Auditory evoked brain responses: Comparison of ON and OFF responses at long and short durations

PAULA KLINGENBERG SCHWEITZER
Saint Louis University, St. Louis, Missouri 63103

Average evoked brain responses (EBRs) to three durations of one kilohertz pure-tone stimuli were computed from human scalp recordings. Stimuli of 25, 75, and 2,000 msec duration were each presented binaurally at each of eight equally spaced intensity levels, ranging from 58 to 86 dB SPL. EBRs computed immediately following presentation, and immediately following removal of the 2,000-msec-duration stimulus result in ON and OFF responses, respectively. EBRs computed immediately following presentation of the 25- and 75-msec-duration stimuli appear to be the result of the sum of separate responses to stimulus onset and offset. Computer-dissected ON and OFF EBRs to short-duration stimuli are very similar in waveform and amplitude to the responses evoked by the onset and offset, respectively, of the 2,000-msec duration stimulus. Dissected ON and OFF responses demonstrate linear amplitude-intensity functions in amplitude ranges similar to respective ON and OFF responses to 2,000-msec stimulation. The data suggest that ON and OFF responses are mediated by independent physiological mechanisms.

The human averaged evoked brain response (EBR) has been shown to be sensitive to both the onset (ON response) and the offset (OFF response) of acoustic stimulation. However, there is considerable disagreement as to the reliability of occurrence of the OFF response and its dependence on stimulus duration. Many investigators suggest that the OFF response is present only when stimulus duration is greater than some critical length. The minimum duration necessary to elicit an OFF response has been reported to be as short as 310 msec (Johannsen, Keidel, & Spreng, 1972) and as long as 1,500 msec, showing much variability across subjects (Rose & Malone, 1965). Cody and Townsend (1973) report an inability to record OFF responses from some subjects with durations as long as 3 sec.

Johannsen et al. (1972) attribute the greater response variability found between subjects for stimuli of durations less than 500 msec to the possible interaction of ON and OFF effects. A number of experimenters have suggested that a possible interaction between ON and OFF responses might account for the slight increase in the amplitude of the EBR to stimulus durations of 20 to 50 msec (Davis & Zerin,

1966; Skinner & Jones, 1968; Spreng, 1969, 1971). This interaction might be a neural interaction and/or the simple algebraic summation of two concomitant waveforms at the scalp. If the dimensions of the ON and OFF responses remain relatively stable with changes in stimulus duration, then ON response data for stimuli less than some critical duration may be directly confounded by OFF responses. That is, a temporal overlap of responses to stimulus onset and offset may affect the waveform of the observed EBR. On the other hand, the observed EBR to such short-duration stimuli may be purely an ON effect if the neural mechanism responsible for the OFF response is sensitive only to longer duration stimuli.

Few studies in the literature directly compare EBR data from short-duration stimuli, where the possibility of ON and OFF interaction exists, with the EBR data from stimuli of sufficient duration to produce clearly separable ON and OFF responses. Only two studies provide some insight into this matter. McCandless and Best (1966) report no consistent differences in the waveform produced by 30- and 700-msec-duration stimuli. Rau (1968) reports no slope differences in amplitude-intensity power functions with durations of 10 and 1,500 msec. Only three to four stimulus intensities were used to compute these functions, making it difficult to validly compare the function slopes. Moreover, neither McCandless and Best (1966) nor Rau (1968) had the study of possible ON and OFF interaction as their primary purpose.

It should be noted that only a small number of

This research was conducted in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Results of this study were presented, in part, at the annual meeting of the Eastern Psychological Association, New York City, April 1976. Requests for reprints should be sent to Paula Klingenberg Schweitzer, Department of Psychology, Xavier University, Cincinnati, Ohio 45207.

