AVERAGED ELECTROENCEPHALIC RESPONSES TO SOUND OBTAINED BY DIRECT METHOD RECORDING AND RADIO TELEMTRY

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Introduction

Traditional methods for obtaining averaged electroencephalic responses (AER) to sound have been to place electrodes on the scalp of the subject and couple lead-in wires directly to the recording equipment. While this method has met with considerable success, it has required either that the subject remain relatively quiet or, with difficult-to-test subjects such as small children or the mentally retarded, the use of sleep-inducing drugs.

A method which is currently in use at the Central Wisconsin Colony Research Laboratory is a radio telemetry system to record electroencephalographic (EEG) activity and subsequent electroencephalic responses (Reneau and Mast, 1968). The eight-channel EEG telemetering system used is a miniaturized adaptation of a unit that was originally designed and built, in the laboratory of Dr. W. Storm van Leeuwen, Institute of Medical Physics, TNO, Utrecht, the Netherlands, under the direction of Anton Kamp (1963). This method requires no restraint on the part of the subject, although the miniaturized electronic equipment is carried by the subject strapped in a back-pack or to an earphone head-band. For a more detailed description of the electronic instrumentation of the system the reader is referred to the publication by Reneau and Mast (1968).

The use of telemetering equipment to record AER's audiometrically is in its infancy (Jerger et al., 1968; Reneau and Mast, 1968; Reneau and Moore, 1968; Walter et al., 1967). Therefore, it was reasoned that the next logical step along these lines would be to compare AER's recorded by a direct method with those recorded via radio telemetry. Consequently, the present investigation was undertaken and these specific questions were asked: 1. is there agreement of the AER-threshold obtained by direct method recording and radio telemetry to the behavioral (hand-raising) threshold and, 2. can the AER be identified at 20- and 40 dB SL using radio telemetry and direct recordings? An AER was defined when the following criteria was met:

1. Negative-positive-negative complex.
2. First negative component occurring 50 msec after tone on-set.
3. A positive peak after the first negative.
4. A negative peak after the first positive.
5. A peak-to-peak amplitude larger than that obtained during a silent run and 250 msec prior to tone on-set.

Method

Subjects: Fourteen (14) females were employed in this study. They range in age from 25 to 44 years with a mean age of 30 years. All subjects were employees of Central Wisconsin Colony. Criteria for inclusion in the study was relatively normal hearing, no known ear pathology, no obvious neurological involvements, free from colds and other upper respiratory infections, and negative history of prolonged use of drugs.

Instrumentation and procedure

Direct stimulus system: The experimental test apparatus employed in the presentation and control of the pure tone stimuli are shown by the block diagram in Figure 1. The specific instruments were those listed below:

Figure 1. Block diagram of instruments used in stimulus presentation and data retrieval system for direct recordings.

1. Power Supply (Tektronix, Type 160A)
2. Waveform Generator (Tektronix, Type 162)
3. Two Pulse Generators (Tektronix, Type 161)
4. Audio Signal Generator (Hewlett-Packard, Model 205AG)
5. Modulating Switch (Grason-Stadler, Model E3382C)
6. Attenuator Set (Hewlett-Packard, Model 350D)

7. Amplifier (Custom made)
8. Earphone (Grason-Stadler, Model TDH39, housed in MX41/AR cushion)

A saw-tooth pulse initiated by the Waveform Generator triggered the first pulse generator for the onset of the tone while this same arrangement triggered the second Pulse Generator which turned the tone off. The Pulse Generator fed into a Modulating Switch which was coupled to the Audio Signal Generator. The stimuli were delivered to an Earphone worn by the subject and an Attenuator controlled the intensity of the tones. The Waveform Generator triggered the sweep of the computer with the tone onset occurring 250 msec after this time period.¹ This allowed for averaging of ongoing activity prior to initiating the tone and served as an extra control period along with a "no sound" recording. Analysis time was 1,000 msec and the intersignal ratio was one tone per 2.0 seconds. The pure tones were held constant at an overall duration of 250 msec (rise and fall time = 25 msec each). In addition, an array of instruments were used to record the onset and offset of the pure tone signals on the fourth channel of the computer and the eighth channel of the Dynograph penwriter (Figure 1).

