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Journal

Electroencephalography and clinical neurophysiology, 28(2)

ISSN

0013-4694

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Publication Date

1970-02-01

DOI

10.1016/0013-4694(70)90182-3

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Peer reviewed

AUDITORY AVERAGED EVOKED POTENTIALS IN MAN DURING SELECTIVE BINAURAL LISTENING

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(Accepted for publication: May 23, 1969)

In this study, the average evoked potential (AEP) to clicks was investigated when the subject engaged in a selective listening task. Two verbal messages were presented, one to each ear, and the subjects were instructed to attend and respond to the message in one ear or the other. Clicks were also presented to each ear, concurrently with the verbal messages. Following the experimental runs in which the subjects attended to the verbal messages, two additional runs were conducted in which the subjects were instructed to ignore the verbal messages and to report the occurrence of the clicks in one ear or the other.

When the subjects attended to the verbal material, the clicks served as probe stimuli to determine the effects of selective listening to one ear on the sensitivity of the other ear. Broadbent and Gregory (1963) conclude from a psychophysical detection study that "the division of attention away from a stimulus produces an effect resembling a reduction in the intensity of the stimulus". They believe that this supports Treisman's (1960) suggestion that the mechanism of selective attention is an attenuation rather than a rejection of the irrelevant messages (see Egeth 1967; Treisman 1964, for reviews of the theoretical issues raised by selective listening studies). As the AEP is sensitive to stimulus

intensity (Davis and Zerlin 1966; Rapin *et al.* 1966; Onishi and Davis 1968), the AEP to clicks presented in the "rejected" ear should reflect the attenuation of irrelevant messages reported by Broadbent and Gregory.

When the subject attended to clicks in one ear, the experimental situation resembled one used earlier by Donchin and Cohen (1967) in which subjects were presented with a multi-element visual field. It was found that the element of the field to which the subject attended elicited an AEP having a prominent positive peak with a latency of 200–300 msec (hereafter referred to as P300). A relationship between P300 and the task relevance of the stimulus has been reported also by Sutton and his co-workers (Sutton *et al.* 1965, 1967) as well as by others (Chapman and Bragdon 1964; Debecker and Desmedt 1966). The present study provided an opportunity to determine whether Donchin and Cohen's result with visual stimuli can be reproduced with acoustic stimuli.

Another objective of the study was to compare the effects of selective listening to verbal material with the effects of selective listening to non-verbal, acoustic stimuli. Studies by Treisman and Geffen (1967) and Lawson (1966) suggest that selective attention follows somewhat different rules for these two types of stimuli.

METHOD

Eight male college students were paid for participating as subjects in the experiment; all had served frequently in other psychophysiological studies. The subject sat in a lounge chair within a dark and sound-attenuating room and listened to stimuli presented via stereo head-

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Fig. 1

A. A block diagram of the equipment used to generate stimuli. Randomly spaced clicks were divided in an electronic switch by having it alternate at 1 sec intervals between its two output channels. Then each series of clicks was mixed with a separate voice recording of numbers and letters and the resulting signals led to separate earphones of a stereo headset. **B:** The signal as it appeared in each ear consisted of three different stimuli: (1) a series of numbers, (2) a series of letters occasionally substituted for the number and (3) a series of clicks.

phones (Monarch ES-300). A block diagram of the equipment used to generate the stimuli is presented in Fig. 1, A, and a schematic drawing of the stimulus presentation schedule is shown in Fig. 1, B.

Two of the four channels of a tape recorder (Ampex SP300) were used to present two different series of verbal stimuli, one to each earphone of the headset. The two series consisted of randomly chosen numbers (1-9) read in a slow, even voice at the rate of approximately 1/sec. Although Fig. 1 indicates that the digits were presented in synchrony to the ears, the method of tape preparation introduced an asynchrony between "simultaneous" letters. This asynchrony did not exceed 300 msec. At a rate of once every 10-15 numbers, a letter (A-Z) replaced one of the numbers. There was no instance in which the same numbers or letter appeared in both earphones at the same time. Clicks were mixed with the output of the tape recorder so that a click appeared in each earphone at an average rate of once every 15 sec. Thus, a total of three stimuli were presented to each ear: (1) numbers, at

the rate of 1/sec; (2) letters substituting for one of the numbers at the average rate of 1/15 sec; and (3) clicks at the average rate of 1/5 sec.