electroencephalogram (EEG) samples are summed to detect the EBR in all of the reported studies. Large EEG samples may be required since OFF responses are relatively small and variable responses. Schweitzer and Tepas (1974) studied the OFF response using a large sample size, but unfortunately investigated only one stimulus duration. These authors presented 2,000-msec-duration stimuli at 10 intensity levels. The OFF EBR was found to be of smaller amplitude than the ON EBR, with both ON and OFF amplitude response measures sensitive to changes in stimulus intensity, as evidenced by linear amplitude-intensity functions. However, the relationship of the OFF EBR to the ON EBR remains inconclusive. The purpose of the present study was to clarify the effects of long- vs. short-duration stimulation on the EBR by systematically investigating the effects of intensity on the human EBR to auditory stimulation at several durations. This experiment studied the question of whether the mechanism responsible for the OFF response is sensitive only to long-duration stimuli or to short-duration stimuli as well. It is possible that the detectability of the OFF response may simply decrease, since it is a small response which may be easily buried at short durations in the larger ON response. In this respect the study was designed to provide further clarification of the extent to which the ON and OFF responses share the same physiological mechanism.

METHOD

Subjects

Three human subjects, two of whom were male, were selected on the basis of their lack of any obvious hearing deficits, and their ability to clearly produce a measurable OFF EBR, since there is no definitive information in the literature as to the appropriate conditions for detecting a reliable OFF response. The subjects ranged in age from 21 to 26 years.

Apparatus and Stimuli

The methodology and recording technique were similar to those reported by Schweitzer and Tepas (1974). One kilohertz pure tones were presented binaurally to the subject at a rate of one stimulus every 4 sec. Three stimulus durations were used: 25, 75, and 2,000 msec. For each duration, eight different intensities were presented: 58, 62, 66, 70, 74, 78, 82, and 86 dB SPL (re $20\mu\text{N/m}^2$). The rise-fall time for all stimuli was 10 msec. The stimuli were delivered through matched Telephonics TDH 39 earphones mounted in MX41/AR cushions and an HD11B headset. The earphones were calibrated with a Brüel and Kjaer Model 158 audiometer calibrator with an NBS 9A 6 cc acoustic coupler.

The EEG was recorded on one channel of a Grass Model 7 polygraph using a Model 7P5A EEG preamplifier. The one-half amplitude bandpass of the amplifier at output to the computer was .15 to 500 Hz, as specified by the manufacturer. The EEG was recorded by means of Grass E55 electrodes placed on the scalp at C_z and O_z (Jasper, 1958). This recording site was chosen in an effort to partially replicate an earlier study and because of ample evidence from our laboratory as to its suitability (Schweitzer & Tepas, 1974; Tepas, Boxerman, & Anch, 1972). A Beckman 16-mm biopotential electrode attached to the forehead served as ground. The AX08 analog input of the DEC LAB-8 computer system

Figure 1. Schematic showing one complete stimulus cycle (4 sec) for each of the durations used. Upward deflection indicates stimulus onset; downward deflection indicates stimulus offset. Rise-fall time is 10 msec. Roman numerals refer to EEG activity summed across sessions over a 500-msec analysis time, as indicated by the vertical broken lines. See text for further explanation.

Procedure

Figure 1 is a schematic showing one complete stimulus cycle for each of the durations used. EEG computations were made at 500 time points distributed over a 500-msec analysis time starting at stimulus onset and at 500 time points distributed over a 500-msec analysis time 2,000 msec after stimulus onset. The broken vertical lines in Figure 1 mark the two 500-msec EEG analysis periods following each stimulus presentation. A trial comprised the sum of the EEG activity following 50 presentations of one stimulus intensity-duration combination. The digital values for each of the 500 time plots of each of the two summed waveforms computed on each trial were then punched on paper tape for subsequent analysis off-line.

Each subject was tested in 18 sessions. A session consisted of 24 separate trials with only 1 of the 24 stimulus combinations (8 intensities and 3 durations) being administered in each trial. The presentation of the stimulus combinations was pseudorandomly determined. After all 18 sessions were completed, the waveforms for separate trials were summed together across the 18 sessions for each subject using the APE program (Tepas, Kress, & Klingaman, 1975). The Roman numerals I through VI in Figure 1 refer to this EEG activity summed across sessions. Thus, I and III refer to responses evoked by 25- and 75-msec-duration stimuli, respectively; V and VI refer to the EBRs following onset and offset, respectively, of the 2,000-msec-duration stimulus. Waveforms II and IV are viewed as control sums. The summed waveforms were then printed out as decimal values, from which amplitude and latency measures were made. A standard square wave (10 μV and 100 msec) was run through the system and averaged at each session, then summed across sessions to provide a scale for calibration.

