ANALYSIS OF CENTRAL NERVOUS SYSTEM INVOLVEMENT IN THE MICROWAVE AUDITORY EFFECT

by

EUGENE M. TAYLOR
and
BONNIE T. ASHLEMAN

UNIVERSITY OF WASHINGTON
SCHOOL OF MEDICINE
DEPARTMENT OF REHABILITATION MEDICINE
BIOELECTROMAGNETICS RESEARCH LABORATORY
SEATTLE, WASHINGTON 98195

Contract No. N00014-67-A-0103-0026
NR 201-054

January 1974

Prepared for

OFFICE OF NAVAL RESEARCH
U.S. DEPARTMENT OF THE NAVY
ARLINGTON, VIRGINIA 22217

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) "Analysis of central nervous system involvement in the microwave auditory effect"		5. TYPE OF REPORT & PERIOD COVERED Technical 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Eugene M. Taylor and Bonnie T. Ashleman		8. CONTRACT OR GRANT NUMBER(s) N00014-67-A-0103-0026
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bioelectromagnetics Research Laboratory Dept. of Rehab. Med., School of Medicine, RJ-30 Univ. of Washington, Seattle, Wn. 98195		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 201-054
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research U.S. Dept. of the Navy Arlington, VA 22217		12. REPORT DATE January 1974 13. NUMBER OF PAGES 8 (eight)
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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

microwave auditory effect
8th cranial nerve
medial geniculate nucleus
cochlear microphonic potentials

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

Nine cats were prepared for the recording of potentials in 3 brain sites evoked by acoustic and microwave stimuli. Loci in which potentials were observed were eighth cranial nerve, medial geniculate nucleus and primary auditory cortex. The effect of cochlear disablement on these potentials was evaluated.

Potentials at all sites were abolished by cochlear damage. There were no differences between acoustic and microwave stimuli in this regard. Data are interpreted as supporting the contention that the microwave auditory effect is

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601 |

-over-

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. cont.

mediated at the periphery as are the effects of conventional acoustic stimuli.

Brain Research, 75 (1974) 201–208

ANALYSIS OF CENTRAL NERVOUS SYSTEM INVOLVEMENT IN THE MICROWAVE AUDITORY EFFECT

EUGENE M. TAYLOR AND BONNIE T. ASHLEMAN

Department of Rehabilitation Medicine, University of Washington School of Medicine, Seattle, Wash. 98195 (U.S.A.)

(Accepted January 18th, 1974)

SUMMARY

Nine cats were prepared for the recording of potentials in 3 brain sites evoked by acoustic and microwave stimuli. Loci in which potentials were observed were eighth cranial nerve, medial geniculate nucleus and primary auditory cortex. The effect of cochlear disablement on these potentials was evaluated.

Potentials at all sites were abolished by cochlear damage. There were no differences between acoustic and microwave stimuli in this regard. Data are interpreted as supporting the contention that the microwave auditory effect is mediated at the periphery as are the effects of conventional acoustic stimuli.

INTRODUCTION

A number of reports have indicated that pulse-modulated microwave energy is capable of eliciting an auditory sensation in human observers[1,3–5]. This effect is of particular interest in that the power levels required are considerably below those implicated in other microwave-biological effects. In fact, the power levels at which these auditory effects have been observed are an order of magnitude lower than the 10 mW/sq.cm value accepted in the United States as the standard 'safe' level of exposure, *i.e.*, the level at which biological effects are assumed to be insignificant. However, the mechanism involved in this effect remains obscure. In fact, few hypotheses have been advanced. Frey[2] has suggested that the effect might result from direct stimulation of the nervous system at a site central to the conventional acoustic transducers. He based this suggestion on his failure to observe cochlear microphonic potentials associated with pulsed microwave stimulation of the auditory systems of cats and guinea pigs and on the low levels of incident power at threshold for the human subject. The latter is taken to rule out a radiation pressure-bone conduction hypothesis

such as presented by Sommer and Von Gierke[8]. Despite Frey's admonishment to use caution in the acceptance of his preliminary suggestion without further experimentation, the direct nervous system effect interpretation has been widely publicized[6,7].

The clarification of this issue has obvious value for those concerned with the evaluation of hazards associated with exposure to microwave energy. In a more general frame of reference, the possibility of interaction of the auditory system with such energy has clear implications for the physiology of the system.