The intensity of the numbers and letters was approximately 55 dB SPL measured free field by

Fig. 2

Eight averaged evoked potentials obtained in one subject to a click stimulus and superimposed to accentuate the consistent components of the response.

a Bruel and Kjaer sound level meter placed 1 in. from the earphone, and the clicks were adjusted to be 27 dB more intense.

The experimental session was divided into four conditions which differed from one another only in the instructions given to the subject. The

four conditions and their order of presentation were:

1. Report letters in the right (or left) earphone.
2. Report letters in the left (or right) earphone.
3. Report clicks in the right (or left) earphone.
4. Report clicks in the left (or right) earphone.

Fig. 3

Average evoked potentials for eight subjects in response to clicks. The potentials were recorded from the vertex while subjects performed a selective listening task under four different instructional conditions. Each pair of AEPs for a subject is arranged according to whether the subject was to report clicks or letters and whether the AEP was elicited by clicks in the "attended" or "non-attended" ear. Each curve is based on the average of 50 responses, negativity upward.

Before the experiment, subjects were told that they would receive a different series of numbers and letters in each ear, but they were not told that clicks would be presented until conditions 3 and 4. They were to report the appropriate stimulus by rapidly closing a micro-switch held in the right hand. For four of the subjects, the initial response was to stimuli in the right earphone. For the other four subjects, this order was reversed.

The data were recorded on FM magnetic tape with an Ampex DAS-100 system. EEG recordings were made from an electrode placed on the vertex, C_z of the "10-20 system" (Jasper 1958), and reference electrodes linking the two ears. The subject was grounded through a forehead electrode. In addition, eye movements were monitored by recording the electro-oculogram (EOG) from electrodes placed above and below the right eye. The frequency response curve of the EEG amplifiers was flat between 1 and 50 c/sec, and roll off slope was 12 dB/octave. For the EOG, the frequency response curve was flat between 0.1 and 50 c/sec. Digitization at the rate of 500/sec, and processing of the data were performed by an IBM 1800 computer. Each AEP was based upon the responses to 50 click stimuli and grouped as to (1) whether the click was presented to the right or to the left ear, and (2) whether the subject was listening to letters or clicks. In all figures, negativity of the vertex electrode is represented by an upward deflection.

RESULTS

The pattern of waves comprising the AEP was consistent both within and between subjects and resembled vertex AEPs to click stimuli reported by other investigators (Davis *et al.* 1966; Goff *et al.*, in press). For purposes of identification, the average evoked potentials obtained under all conditions for one subject are superimposed in Fig. 2.

Four of these peaks (a-d) occur in approximately the first 110 msec, a fifth (e) between 200-300 msec (P300), and the sixth (f) 275-400 msec following onset of the stimulus.

For all eight subjects, click AEPs obtained in each of the four experimental conditions are presented in Fig. 3. In this figure, the pair of

AEP curves obtained for each subject is arranged according to whether he was to report clicks or letters and whether the AEP was elicited by clicks in the attended or the non-attended ear. The upper curve of each pair is for clicks presented in the right ear and the lower curve for clicks in the left ear.

Inspection of this figure indicates that the task relevance of the click affected the amplitude of the AEP. In six of the eight subjects, enhancement of the P300 component occurred when subjects were told to report clicks as compared to when they were told to report letters. In contrast, inspection of the AEPs during selective attention to one or the other ear revealed no systematic effects. Of the two subjects (TD and HG) not showing this difference, one (TD) reported being very drowsy during the experiment and, in fact, identified only about half of the clicks during the "subject to report clicks" condition.