Waveform Manipulations

In addition to computation of the basic, or naturally occurring, waveforms at each intensity, a series of computer-dissected (d) and synthesized (s) waveforms was produced using APE (Tepas et al., 1975) by appropriate subtraction and addition of the naturally occurring summed waveforms I through VI at each intensity. Table 1 lists all of these waveforms, the hypothetical EBR corresponding to each waveform or manipulation, and the abbreviations used subsequently throughout this paper. Waveforms I and III were labeled multiple-response (MR) EBRs because it is at these short stimulus durations (25 and 75 msec, respectively) that some kind of interaction to stimulus onset and offset may exist in the recorded waveform. Dissected hypothetical

Table 1
List of Waveforms Computed for Each Subject

Manipulation	Hypothetical EBRs	Abbreviation
Naturally Occurring		
I	25 msec multiple response control; no EBR	25 MR
II	75 msec multiple response control; no EBR	75 MR
III	2,000 msec ON	2,000 ON
IV	2,000 msec OFF	2,000 OFF
V		
VI		
Dissected		
I - V	dissected 25 msec OFF	d25 OFF
III - V	dissected 75 msec OFF	d75 OFF
VI - II	2,000 msec OFF control	
IV - II	control; no EBR	
I - VI at 35 msec past onset of I	dissected 25 msec ON	d25 ON
III - VI at 85 msec past onset of III	dissected 75 msec ON	d75 ON
Synthesized		
V + VI at 35 msec past onset of V	synthesized 25 msec multiple response	s25 MR
V + VI at 85 msec past onset of V	synthesized 75 msec multiple response	s75 MR

Note—All entries refer to waveforms summed across sessions. Addition of waveforms is indicated by a plus (+) sign, subtraction by a minus (−) sign. See Figure 1 for graphic understanding of Roman numerals.

OFF responses were produced by subtraction of the 500 digital values for waveform V from the corresponding 500 digital values for waveform I (for d25 OFF) or III (for d75 OFF). That is, an ON EBR was subtracted from an EBR which may have comprised potentials to both stimulus onset and offset, hypothetically yielding a dissected OFF response. Dissected hypothetical ON responses were similarly produced by subtraction of waveform VI from waveform I (for d25 ON) or III (for d75 ON), beginning at a point equivalent to where offset of the 25- or 75-msec stimulus occurred. Synthesized hypothetical MR EBRs were produced by adding waveform VI to waveform V, beginning at a point equivalent to where offset of a 25-msec (for s25 MR) or 75-msec (for s75 MR) stimulus would occur. This synthesis of an ON response plus an OFF response resulted in an EBR comprising potentials to both stimulus onset and stimulus offset where stimulus duration was artificially determined.

In addition, as indicated in Table 1, a number of control manipulations were carried out at each intensity. Control waveforms II and IV have been mentioned. Manipulations VI-II and VI-II were introduced to control for possible artifacts which may have been produced by the computer subtraction procedure.

RESULTS

Figures 2 and 3 show the EBRs to the onset and offset of three durations of acoustic stimulation for subject D.D. at each intensity. Both naturally occurring and computer-dissected and synthesized EBRs are presented. Peak deflections were labeled in accordance with the nomenclature system used in previous studies from this laboratory (Tepas, 1974).

As Figure 2 indicates, there are some striking similarities between the three sets of ON responses as well as between the three sets of OFF responses. The waveshapes of the computer-dissected ON EBRs are

remarkably similar to the waveshape of the naturally occurring 2,000-msec ON response. Analogously, the waveshapes of the dissected OFF responses are obviously similar to the naturally occurring OFF EBR at 2,000 msec. As the figure indicates, the three sets of ON responses are very similar in size, less variable and much larger than the three sets of OFF responses which are also close to one another in size. Figure 3 indicates additional similarities between the computer-synthesized MR and naturally occurring MR EBRs to 25- and 75-msec-duration stimuli. The data shown are representative for all subjects.