The present experiments were designed to establish the locus of action of the microwave auditory effect, *i.e.*, whether this effect is initiated at a central or at a peripheral site. Activity was evoked in 3 successive levels of the auditory nervous system using both acoustic and microwave stimuli. The cochlea, the known first stage of transduction for acoustic stimuli, was then inactivated. Finally, we assessed the effect of this deactivation on the potentials evoked by both forms of stimulus energy.

METHODS

Subjects were 9 cats weighing from 2.0 to 3.4 kg. Cats were assigned to 3 groups of 3. Each group was prepared surgically for the recording of potentials from a particular nervous system locus as follows.

Group 1. Eighth cranial nerve

Three cats were anesthetized with sodium pentobarbital (50 mg kg) following premedication with Acepromazine. The cats were placed in a head holder of conventional design being constructed of microwave transparent material. After reflection of the pinna and removal of the underlying muscles to expose the temporal bone, a hole was drilled and extended with rongeurs to remove most of the squamous portion and a portion of the parietal bone. Through this opening sufficient brain tissue was removed by suction to expose the tentorium cerebelli. Again using a drill and rongeur, an opening approximately 1.5 cm in diameter was made in the tentorium. From this point the dissection was continued with the aid of a B & L dissecting microscope with vertical illumination. Cerebellar tissue was removed by suction to expose the eighth cranial nerve as it emerged from the internal auditory meatus. A dissecting microscope and a micromanipulator were used to place a Ringer's solution filled glass pipette electrode (tip diameter $\sim$ 100 μm) within the nerve. Ringer's solution filled pipettes were used because of their transparency to microwaves. During recording, the nerve and surrounding tissue were covered with warm mineral oil.

Group 2. Medial geniculate nucleus

Cats were anesthetized with alpha-chloralose in saline (40 mg/kg), administered intravenously with supplements as needed during the surgery and recording sessions. Tracheostomies were performed, the cats were paralyzed with Flaxedil (20 mg), and then maintained on artificial respiration. The cats were placed in a Kopf stereotaxic instrument using truncated hollow earbars. Following exposure of the dorsal surface of the skull by conventional methods of skin incision and reflection of the

underlying muscle, a burr-hole was made in the parietal bone. The electrode was directed toward the medial geniculate nucleus by the stereotaxic method. The electrode used was similar to that employed in the eighth nerve preparation, *i.e.*, a Ringer's solution filled glass pipette with a tip diameter of 80–100 μm. As the electrode was advanced vertically, the responses evoked by acoustic stimulation provided by clicks from a speaker were continuously monitored. Placement of the electrode tip in the nucleus was assumed when acoustically evoked potentials with appropriate latency characteristics were realized. The electrodes were then cemented in place with dental acrylic and the animals were removed from the stereotaxic instrument and placed in the microwave-transparent head holder. Electrode placements were verified by histological examination of the brains.

Group 3. Primary auditory cortex

The remaining 3 cats were anesthetized with sodium pentobarbital (50 mg/kg) following premedication with Acepromazine and were placed in the head holder. Skin and soft tissue were excised to expose the temporal bone and lateral portion of the parietal bone. Bone was removed to expose the ectosylvian gyrus. A teflon covered carbon electrode was placed, with direct observation, upon the surface of the anterior ectosylvian gyrus.

In addition to the specific surgical procedures for recording from these 3 sites, certain surgical preparation was common to all 9 animals. In all cases atropine sulfate (0.2 mg) was administered after induction of anesthesia. The cats were placed on a

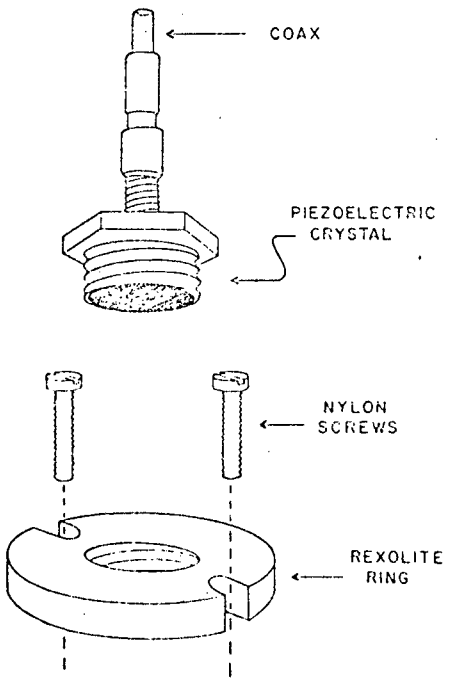

Fig. 1. Piezo-electric acoustic transducer assembly. See text for details of application.

heating pad controlled by rectal temperature monitor. Each cat was fitted with a piezo-electric crystal transducer for the presentation of acoustic stimuli. This device consisted of two parts (Fig. 1). A ring of rexolite plastic 18 mm in diameter and 2 mm thick was fitted to the dorsal surface of the frontal bone just anterior to the coronal suture and was held rigidly in place by 4–40 nylon screws and dental acrylic cement. The ring bore internal threads to receive the crystal which allowed easy removal of the crystal during microwave stimulation to prevent artifacts due to excitation of the transducer by the microwave field.

