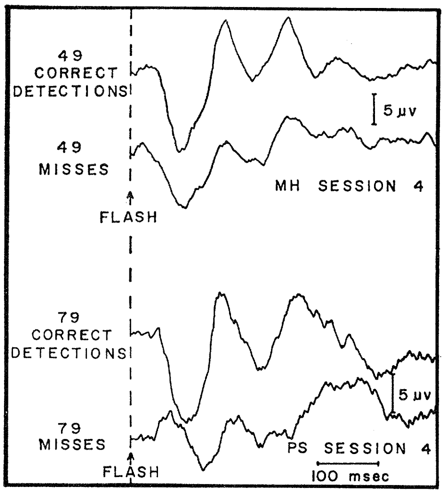

Fig. 2. Computer-averaged evoked-potentials for equal numbers of detected and missed signal stimuli by subjects M.H. and P.S. Both subjects show evoked-responses of reduced amplitude to the missed signals.

evoked-potentials and performance efficiency. These relatively short-term fluctuations in detection performance and in evoked-potentials to nonsignal stimuli appear to reflect changes in the subject's attentive state.

Heretofore the average evoked-potentials were computed for nonsignal stimuli only and reflect long-term changes in vigilance and shorter-term fluctuations in attentiveness. To focus upon a more specific aspect of attention pertaining to the detection of specific signal stimuli, average evoked-responses to signal stimuli were separately computed for signals which were correctly detected, and for those which were not detected, thus contrasting attentive and non-attentive conditions. Figure 2 shows clearly the differences between the evoked-potentials under these two conditions. The evoked-responses to signals which a subject failed to detect (misses) during an experiment were typically reduced in amplitude as compared with those of an equal number of signals which were correctly detected. These differences between detected and missed signals were equally marked during both early and late stages of the experimental task, thus showing that the differences were not dependent upon the general decline of vigilance. In all 15 experiments the differences were in the same direction; however, the magnitude of the differences varied considerably.

These results indicate that reduced attentiveness, as measured objectively by signal detection in a vigilance task, is paralleled by corresponding reductions in amplitude of visual, cortical evoked-potentials in humans. Although this experiment did not deal specifically with the related question of whether enhanced attentiveness increases the amplitude of the evoked potential, results obtained by Davis (*5*) in an auditory discrimination situation indicate that this may be the case.

In vigilance research many workers have long been aware of the need for an independent measure of observing-behavior (attentive states) during those periods of the task when signal stimuli are not presented. The evoked-potential data for the nonsignal stimuli indicate that as vigilance, defined by detection performance, fluctuated and declined during the course of the task, there were corresponding changes in the evoked-potentials to these stimuli. Thus, changes in the amplitude and latency of the evoked-potentials to non-signal stimuli may serve as a direct measure of observing-behavior in vigilance tasks of this type. Additionally, evoked-potentials averaged separately for specific signals to which the subject is instructed to respond, and to which he may or may not respond, provide a measure of fluctuations in focal attentiveness.

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Enhancement of Evoked Cortical Potentials in Humans Related to a Task Requiring a Decision

Abstract. *The averaged, slow response evoked by auditory stimuli and recorded from the vertex of the human skull can usually be enhanced by requiring the listener to make a rather difficult auditory discrimination. An easy routine reaction is not effective.*

An electroencephalographic response to auditory, visual or tactile stimuli (*1*) can readily be recorded from the vertex of the human skull by means of an average response computer. The response is polyphasic, with a well-marked negative peak at about 100 msec (for auditory stimuli) and a positive peak at about 175 msec.

Actually this slow evoked response, from 50 to 500 msec after the stimulus, is very complex. We think we can recognize at least four components which overlap more or less and which may vary independently both across subjects and across conditions. Analysis of these wave forms will be presented elsewhere, but a useful approximate measure is the peak-to-peak voltage from the (largest) negative peak at about 100 msec to the (largest) positive peak between 150 and 200 msec (*2*).

The slow response in question must not be confused with earlier evoked responses, at 50 msec or less, which are chiefly muscular in origin (*3*). The latter are best recorded near the inion or over the temporalis muscle and are increased by increase of resting muscular tone. Our slow responses are best recorded from the vertex, which is remote from major muscles, or from more frontal areas and they are unaffected by changes in muscular tone. Their slow time course and very long recovery period are hardly compatible with a muscular origin. On the other hand, the slow evoked responses do not originate in the primary auditory area. They arise diffusely from the cortex near the top and front of the head and they are not specific to any one sensory modality.

The amplitude of the various slow waves varies not only with the intensity of, and the intervals between, the stimuli but with the individual subject, his state of arousal, the novelty of the stimulus, and other experimental conditions. This average response varies considerably from run to run, but it is not clearly influenced by simple tasks such as "attending" to the stimuli, counting them (*2*), or pressing a button in response to each one. A more difficult task, however, requiring an auditory discrimination with the response, has, in our experiments, almost always caused an enhancement of the evoked response.