Figure 4 presents the latency range for each of the measurements made from the naturally occurring EBRs for each subject. The figure shows that, while there is some variability in latency across subjects, similar relationships between latency measures exist for all subjects. For each individual subject, measures A and E are very similar in range. Measure C has a shorter response latency than A and E for all subjects, showing greater variability for subject B.J. than for subjects D.D. and J.O. In addition, response measures B and F are similar in range for each individual subject. Measure D has a shorter latency than B and F for subject B.J. with approximately the same range as B and F for subjects D.D. and J.O.

As a test for linearity of amplitude-intensity relationships and a demonstration of stimulus control, linear regression lines were computed by the method of least squares and correlation coefficients were calculated for measures A-B, C-D, and E-F from both naturally occurring and computer-generated waveforms for each subject and for data pooled across subjects. Because of variability across subjects in the latencies of the response measures chosen for measurement, pooling was accomplished by averaging the measured microvolt amplitude across subjects. The correlation coefficients for the individual and pooled data are shown in Table 2. The regression analysis revealed significant correlations between amplitude and SPL for every measure except d75 ON for subject B.J.

The regression lines and mean data points for the ON (A-B) and OFF (C-D) EBRs at each duration are graphically presented in Figure 5 for subject D.D. The figure points out again the close similarity between dissected EBRs and their respective naturally occurring counterparts. The amplitude-intensity functions for the three ON responses cluster together, while the functions for the three OFF responses also cluster together but at a different microvolt level. Over the range of intensities used, there is no overlap whatsoever between the ON and OFF functions.

The regression lines and mean data points for the naturally occurring multiple-response (E-F) EBRs and the dissected ON (A-B) EBRs at 25 and 75 msec

Figure 2. Naturally occurring and computer-dissected ON and OFF EBRs for subject D.D. Downward deflection indicates that the O_2 electrode was positive with respect to the C_2 electrode. Note the different microvolt calibrations for ON and OFF responses. Nomenclature is compatible with Figure 1 and Table 1. The sharp vertical shift seen in the computer-derived ON waveforms is a baseline shift resulting from the subtraction procedure.

Table 2
Correlations of EBR Amplitude Measures with SPL

EBR	Measure	Subject			
		D.D.	J.O.	B.J.	Pooled
2,000 ON	A-B	.767*	.847**	.712*	.841**
d25 ON	A-B	.861**	.861**	.920**	.927**
d75 ON	A-B	.947**	.976**	.625	.969**
2,000 OFF	C-D	.966**	.914**	.910**	.991**
d25 OFF	C-D	.761*	.907**	.947**	.963**
d75 OFF	C-D	.774*	.942**	.818*	.970**
25 MR	E-F	.992**	.963**	.981**	.972**
s25 MR	E-F	.933**	.960**	.774*	.979**
75 MR	E-F	.978**	.959**	.957**	.981**
s75 MR	E-F	.775*	.885**	.911**	.889**

* $p < .05$

** $p < .01$

are compared in Figure 6 for subject D.D. The amplitude-intensity functions for the two multiple-response EBRs are nearly identical. Subtraction of an OFF response from these multiple response EBRs results in ON response functions which are smaller in amplitude than MR functions. Such subtraction also results in a separation of the derived 25- and 75-msec ON functions. That is, the amplitude difference between d25 ON and 25 MR is much larger than the amplitude difference between d75 ON and 75 MR.

Figure 7 compares the (E-F) amplitude-intensity functions derived from the brain responses to short-duration stimuli with those functions derived from a synthesis of separate ON and OFF responses for

Figure 3. Naturally occurring and computer-synthesized multiple response EBRs for subject D.D. Nomenclature is compatible with Figure 1 and Table 1. The sharp vertical shift seen in the synthesized waveforms is a baseline shift resulting from the addition procedure.

subject D.D. While the functions derived from the two naturally occurring MR waveforms are almost superimposed on one another, the functions derived from the two synthesized MR waveforms do not overlap. At the same time, however, the functions derived from s25 MR and s75 MR are similar to those derived from 25 MR and 75 MR, respectively.