Likewise, with each animal a surgical exposure of the acoustic bulla was performed. Most of the lateral and ventral surface of the bulla was exposed by reflection and removal of the overlying soft tissue. The lateral wall of the bulla was perforated with a drill and the drill hole was expanded with a small rongeur until the round window of the cochlea could be clearly visualized. In the eighth nerve group the round window exposure was limited to the side on which the nerve had been exposed. In the medial geniculate and cortical cats the round windows were exposed bilaterally.

Stimulation parameters

Acoustic stimuli were presented by exciting the piezo-electric transducer with square wave pulses 10 μsec in duration with a repetition rate of 1 pulse/sec. The pulses were produced by a Hewlett Packard model 214A pulse generator.

Microwave stimuli consisted of pulses of 2450 MHz energy produced by an Applied Microwave Laboratory Microwave signal source model PH 40K. Pulse repetition rate was 1/sec, as in the case of acoustic pulses. Pulse width was 32 μsec. Microwave energy was led from the generator through coaxial cable to a directional coupler and horn radiator. The radiator was positioned posterolaterally to the cat's head at a distance of 10 cm and an angle of 30° from the sagittal plane. The field was oriented in the vertical plane. A bolometer, used in conjunction with the directional coupler allowed measurement of incident power levels.

The spatial arrangement of the microwave horn radiator relative to the cats is indicated in Fig. 2. Given this configuration, the entire head of the cat is within the microwave field. The specific distribution of energy within this field is complex.

Both the microwave energy and the acoustic pulses could be graded in intensity. Microwave incident power could be adjusted over a range of 0–6 mW. The excitation voltage of the crystal transducer could be adjusted continuously from 0 to 240 V. We capitalized upon this to insure that the stimulus values were always well above threshold. Tests following deactivation of the cochlea were conducted with the maximum available power for both the acoustic and the microwave case.

Within each experiment we established the power levels for both forms of stimulus energy at which the earliest detectable evoked potentials appeared on the monitor oscilloscope. This provided an index of viability of the particular preparation and indicated relative responsiveness between animals for a given recording site. We do not regard these values as 'threshold' values, as will be discussed later.

Recording of responses

Signals were led from the active electrodes through high resistance carbon leads

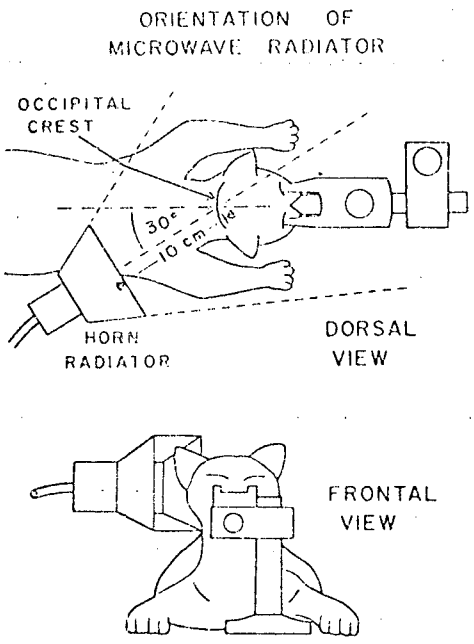

Fig. 2. Orientation of microwave radiator relative to cats. With this configuration the entire head is located within the microwave field.

to a microwave filter and then to a type 2A61 Tektronix amplifier and type 565 Tektronix oscilloscope. Some of the signals were further processed with a TMC 400C signal averaging computer, the averaged signals being printed out on a Moseley 7000AM X–Y plotter.

Oscilloscope traces were photographed with a polaroid camera or with a Nihon Kohden PC-2A oscilloscope camera.

Experimental protocol

The sequence of experimental treatment was the same for all recording sites.