Direct recording system: The experimental test apparatus employed in the collection of the data are also shown by the block diagram in Figure 1. The specific instruments were those listed below:

1. Electrode (Four silver-silver chloride disc, Neher type)
2. Terminal Board (Beckman, Type 902)
3. Lead Selector (Beckman, Type 700)
4. A-C Coupler (Beckman, Type 9806A)
5. Pre-Amplifier (Beckman, Type 481B)
6. Power Amplifier (Beckman, Type 482)
7. Amplifier (Beckman, Type 428)
8. Dynograph Penwriter (Beckman, Type 503)
9. Tape Recorder (Mnemotron, Model 700)
10. Data Retrieval Computer (Nuclear-Chicago, Model 7100)
11. X-Y Recorder (Mosley, Model 7030A)

The electrode arrangement was that depicted in Figure 1. Each electrode attached to the subject went to a terminal board, lead selector, and A-C coupler. Amplification of the signal from the scalp was accomplished by an arrangement of amplifiers, (481 B, 482, 428), which fed the EEG signals to the penwriter and tape recorder simultaneously. The signals were then averaged using a Data Retrieval Computer (DRC) and a graphic record was obtained by utilizing an X-Y Recorder.

Telemetry stimulus system: The same instrumental array which was used during direct recording was also used for telemetry, except for the final amplification stage of the test signals (Figure 2). To this, however, was added:

¹ This procedure was suggested by Darrell E. Rose, Ph. D., Colorado State University, Fort Collins, Colorado.

Figure 2. Block diagram of instruments used in stimulus presentation and data retrieval system for telemetering recordings.

1. Tone Transmitter (Modified commercial set)
2. Transmitting Antenna (Custom made)
3. Receiving Antenna (Custom made)
4. Tone Receiver (Custom made)

Tones were generated in the manner described under the direct stimulus system and the tone transmitter was set to transmit on a frequency of 27 MHz. The tone receiver which is attached to the earphone head-band is depicted in Figure 2. Also depicted is the telemetry unit being worn by a subject.

Telemetry recording system: The instruments used for recording evoked potentials and EEG activity are shown by the block diagram in Figure 2.

The specific instrumentation was:

1. Electrodes (Four silver-silver chloride disc, Neher type)
2. Telemetry unit (Medtronix)
3. Receiving Antenna (Custom made)
4. FM Tuner (Sherwood, Model S-3000)
5. Monitor Scope (Dumond, Type 245)
6. Demodulator (Custom made)
7. Power Amplifier (Beckman, Type 482)
8. Amplifier (Beckman, Type 428)

9. Dynograph Penwriter (Beckman, Type 503)
10. Tape Recorder (Mnemontron, Model 700)
11. Data Retrieval Computer (Nuclear-Chicago, Model 7100)
12. X-Y Recorder (Moseley, Model 7030A)

EEG activity and subsequent electroencephalic responses were recorded from the scalp by silver-silver chloride (Ag-AgCL) electrodes. These electrodes were coupled to the telemetry unit which was strapped to the subject's back. EEG signals were then fed via the transmitting antenna housed in the telemetry system and received by an antenna located about 30 ft. away from the subject. The FM Tuner was set to 106 MHz which sent the signals to the demodulator. A Monitor Oscilloscope was used to observe the position and stability of the telemetry channel pulses. From the demodulator the signals were fed to a series of Amplifiers (Beckman, 482, 428).

A 25 μ V signal was used to calibrate the system for one centimeter pen deflection. EEG activity was then displayed on three channels of the Dynograph Penwriter with a fourth channel serving to monitor the on-set and offset of the pure tone signal. Data was then fed to the tape recorder, DRC, and the X-Y Recorder for write-out.

Test procedure: EEG activity was read between the vertex-right mastoid, vertex-left mastoid, and vertex-nasion. A ground electrode was attached to the right earlobe. Intra-electrode resistances were read both prior to and following each test. All initial values were less than 5000 ohms and values obtained at the end of each test (45 minutes — one hour) were less than 10,000 ohms. Data obtained from both mastoid leads were examined for an AER. The electrode on the nasion served as a monitor for forehead movement or eyeblinks that may have been time-locked to the auditory stimulus. The ongoing EEG tracing was also monitored for muscle or movement artifact.

