pulse could be heard as a distinct click with the sound originating from somewhere within and near the back of the head. Short pulse trains could be heard as chirps with tone corresponding to the pulse recurrence rate. When the pulse generator was keyed manually, transmitted digital codes could be accurately interpreted by the subject. The threshold for two pulses within several hundred microseconds apart was the same as one pulse with the same total energy as the pulse combination.

Conclusion

While there is thus considerable evidence for the perception of pulsed microwave radiation as an auditory sensation, a number of questions regarding the mechanism responsible for the phenomenon remain. Further analysis of the mechanical, electrical, as well as the neural mechanisms involved is necessary, particularly as this phenomenon seems to represent the elusive class of "non-thermal" EM radiation effects in a situation accessible to experimental analysis.

References

1. Frey, A.H. "Human Auditory System Response to Modulated Electromagnetic Energy." J. Appl. Physiol., 17:689-692 (1962).

2. Frey, A.H. "Some Effects on Human Subjects of Ultra-High-Frequency Radiation." Amer. J. Med. Elec., 2:28-31 (1963).

3. Frey, A.H. and R. Messenger. "Psychophysical Data on the RF Hearing Effect." IMPI Microwave Power Symp., May (1972), Ottawa, Canada, p. 169.

4. Frey, A.H. "Biological Function as Influenced by Low-Power Modulated RF Energy." IEEE Trans. Micro-

wave Theory & Techniques, 19:2:153-164, Feb. (1971).

This work was supported in part by National Science Foundation Grant GK-34730, in part by Office of Naval Research Contract N00014-67-A-0103-0026, and in part by USPHS, Food and Drug Administration, Bureau of Radiological Health Grant 2 RO1 RL 00528-03.

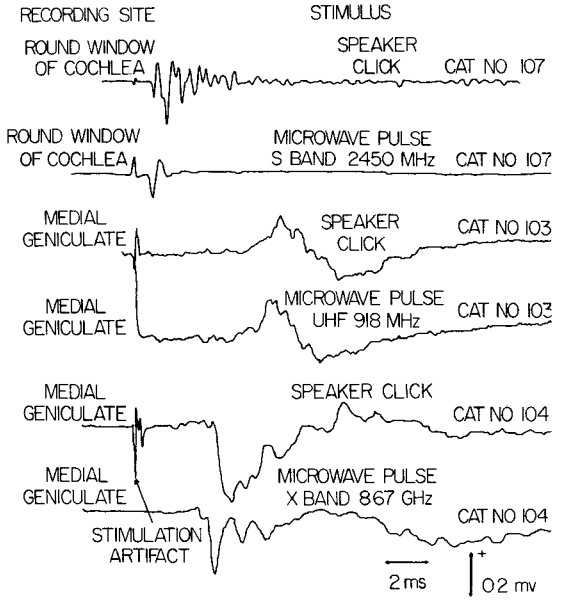

FIG. 1* Peripheral and central auditory responses to speaker clicks and microwave pulses in the cat.

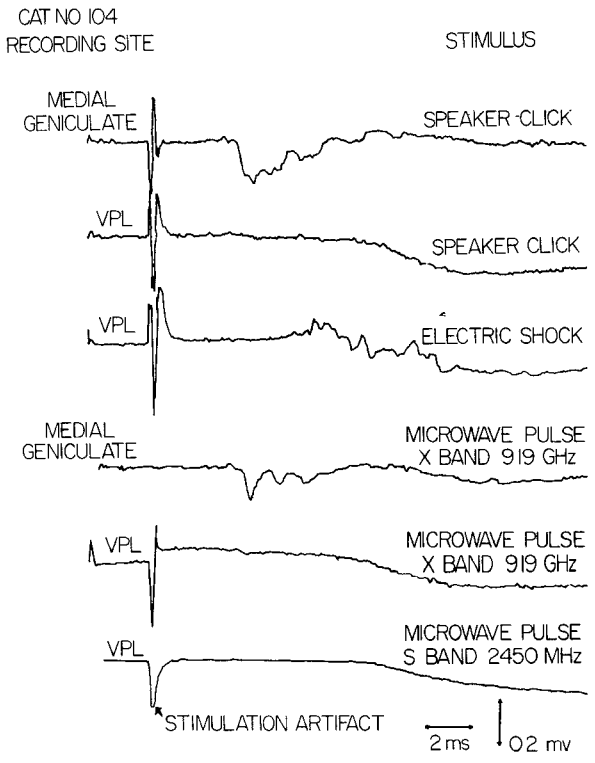

FIG. 2 Cross-modal CNS responses to speaker clicks and microwave pulses in the cat.