The regression lines from subject J.O. show the same relationships to one another as those of subject D.D. The data from subject B.J. show reasonable consistency with the data from the other two subjects, although d75 ON fails to show a linear amplitude-intensity function. The data pooled across subjects are in close agreement with the individual data, as can be seen by a comparison of the pooled ON and OFF functions in Figure 8, with the individual data from subject D.D. shown in Figure 5. All control manipulations yielded information in support of the above results.

DISCUSSION

The results of this study suggest that an auditory evoked brain response occurs to the offset of short-duration stimuli of 25 and 75 msec as well as to the offset of a long-duration stimulus. The data show that dissected OFF EBRs to short-duration stimuli are very similar in waveform and amplitude to the naturally occurring response evoked by offset of a 2,000-msec-duration stimulus. At the same time,

dissected ON EBRs to short-duration stimuli are very similar in waveform and amplitude to the naturally occurring response evoked by onset of a 2,000-msec stimulus.

The responses recorded to the onset and offset of the 2,000-msec-duration stimulus replicate the results of Schweitzer and Tepas (1974). That is, the OFF EBR is of smaller amplitude than the ON EBR, and both the ON and the OFF responses are sensitive to changes in the intensity of stimulation. Dissected ON and OFF EBRs also demonstrate this

Figure 4. Latency range in milliseconds for measures made from naturally occurring EBRs for each subject.

Figure 5. Amplitude-intensity functions for naturally occurring and computer-dissected ON (A-B) and OFF (C-D) EBRs for subject D.D. The regression lines were fit to the mean data points using the method of least squares. Measurements were made from the digital values of the waveforms. $N = 900$.

Figure 6. Amplitude-intensity functions for naturally occurring MR (E-F) and dissected ON (A-B) EBRs for subject D.D. $N = 900$.

sensitivity to stimulus control as evidenced by linear amplitude-intensity functions in amplitude ranges similar to respective ON and OFF responses to 2,000-msec stimulation. Further indication of the existence of the OFF response at short durations can be seen in the synthesized multiple response waveforms, where an OFF response was algebraically added to an ON response at an appropriate delay.

The amplitude-intensity functions, derived from dissected and synthesized EBRs and shown in Fig-

ures 6 and 7, point out that the OFF response appears to contribute more to the response evoked by the shorter duration stimulus of 25 msec than that evoked by the longer duration stimulus of 75 msec. This is not surprising in view of the latencies of the response deflections measured and shown in Figure 4. Since stimulus offset occurs at a later point in time with a longer duration stimulus, the OFF response to such a stimulus might be expected to affect the ON response at an equivalently later point in time. Thus, with a stimulus of sufficient duration, the effect of the OFF response on the early components of the ON response might be expected to diminish. It should be noted that the amplitude of s25 MR may be artificially inflated because the ON and OFF EBRs summed together to produce the synthesized response may not be (and probably are not) identical to the ON and OFF responses to the shorter 25-msec-duration stimulus. Such artificial inflation of E-F amplitude of s75 MR, on the other hand, might not be expected because of the relative latencies of the response to stimulus onset and offset at this longer duration. Evidence that the OFF response to a 2,000-msec stimulus is larger than that to a shorter duration stimulus is demonstrated in Figure 3. The synthesized 75-msec MR waveforms show, beyond the peak labeled F, a slight hump and some broadening which is not apparent in the naturally occurring EBRs to 75-msec stimulation. These observations could explain why, as seen in Figure 7, the two E-F functions derived from synthesized MR EBRs are not superimposed on one

Figure 7. Amplitude-intensity functions for naturally occurring and synthesized multiple response (E-F) EBRs for subject D.D. $N = 900$.

Figure 8. Amplitude-intensity functions for naturally occurring and computer dissected ON (A-B) and OFF (C-D) EBRs for data pooled across subjects. Measurements were made by averaging the measured amplitude values across subjects at each intensity for each response measure. $N = 900$.

another like the two E-F functions derived from naturally occurring MR EBRs.