These visual impressions were confirmed by measurements between the peak and trough of the various components identified in Fig. 2. The data for each pair of curves in Fig. 3 were combined, since these AEPs were obtained in identical experimental conditions and differed only in whether they were elicited by clicks in the right or left ear. The mean and standard error of the mean were calculated for each component; the results are shown in Fig. 4.

Fig. 4

Mean amplitude for the components of the click AEPs of Fig. 3. The component designation is indicated in Fig. 2. Cross-bars represent ± 1 standard error of the mean.

Statistical analysis of these data, using Friedman's two-way analysis of variance by ranks (Siegel 1956) confirmed the observations made from the graphic analysis. There was a significant difference ($P < 0.01$) in the amplitude of the late positive component (d-e, P300) when the subject was asked to report the clicks compared to when he was asked to report the letters. In contrast, there was no difference in the P300 component when the comparison was made between AEPs derived from clicks presented to the attended ear compared to clicks presented to the non-attended ear for the same condition of response. Furthermore, both the early components (a-d) and the later negative component (e-f) of the AEP show no significant differences as a function of either task relevance or selective listening to one ear.

Analysis of eye movement recordings revealed some blinking and movement by several of the subjects, but averaging the potentials derived from the eye movement electrode showed no time locked activity in relation to the click onset. Thus, the amplitude of P300 or other features of the AEP is not likely to be the result of such eye movement.

Except for subject TD, the subjects were able to perform the assigned task to perfection. There were practically no missed signals and no false alarms throughout the study. All subjects responded to all the stimuli to which they were instructed to respond and did not respond to any of the stimuli to which they were not to respond.

DISCUSSION

The results may be summarized as follows. When the subject is instructed to respond to clicks that are delivered to one ear, all clicks, regardless of the ear in which they are presented, elicit a P300 component in the AEP larger than the P300 elicited by clicks when the subject is attending to a verbal message. Furthermore, the amplitudes and latencies of earlier components of the click AEP (a-c in Fig. 2) are the same (in the same subject), regardless of the ear stimulated and the instructions to the subject.

The enhancement of P300 in the click AEP

when clicks were responded to by the subject is consonant with reports of increases in this component that have been variously ascribed to "task relevance" (Chapman and Bragdon 1964; Donchin and Cohen 1967), information delivery (Sutton *et al.* 1965), and similar psychological variables. The present study is most similar to a study by Donchin and Cohen in which it was shown that if the subject's attention is focused on some specific aspect of a complex stimulus field, in which a number of elements vary independently, the AEP elicited by elements in the focus of attention would have a large P300. This effect is now shown to occur with acoustic stimuli.

If P300 is an indicator of task relevance, it is puzzling that the amplitude of this component was the same regardless of whether the clicks were presented to the "attended" or to the "non-attended" ear. This finding cannot be attributed to a failure of the subject to discriminate between the signals because they only responded to clicks in the attended ear. These results are consistent with the data reported by Lawson (1966) in an interesting replication of Treisman and Geffen's study of selective attention. Treisman and Geffen (1967) have shown that when the subject is instructed to shadow (*i.e.*, repeat word for word) a verbal message in one ear he virtually ignores a verbal message arriving in the other ear. Lawson (1966) has shown that this apparent blocking of the rejected ear is unique to verbal materials and that subjects are perfectly capable of reporting tone pips arriving in *either* ear when they shadow a verbal message in one ear. Reporting the occurrence of a click or a tone pip is considerably simpler than shadowing a verbal message or discriminating between letters and digits presented acoustically. It is not surprising, therefore, to find that subjects are capable of reporting the occurrence of a click in a rejected ear while they are incapable of interpreting the verbal messages coming in the same ear. Our data are in accord with Lawson's. Our data thus clearly demonstrate that the clicks in both ears were monitored continuously, and that the decision made by the subject that a click has occurred preceded the decision whether to respond to the click.

These results have two interesting implications. First, they reinforce strongly the point

made often by Broadbent that the "channels" conceived of in his theories regarding selective listening (Broadbent 1958) do not necessarily correspond to a sense organ but may be related to different aspects of the stimulus situation, and that subjects do not necessarily choose to block one or the other of the sense organs when instructed to attend to information in another sense organ.