Following surgical exposure of the area of interest the animal was allowed to stabilize as evidenced by uniformity in the waveform and latency of acoustically evoked responses. The lowest voltage of crystal excitation capable of eliciting a response was noted. Crystal voltage was then elevated to a level which appeared to be maximal in evoking activity and random samples of the activity at these levels were taken. The crystal was then removed from the mounting ring and the microwave generator was turned on. Minimum microwave energy values evoking detectable responses were noted, the microwave energy was elevated to a maximal level and responses were again recorded.

When it had been established in each case that the animal showed clearcut responses to both acoustic and microwave pulses, the cochlea was disabled by careful perforation of the round window with a microdissecting knife and aspiration of perilymph. The response to each form of energy, acoustic and microwave, was evaluated. For the medial geniculate nucleus and auditory cortex, sites assumed to have some

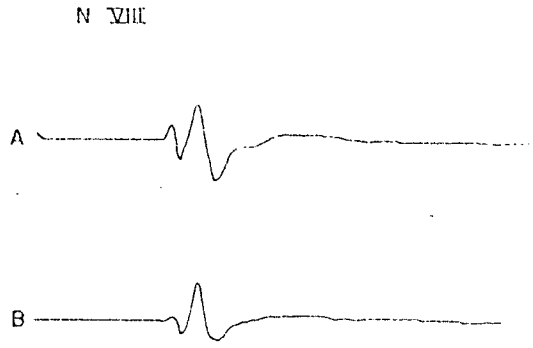

Fig. 3. Activity evoked in the eighth cranial nerve by A, acoustic and B, microwave single pulses. Evoked responses to both forms of energy were eliminated by cochlear aspiration.

degree of bilateral representation, the responses were assessed after destruction of each of the two cochlea. In the absence of an evoked response in a particular site following damage to the cochlea we raised the levels of both forms of stimulus to the maximum available to optimize conditions for evoking activity.

In the eighth nerve and cortical preparations the electrodes were repositioned following cochlear disablement in an attempt to reestablish evoked activity and to insure that the initial loss of activity did not simply result from movement of the electrode incident to the manipulation involved in cochlear surgery.

RESULTS

Acoustic and microwave evoked signals in the 3 nervous system sites are shown in Figs. 3, 4 and 5. Cochlear destruction led to total loss of these evoked potentials to both acoustic and microwave stimuli.

Eighth cranial nerve potentials were lost with unilateral cochlear ablation. In the case of medial geniculate potentials and those recorded from the auditory cortex, aspiration of the contralateral cochlea led to marked attenuation of the amplitude of

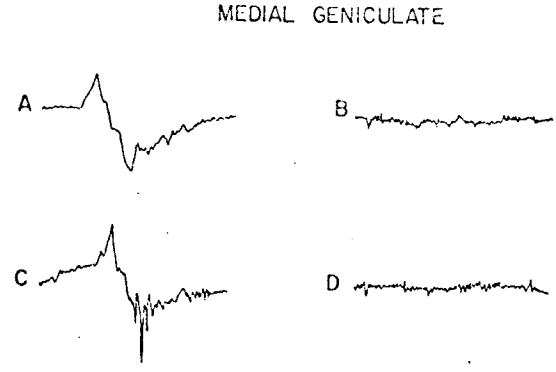

Fig. 4. Medial geniculate nucleus activity evoked by acoustic and microwave stimulation and loss of such activity following cochlear aspiration. A and C: responses evoked by acoustic and microwave pulses, respectively. B and D: traces following bilateral cochlear aspiration. No activity is apparent to either acoustic or microwave stimulation.

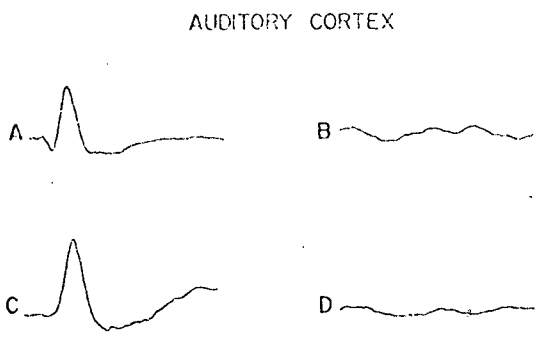

Fig. 5. Auditory cortex response to acoustic and microwave stimulation and loss of such response with cochlear aspiration. A and C: responses evoked by acoustic and microwave stimulation, respectively. B and D: corresponding traces recorded following bilateral cochlear aspiration.

the evoked potentials. Disablement of the remaining cochlea in these animals resulted in total loss of the signal, as shown in Figs. 4 and 5. We were unable to detect activity following cochlear manipulation even though we took additional steps, such as increasing the numbers of successive signals averaged.