The subject is seated in an easy chair in front of a loudspeaker. Silver disc electrodes are applied to his vertex and right mastoid, and connected to a conventional electroencephalograph. The electroencephalographic output is sampled at brief intervals for 375 msec after each stimulus and the average response for each sample is calculated by an online digital computer that was designed and constructed in our institution (*4*). In the series described in this report, the evoked responses were brought out quite effectively from the background of electroencephalographic activity by averaging 32 responses.

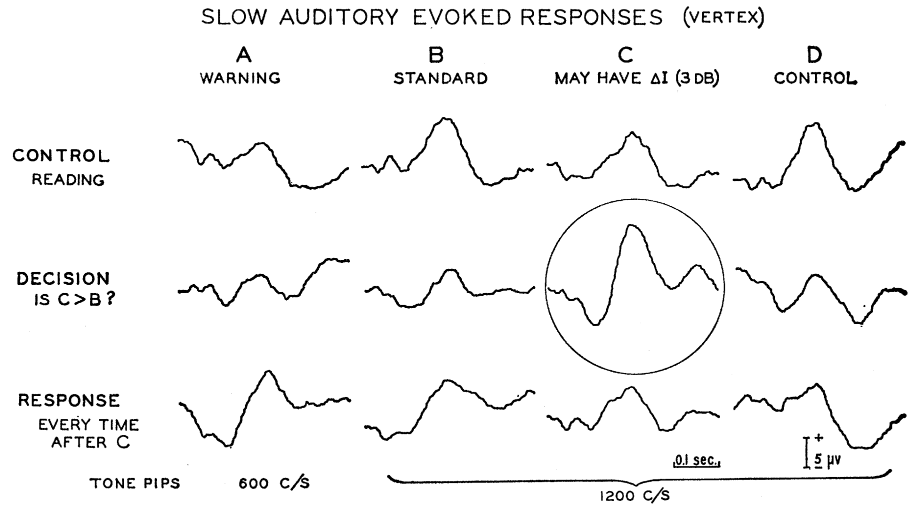

Fig. 1. Slow responses evoked by auditory stimuli and recorded from the vertex. Tone pips at about 70 db hearing level were delivered at the start of each trace. The intervals, A–B, B–C, C–D, D–A, were all 2.5 seconds. Responses to 32 cycles were averaged. ΔI (3 db) was added 10 times and also subtracted 10 times in the "decision" series. Upward deflection indicates that the vertex is becoming more positive relative to the right mastoid. The band-width of the electroencephalogram was 0.3 to 35 cy/sec.

Tone pips (filtered clicks) (*5*) were delivered at regular intervals of 2.5 seconds. Four pips constituted a cycle. The first was low pitched (600 cy/sec) and served as a warning, as indicated in column *A* of Fig. 1. The second, third, and fourth were all of higher pitch and of equal intensity except for a small increment or decrement (3 db) that was added to or subtracted from the third pip of the cycle in the "decision" trials. The responses to pips A, B, C, and D of each cycle were averaged separately in different segments of the memory of the computer.

Eight experiments in all were performed on six different subjects. A typical result is shown in Fig. 1. In the control series (top line) the subject was reading a magazine. The responses show the usual differences in amplitude. It is typical of this subject that the negative wave at 100 msec is small or absent in most of his responses.

In another series (bottom line) the subject was instructed to press a button immediately after each "C" pip—that is, the second high-pitched one. The subject found this an easy routine. Neither he nor any other subject tested showed any consistent difference in response within the first 375 msec related to the simple act of pressing the button.

In a third series (middle line) the subject was instructed to press the button when, but only when, the second high-pitched pip sounded louder than the first. Actually an increment of 3 db was added 10 times during the 32 trials and 3 db were subtracted 10 times in quasi-random sequence. The subtraction counter-balanced the very slight enhancement that might be expected from a simple increase in loudness (*6*). In this particular experiment the subject scored the ten possible hits, but he also gave five "false alarms." His average evoked response to the test stimulus during this trial (encircled in the figure) is increased well beyond the usual range of variation. In many runs with other subjects the response to B is also increased, but less than C, and the response to D is either unchanged or diminished.

Our first five subjects showed this pattern of change in nearly every run. One subject consistently showed, in addition, an increase in a late positive wave at about 300 msec. Our sixth subject, however, failed consistently to show any differences related to the task, although she finally achieved a perfect score of 12 hits, no misses, and no false alarms in a sequence of 32 cycles from which the decrements of intensity were omitted. It may or may not be significant that she was the only subject who was quite new to such an experimental situation. In addition, although she clearly understood the task, she did not speak English fluently. All of her averaged evoked potentials were relatively large, although not extremely so.

We encounter many differences in the slow evoked responses, both across subjects and across trials. So far, the task described above has been our most consistent way of enhancing the response. We believe that this effect of making a rather difficult sensory discrimination is a counterpart of the relation of the amplitude of the evoked response to vigilance, recently demonstrated by Haider *et al.* (*7*).

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5. The maximum amplitude of each pip is reached by the third sound wave, regardless of frequency. There is no plateau, and fall of amplitude is nearly as fast as its rise.
6. Other studies, unpublished, show that the expected enhancement would be less than 0.5 μv.
7. M. Haider, P. Spong, D. B. Lindsley, *Science*, this issue.

8. This investigation was supported by USPHS program project grant No. NB-03856-02, from NIH.

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