The direct recordings were always first with the telemetry recordings following within intervals of one week to two months. Behavioral threshold (hand raising) was obtained prior to either recording at 2000 Hz using a modified Hughson-Westlake procedure (Carhart and Jerger, 1959). A modified Hughson-Westlake procedure was also used in obtaining threshold while testing via the direct method and radio telemetry. A "no sound" recording was also obtained either during the ascending or descending trial. When the AER-threshold was obtained, the intensity was increased to 20 dB SL or 40 dB SL in a counterbalanced fashion and an AER was attempted at that level.

Results and Discussion

Table 1 is the results obtained for the 14 subjects under the four conditions of testing. Sound pressure levels (SPL) have been converted to dB re 1964 ISO Standard. A "+" sign under the column labeled "difference" indicates that the AER threshold is greater in dB than the corresponding behavioral threshold. It is evident that several of the behavioral thresholds are somewhat elevated. This is attributed to the laboratory test environment in that acoustically treated rooms are not available. Ambient noise level at the 2000 Hz band is 44.3 dB (re .0002 μ bar), and 56.9 dB on the "C" scale (B and K Precision Sound Level Meter, Type 2203, and octave Filter Set, Type 1613). Notwithstanding, however, the mean difference between the behavioral

Table 1. Comparison of evoked response thresholds via direct and radio telemetry to behavioral threshold of 14 normal subjects. Thresholds are in dB re 1964 ISO Standard. A "+" sign indicates AER-threshold was greater (in dB) than behavioral threshold.

Subjects	Behav.	Direct	Diff.	Behav.	Telemetry	Diff.
A D	20	20	0	0	0	0
L P	15	20	+5	20	30	+10
A C	15	10	-5	20	20	0
J W	10	25	+15	20	30	+10
J L	10	15	+5	20	20	0
B P	20	30	+10	20	20	0
L S	10	15	+5	20	30	+10
G L	20	35	+15	30	30	0
D D	10	15	+5	20	15	-5
V L	-5	5	+10	10	25	+15
M M	15	20	+5	10	20	+10
J W	10	20	+10	20	20	0
D M	20	20	0	20	20	0
B S	30	30	0	30	50	+20
Mean =	14.2	20.0	+5.7	18.5	23.5	+5.0
Standard deviation =	8.0	8.0		7.7	10.9	
Difference between direct and telemetry = +3.5 dB.						

threshold and the AER-direct is 5.7 dB. For telemetering, the AER threshold is greater by 5.0 dB. These two results are not significant at the .05 level of confidence (t ratio). The threshold difference between the direct and the telemetering is 3.5 dB. This is not a statistically significant difference. Therefore, if a deviation of +5-15 dB (Table 2) is acceptable clinically, the telemetering test is as effective as the direct testing in recording AER to sound. Note that for the direct recordings, all subjects gave an AER within a -5 to a +15 dB of the behavioral threshold. For telemetering, 13 subjects

Table 2. Total number of subjects that yielded AER thresholds within -5 to +20 dB of their behavioral threshold and direct vs telemetric comparisons from -20 to +20 dB of AER threshold.

dB Levels	Direct		Telemetry	
	Ss		Ss	
-5	1		1	
0	3		7	
+5	5		0	
+10	3		4	
+15	2		1	
+20	0		1	

dB Levels	Direct vs Telemetry	
	Ss	
-20	1	
-10	1	
-5	1	
0	4	
+5	2	
+10	2	
+15	1	
+20	2	

— Telemetry better than Direct
+ Telemetry poorer than Direct

yielded an AER from a -5 to a +15 dB, with the other remaining subject revealing an AER that was 20 dB greater than the behavioral threshold. At the 20 dB SL, the criteria for an AER was met by all 14 subjects. This was evident for 11 subjects using telemetry with the other three subjects revealing responses that were either negative-positive or positive-negative. At the 40 dB SL, a negative-positive-negative response was identified for the entire group for direct recordings and for 13 subjects using radio telemetry. No significant differences in latency and amplitude were noted between the direct and telemetering recordings. In this investigation, there was a slight tendency for the amplitude of the N_1 - P_2 component to be reduced in the telemetry recordings, however, variability between and within subjects often obscured a consistent relationship. The results obtained on one of the subjects are presented in Figures 3 through 10.