These results were common to all 9 of the cats studied. Attenuation and loss of the acoustic evoked signal was, without exception, accompanied by a parallel effect on microwave evoked activity. In no case did subsequent elevation of the stimulus intensity lead to return of the evoked activity.

CONCLUSIONS AND DISCUSSION

We believe that the data strongly support the contention that the microwave auditory effect is exerted on the animal in a manner similar to that of conventional acoustic stimuli. Clearly, the elimination of the first stage of transduction affects the central nervous system response to both of these forms of stimulus energy in the same way.

The failure of other investigators to observe cochlear microphonic potentials with microwave stimulation does not present any particular problem for this interpretation. Wever[9] has pointed out a number of factors denying the adequacy of cochlear potential identification at low stimulus intensity in particular. He cites work, for example, in which auditory thresholds in cats, as determined by behavioral levels, were established as being 40 dB below the stimulus levels first effective in producing cochlear microphonic potentials of sufficient magnitude to be identified with the conventional oscilloscope display. In our own studies (unpublished observations), we have not seen cochlear microphonics while recording at the round window during microwave stimulation sufficient to produce well defined N_1 and N_2 responses. However, we have also observed well defined nerve response to acoustic stimuli in the same cats with no detectable microphonic potentials.

A second point of discussion merits consideration. The question as to whether the microwave acoustic effect is mediated at a peripheral or a central site has involved a consideration of thresholds that is perhaps inappropriate. Frey[3,4] has contended

that the radiation pressure concept of transduction is not reasonable in the microwave case because the calculated radiation pressures for his lowest effective stimulus levels were an order of magnitude below those sound-pressure levels regarded as the threshold level for bone conduction. Subsequent work, including some performed in our laboratory has involved some attempt to relate minimally effective magnitudes of microwave energy with such sound pressure thresholds.

Disagreement in this regard points to a serious problem in interpretation. Since we do not know the mechanism by which microwave energy might exert an effect on the peripheral portion of the auditory system, we cannot necessarily equate sound pressure with radiation pressure. Ultimately, a peripheral response to microwave pulses should involve displacement of the skull with resultant dynamic effects on the cochlear fluids and nervous system consequences that have been well described for the acoustic case. The presence or absence of such displacement should be determined prior to invoking relative thresholds based on radiation pressure models, piezoelectric models or the like. In the meantime, the present study supports the view that microwave pulses act at the periphery and allows the parsimonious conclusion that microwave pulses are similar to conventional acoustic pulses in this regard.

ACKNOWLEDGEMENTS

This work was supported in part by National Science Foundation Grant GK-34730, Proposal No. P2K1787; Office of Naval Research Grant No. N00014-67-A-0103-0026; Bureau of Radiological Health, Food and Drug Administration Grant No. RL 00528-04; and Social and Rehabilitation Service Research and Training Grant No. 16-P-56818/0-11.

REFERENCES

1 FREY, A. H., Human auditory system response to modulated electromagnetic energy, *J. appl. Physiol.*, 17 (1962) 689–692.
2 FREY, A. H., Brainstem evoked responses associated with low intensity pulsed UHF energy, *J. appl. Physiol.*, 23 (1967) 984–988.
3 FREY, A. H., AND MESSENGER, R., Psychophysical data on the RF hearing effect, *IMPI Microwave Power Symp., Ottawa*, May, 1972, p. 169.
4 FREY, A. H., AND MESSENGER, R., Human perception at illumination with pulsed ultrahigh-frequency electromagnetic energy, *Science*, 181 (1973) 356–358.
5 GUY, A. W., TAYLOR, E. M., ASHLEMAN, B., AND LIN, J. C., Microwave interaction with the auditory systems of humans and cats, *Presented at the 1973 IEEE G-MTT Microwave Symposium, University of Colorado, Boulder, Colo.*, (1973).
6 JOHNSON, C. C., AND GUY, A. W., Nonionizing electromagnetic wave effects in biological materials and systems, *Proc. IEEE*, 60 (1972) 692–718.
7 MICHAELSON, S. M., Human exposure to nonionizing radiation energy-Potential hazards and safety standards, *Proc. IEEE*, 60 (1972) 389–421.
8 SOMMER, H. C., AND VON GIERKE, H. E., Hearing sensations in electric fields, *Aerospace Med.*, 35 (1964) 834–839.
9 WEVER, E. G., Electrical potentials of the cochlea, *Physiol. Rev.*, 46 (1966) 102–127.