Differences in the relative latencies of the ON and OFF responses may explain the slight apparent discrepancies in the data of subject B.J. As a consequence of the variability of C and the shorter response latency of D compared to B for subject B.J., any algebraic manipulation of data which involves the EBR recorded to stimulus offset (such as d25 ON and d75 ON) may be somewhat distorted in phase. Subjects D.D. and J.O. do show latency data comparable to that reported by Schweitzer and Tepas (1974).

Figure 9 shows EBRs to the onset and offset of acoustic stimulation summed across intensities for subject D.D. Although pooling data in this manner has little or no parametric value, this figure does provide a reasonable model, or demonstration, of one of the major results of this experiment. That is, the study demonstrates that dissected and synthesized waveforms, with characteristics similar to their naturally occurring counterparts, can be produced by appropriate algebraic manipulation of these natural waveforms. This indicates that the observed EBR to short-duration stimuli probably is the result of overlapping responses to the onset and offset of stimulation. Therefore, the waveform evoked by a short-duration auditory stimulus appears to be the result of a temporal summation of separate responses to stimulus onset and offset, rather than a direct neural interaction. The fact that the waveforms pro-

duced by algebraic manipulation are not perfectly identical to the naturally occurring EBRs may be due to several reasons: (1) A small amount of the total variance may be due to neural interaction; (2) the waveforms of the ON and OFF responses probably vary somewhat in amplitude and latency with changes in stimulus duration; (3) the time constant of the amplifier may produce some amplitude and phase distortion of temporally close EEG potentials; (4) EBR signal variability may vary; and (5) the EEG sample may not be large enough to minimize all unrelated noise. While the conclusions presented here are strongly supported by the data, one must be cautious in generalizing the results beyond the stimulus parameters of this study. Pilot data using several stimulus durations and inter-stimulus intervals plus recording of the entire interval lend preliminary support to such generalization.

One may question whether the results of this study conflict with the results obtained in previous experimentation using short-duration stimuli where the ON and OFF responses have been summed without the knowledge or consideration of the investigator. Although some reinterpretation of data investigating the effect of stimulus duration is called for, the fact that EBRs to short-duration stimuli have been shown to be subject to stimulus control would be expected since both ON and OFF responses vary with stimulus intensity. For audiometric purposes (Davis, 1966; Rapin & Graziani, 1967), it may in practice be desirable to choose a short duration, such as 25 msec, to maximize the probability of seeing a response to an auditory stimulus, since ON and OFF intensity effects will probably sum. On the other hand, if one is mainly interested in measuring peaks A and B of the ON response, one need only to choose a stimulus of sufficient duration (for example,

Figure 9. Naturally occurring and computer derived ON, OFF, and MR EBRs summed across the eight intensities for subject D.D. Each waveform is the sum of eight separate waveforms, resulting in a total sample size of 7,200.

200 msec) to minimize the temporal interaction of the ON and OFF responses for these measures.

Given that the response evoked by short-duration stimuli appears to be the result of the sum of separate responses to stimulus onset and offset, it seems quite unlikely that the ON and OFF responses are mediated by a single physiological mechanism sensitive to changes occurring over such short durations and capable of responding in two different forms at the same point in time. While single units responsive to both stimulus onset and offset have been found in the auditory cortex of mammals (Galambos, 1960; Goldstein, Hall, & Butterfield, 1968; Katsuki, Watanabe, & Maruyama, 1959), this author could find no report of such ON-OFF units for durations of less than 100 msec. This may be due to the dearth of appropriate stimulus manipulations and data analysis strategies. The presence of single units sensitive only to stimulus onset or only to stimulus offset but not sensitive to both onset and offset strongly suggests that separate neuronal populations contribute to the production of ON and OFF EBRs. In addition, the shorter response latency for measure C as compared to measure A further suggests that the ON and OFF responses are functions of independent physiological mechanisms with different response latencies. This evidence argues for clinical audiometric study of both ON and OFF response mechanisms separately. Future research should also focus on the question of whether the OFF response exists at durations shorter than 25 msec. In addition, a systematic study of the interaction of stimulus duration and interstimulus interval on the OFF response should be undertaken.