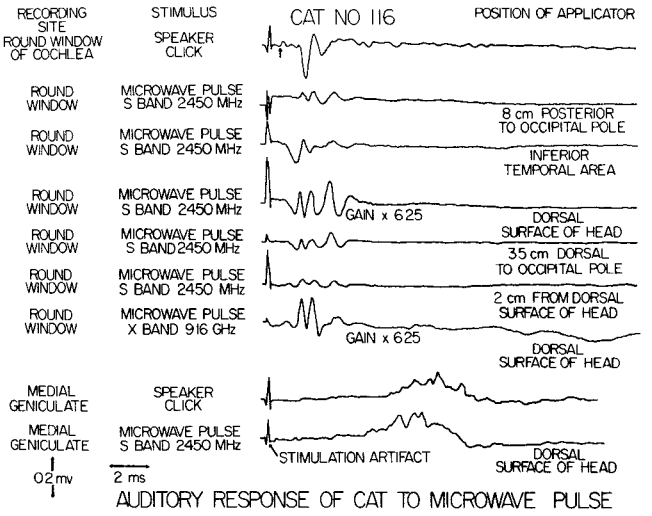

FIG. 3 Peripheral and central auditory responses to speaker clicks and microwave pulses in the cat. Arrow indicates cochlear microphonic.

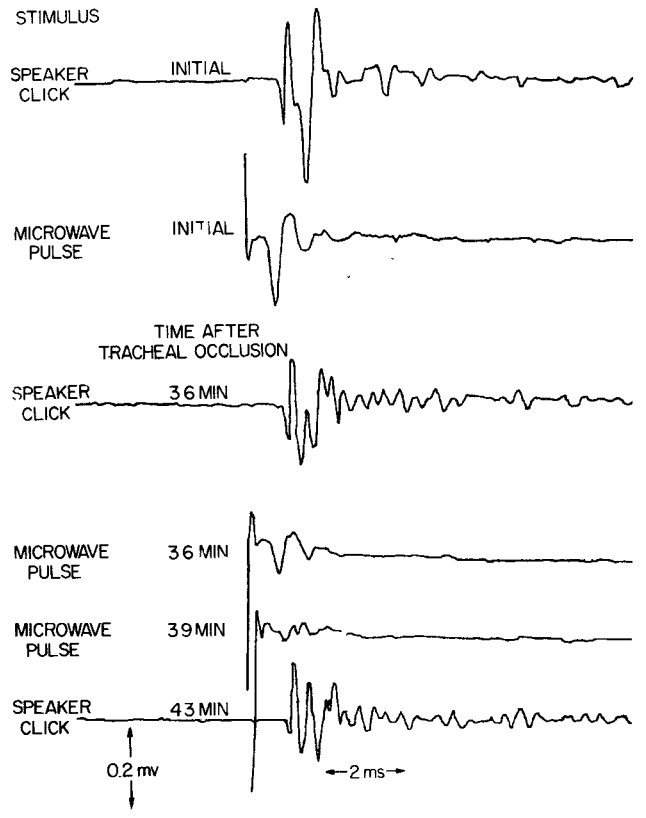

FIG. 4 Decrement in speaker and microwave pulse-induced round window response resulting from tracheal occlusion. Microwave-induced response dropped out at 4.0 minutes, coincident with the loss of the N_1 and N_2 components of the speaker-induced response.

* For microwave pulses, pulse rate = 1 pulse/sec., pulse width = 32 μsec. Energy density/pulse >47.0 μJ/cm^2 for S band, >28.3 μJ/cm^2 for UHF and >500 μJ/cm^2 for X band.

TABLE I

Pulse characteristics at threshold of evoked auditory responses.