Figure 3 are tracings obtained at the 40 dB SL for the direct recording. In

Figure 3. Direct recording for subject B.S. at 40 dB SL. Attenuation, vertical scale counts, and computer readout refers to control settings on data retrieval computer.

In this figure and all subsequent figures, the top four tracings are the electronically averaged data and the four bottom tracings are segments taken from the ongoing EEG that corresponds to the top tracings. Readings taken bilaterally from the vertex represent the first two recordings in each panel, the third is the forehead placement, with the fourth channel monitoring the onset and offset of the pure tone signal.

Figure 4 is the corresponding telemetering recording for subject B.S. at the 40 dB SL. Note that for the telemetering runs, positive is down, whereas for the direct recordings, positive is in the up direction.

Figure 4. Radio telemetric recording for subject B.S. at 40 dB SL.

Data obtained for the direct recordings at the 20 dB SL is depicted in Figure 5. Note that the calibration signal for the averaged data is $10 \mu V$ and for the ongoing EEG activity it is $50 \mu V$. Figure 6 depicts the telemetering recording

Figure 5. Direct recording for subject B.S. at 20 dB SL.

Figure 6. Radio telemetric recording for subject B.S. at 20 dB SL. The response is not as pronounced as the direct recording but nevertheless, an AER is present particularly in the right mastoid lead. "Eyes

Figure 7. Direct recording at "threshold" for subject B.S.

Figure 8. Radio telemetering recording at "threshold" for subject B.S.

Figure 9. Direct recording for "no sound" condition for subject B.S.

open" in the direct recordings refers to the fact that the recordings were taken while the subject had her eyes open due to very high Alpha rhythm when she tended to close her eyes.

Threshold for the direct recording was identified by the tracings noted in Figure 7 and for telemetering in Figure 8. The recordings shown in these two figures were judged more on the response observed in the right mastoid lead. Using two leads referred to the right and left sides have proven to be most efficient in recording averaged responses, especially during telemetering recordings. That is, responses at times will be larger on the contralateral side as opposed to the ipsilateral side and vice versa. This is especially true at or near threshold.

Figure 9 is the control (no sound) condition for the direct recording. There are some relatively large waves in the left mastoid lead; however, the tracing is different from all other recordings and differs from the one labeled as "threshold". Figure 10 is the control condition for radio telemetry.

Figure 10. Radio telemetering recording for "no sound" condition for subject B.S.

It is concluded, then, that on the basis of the results obtained for the 14 subjects in this investigation, that radio telemetry is a feasible tool for obtaining AER's to sound. Answers to the questions posed at the beginning of the text can be answered in the affirmative.

SUMMARY

Averaged electroencephalic responses (AER) to sound were obtained from humans in two phases of an experiment, 1. direct method recording and 2. radio telemetry. In both phases, a clear AER was obtained at a level of 70 or 80 dB SPL at 2,000 Hz. An AER was then elicited at the behavioral threshold

level, if possible, or in subsequent 5 or 10 dB steps using a modified Hughson-Westlake procedure. When the AER-threshold was reached, AER's were then recorded at 20 and 40 dB SL. Comparisons were made between direct and telemetry runs at 1. the AER-thresholds to the behavioral threshold, 2. 20 dB SL, and 3. 40 dB SL. Data obtained reveals good agreement between direct and telemetry AER-threshold and the behavioral threshold, and at the two sensation levels.

RÉSUMÉ

Des moyennes de réactions électroencéphalographiques au son (AER) furent obtenues sur des sujets humains dans deux phases d'une expérience, 1. enregistrement par méthode directe et 2. radio-télémétrie. Dans les deux cas, une AER nette fut obtenue à un niveau de 70 ou 80 dB SPL à 2000 Hz. Une AER fut alors sollicitée au niveau du seuil de réaction de conduite, si possible, ou par étapes subséquentes de 5 ou 10 dB, en utilisant une méthode Hughson-Westlake modifiée. Lorsque le seuil AER fut atteint, des AER furent alors enregistrés à 20 et 40 dB SL. Des comparaisons furent faites entre des séries d'expériences directes et télémétriques au niveau 1. des seuils AER au seuil de réaction de conduite, 2. de 20 dB SL, et 3. de 40 dB SL. Les résultats obtenus révèlent une bonne concordance entre les seuils AER directs et télémétriques et le seuil de réaction de conduite, et aux deux niveaux de sensation.

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