REFERENCES

- CODY, D. T. R., & TOWNSEND, G. L. Some physiologic aspects of the averaged vertex response in humans. *Audiology*, 1973, 12, 1-13.
- DAVIS, H. Validation of evoked response audiometry (ERA) in deaf children. *International Audiology*, 1966, 5, 77-81.
- DAVIS, H., & ZERLIN, S. Acoustic relations of the human vertex potential. *Journal of the Acoustical Society of America*, 1966, 39, 109-116.
- GALAMBOS, R. Studies of the auditory system with implanted electrodes. In G. L. Rasmussen & W. F. Wingle (Eds.), *Neural mechanisms of the auditory and vestibular systems*. Springfield, Ill: Thomas, 1960. Pp. 137-151.
- GOLDSTEIN, M. H., HALL, J. L., & BUTTERFIELD, B. O. Single-unit activity in the primary auditory cortex of unanesthetized cats. *Journal of the Acoustical Society of America*, 1968, 43, 444-455.
- JASPER, H. The ten-twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology*, 1958, 10, 371-375.
- JOHANNSEN, H. S., KEIDEL, W. D., & SPRENG, M. Der Einfluss von Intensität und Dauer der Beschallung auf den OFF-Effekt des akustisch evozierten Potentials. *Archiv fuer klinische und experimentelle Ohren-, Nasen-, und Kehlkopfheilkunde*, 1972, 201, 208-221.
- KATSUKI, Y., WATANABE, T., & MARUYAMA, N. Activity of auditory neurons in upper levels of brain of cat. *Journal of Neurophysiology*, 1959, 22, 343-359.
- MCCANDLESS, G., & BEST, L. Summed evoked responses using pure tone stimuli. *Journal of Speech and Hearing Research*, 1966, 9, 266.
- RAPIN, I., & GRAZIANI, L. J. Auditory evoked responses in normal, brain damaged and deaf infants. *Neurology (Minn.)*, 1967, 17, 881-894.
- RAU, R.-M. Über die Abhängigkeit der objectiv ermittelten Intensitätsfunktion des menschlichen Gehörs von der Tonfolgefrequenz. *Archiv fuer klinische und experimentelle Ohren-, Nasen-, und Kehlkopfheilkunde*, 1968, 190, 133-145.
- ROSE, D., & MALONE, J. Some aspects of the acoustically evoked response to the cessation of stimulus. *Journal of Auditory Research*, 1965, 9, 412-422.
- SCHWEITZER, P. K., & TEPAS, D. I. Intensity effects of the auditory evoked brain response to stimulus onset and cessation. *Perception & Psychophysics*, 1974, 16, 396-400.
- SKINNER, P. H., & JONES, H. C. Effects of signal duration and rise-time on the auditory evoked potential. *Journal of Speech and Hearing Research*, 1968, 11, 301-306.
- SPRENG, M. Problems in objective cerebral audiometry using short sound stimulation. *International Audiology*, 1969, 8, 424-429.
- SPRENG, M. Small computers in evoked response audiometry (ERA). *Archiv fuer klinische und experimentelle Ohren-, Nasen-, und Kehlkopfheilkunde*, 1971, 198, 50-70.
- TEPAS, D. I. Computer analysis of the electroencephalogram: Evoking, promoting and provoking. *Behavior Research Methods & Instrumentation*, 1974, 6, 95-110.
- TEPAS, D. I., BOXERMAN, L., & ANCH, A. M. Auditory evoked brain responses: Intensity functions from bipolar human scalp recordings. *Perception & Psychophysics*, 1972, 11, 217-221.
- TEPAS, D. I., KRESS, G., & KLINGAMAN, R. L. APE: Average potential evaluation software for the LAB-8 system. *Behavior Research Methods & Instrumentation*, 1975, 7, 120-124.

(Received for publication August 9, 1976;
revision received May 6, 1977.)