THRESHOLD OF EVOKED AUDITORY RESPONSES IN CAT

a. 918 MHz (ONE PULSE/SEC) BACKGROUND NOISE 64 DB

PEAK POWER DENSITY (W/cm^2)	AVG POWER DENSITY ($\mu W/cm^2$)	MAX POWER DENSITY ($\mu W/cm^3$)	PULSE WIDTH (μs)	ENERGY DENSITY PULSE ($\mu J/cm^2$)
5.8	17.4	12.3	3	17.4
3.88	19.4	13.8	5	19.4
2.26	22.6	16	10	22.6
1.37	20.6	14.6	15	20.6
1.17	20.6	16.6	20	23.4
0.97	24.3	17.2	25	24.3
0.80	28.3	20	32	28.3

(a)

THRESHOLD OF EVOKED AUDITORY RESPONSES IN CAT

b. 2450 MHz (ONE PULSE/SEC) BACKGROUND NOISE 64 DB

PEAK INCIDENT POWER (W/CM^2)	AVG INCIDENT POWER ($\mu W/CM^2$)	PULSE WIDTH (μS)	ENERGY DENSITY/ PULSE ($\mu J/CM^2$)
35.6	17.8	0.5	17.8
17.8	17.8	1	17.8
10	20.3	2	20.3
5.0	20.3	4	20.3
4.0	20.3	5	20.3
2.2	21.6	10	21.6
1.9	28.0	15	28.0
1.7	33.0	20	33.0
.61	15.2	25	15.2
1.5	47	32	47

(b)

THRESHOLD OF EVOKED AUDITORY RESPONSES IN CAT

c. CAT[1] (ONE PULSE/SECOND, X BAND)

BACKGROUND NOISE 64 DB

	APPROXIMATE VALUES
PEAK INCIDENT POWER (W/CM^2)	14.8 TO 38.8
AVG INCIDENT POWER ($\mu W/CM^2$)	472 TO 1240
PULSE WIDTH (μS)	32
ENERGY DENSITY/PULSE ($\mu J/CM^2$)	472 TO 1240

(c)

THRESHOLD OF EVOKED AUDITORY RESPONSES IN

d. HUMAN[2] (2450 MHz 3 PULSES/SEC) BACKGROUND NOISE 45 DB

PEAK INCIDENT POWER (W/CM^2)	AVG INCIDENT POWER ($\mu W/CM^2$)	PULSE WIDTH (μS)	ENERGY DENSITY/ PULSE ($\mu J/CM^2$)
40	120	1	40
20	120	2	40
13.3	120	3	40
10	120	4	40
8	120	5	40
4	120	10	40
2.33	105	15	35[3]
2.15	129	20	43
1.8	135	25	45[4]
1.25	120	32	40

(d)

Footnotes:

1. Application of power directly to top of exposed skull required to elicit responses.
2. Thresholds for subject #1 in FIG. 5.
3. 28 with earplugs.
4. 135 for subject #2 in FIG. 5.

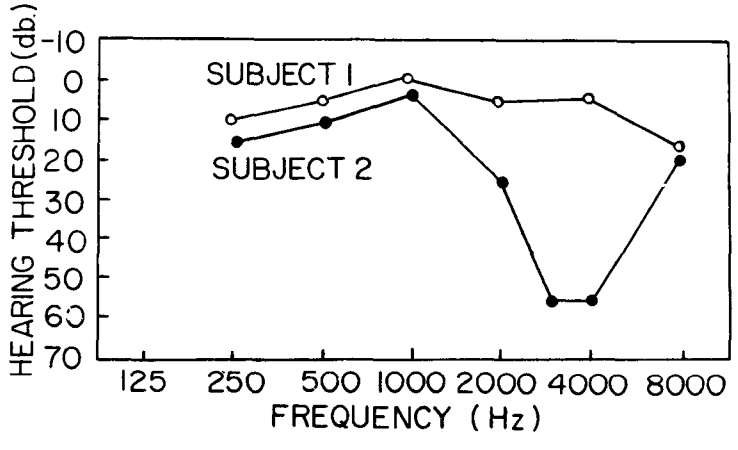

FIG. 5 Audiograms of human subjects used for determining thresholds of audibility to pulsed microwave.