Second, the results suggest that P300 is not related to the "information" delivered by the stimuli as much as to the fact that some decision has been made by the subject concurrently with the appearance of the stimulus. In our case, the appearance of a click is expected by the subject, and on its presentation he has to decide whether to press the report key. That P300 is a concomitant of a decision regarding the stimulus rather than of some specific attributes of the stimulus is consistent with the demonstration of Sutton *et al.* (1967) that P300 can be elicited by the absence of a stimulus as much as by the presentation of a stimulus.

In studies of selective attention, the interpretation of the results is often difficult because the subject is usually asked to respond to those stimuli to which he is attending and to refrain from responding to stimuli to which he is not attending. It is thus difficult in such circumstances to determine whether differences are due to selective responding or to selective attention. In the present study, the subject's motor responses cannot account for the observed results. During the condition in which the subject responded to clicks in *one* ear, clicks in *either* ear evoked a large P300. Thus, the motor response clearly cannot be considered as contributing to the amplitude of the P300 component.

One of the objectives of this study has been to test the prediction deriving from Broadbent and Gregory's (1963) report that the sensitivity of a rejected channel is reduced when alternate channels are attended to. There is considerable physiological evidence that centrifugal pathways are available for such a reduction in sensitivity (Fex 1962; Starr 1964). If there is, indeed, a change in the sensitivity of an ear when another ear is in the focus of attention, an attenuation in the early components of the AEP and an increase in their latency are to be expected.

Our data provide no support for this suggestion. There was no significant difference between the early components of the click AEP obtained in our different experimental conditions.

These results, of course, do not negate the theoretical statements made by Broadbent and Treisman. First, it is possible that the sensitivity changes produced are too small to generate a detectable difference in the AEP, at least with the click intensities we have used. Furthermore, as pointed out above, it appears that the subjects admitted clicks equally from both ears, and that the decision about the origin of the stimulus was done at some central level and therefore no effect on the primary components of the click AEP should be expected.

A clearer result would have been obtained had we been able to record AEPs to the letters. From Treisman and Geffen's results, it follows that the AEPs to letters in the rejected ear would show a marked attenuation compared to the AEPs to letters in the attended ear. Unfortunately, our stimulus generation procedure did not permit a precise determination of the onset of each letter stimulus, and therefore we did not obtain these AEPs.

In conclusion then, our data provide a strong confirmation for the proposition that P300 can be used as an index of the degree to which the stimuli are task relevant; the data also reinforce the distinction between selective attention to verbal material and selective attention to clicks. However, they provide neither confirmation nor rejection for the proposition that an attended ear is generally more sensitive than a rejected ear.

SUMMARY

Average evoked potentials (AEPs) to clicks were obtained while a subject performed a selective listening task: the stimuli consisted of a series of numbers, letters and clicks, with separate series presented to each ear. Subjects were instructed to attend to one or the other ear and at different times to report the letters or clicks. The results show enhancement of a late positive component of the click AEP when clicks, but not when letters were reported. No differences in the AEP were found for those clicks

presented in the attended ear as compared to those in the rejected (non-attendant) ear.

RÉSUMÉ

POTENTIELS ÉVOQUÉS AUDITIFS MOYENS CHEZ L'HOMME PENDANT L'ÉCOUTE BI-AURICULAIRE SÉLECTIVE

Des potentiels évoqués moyens à des clics sont obtenus pendant qu'un sujet réalise une tâche d'écoute sélective: les stimuli consistent en séries de nombres, de lettres et de clics, des séries séparées étant présentées à chaque oreille. Les sujets ont comme instruction de prêter attention à l'une ou l'autre oreille et à certains moments de dire les lettres ou les clics. Les résultats montrent l'augmentation d'une composante positive tardive des potentiels évoqués moyens aux clics, lorsque les clics sont rapportés, mais non lorsque ce sont les lettres. Il n'a été trouvé aucune différence entre les réponses évoquées moyennes aux clics présentés à l'oreille attentive et ceux présentés à l'oreille négligée.

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