Evoked-Potential Correlates of Stimulus Uncertainty

Abstract. *The average evoked-potential waveforms to sound and light stimuli recorded from scalp in awake human subjects show differences as a function of the subject's degree of uncertainty with respect to the sensory modality of the stimulus to be presented. Differences are also found in the evoked potential as a function of whether or not the sensory modality of the stimulus was anticipated correctly. The major waveform alteration is in the amplitude of a positive-going component which reaches peak amplitude at about 300 milliseconds.*

While the dictum that the brain is the organ of thought is little questioned in scientific circles, it is only in the last few years that specific information has been obtained on the relation between complex psychological variables and the activity of the brain. Studies on sensory evoked potentials from human scalp have yielded information on the influence of such variables as fluctuations of vigilance, direction of attention, distraction, habituation, conditioning, meaningfulness, type of task, and difficulty of discrimination (*1*). Our investigations have dealt with still another complex variable, that of certainty and uncertainty with respect to the nature of the stimulus presented. These experiments are an outgrowth of our earlier work on psychomotor reaction time as influenced by stimulus uncertainty (*2*).

All recordings reported in this paper were made with the active electrode placed one-third of the distance along a line from the vertex to the external auditory meatus. The reference electrodes were attached to both earlobes. Data were recorded on multichannel magnetic tape to facilitate sorting of evoked-potential responses obtained for different experimental categories. Since individual responses are obscured by the "noise" from many sources, average responses were used. The number of evoked responses contributing to an average varied from 30 to 360, 90 or more being typical.

The stimuli were clicks or brief light flashes presented at a comfortable intensity substantially above threshold. A variety of programs were devised in order to generate varying degrees of probability of occurrence of sound and light stimuli. Stimuli were delivered in pairs; the first member of the pair served as a cueing stimulus and the second, which followed after a random interval of 3 to 5 seconds, was the test stimulus. There were two kinds of pairs. In one kind a cueing stimulus was followed by a test stimulus which was always a sound or always a light. The subject could thus be certain of the sensory quality of the test stimulus before it occurred. In the second kind of pair a different cueing stimulus was followed by a test stimulus which was either a sound or a light. The subject thus was uncertain as to the sensory quality of the test stimulus. Approximately 1000 certain and uncertain pairs were presented in random sequence in any single experiment. During the interval between the cueing and test stimuli the subject stated his guess as to the sensory modality of the next stimulus.

In Fig. 1 are presented average-response curves to sound test stimuli for five subjects. The solid tracing is the average-response curve to sound stimuli which the subject was certain would be sounds; the dashed tracing is the average-response curve to identical sound stimuli of whose sensory modality the subject was uncertain. To facilitate comparison, the average curves to certain and uncertain stimuli have been superimposed, a common early component being used as a point of reference. There are, as always, marked individual differences, but there are also marked similarities among subjects in the change brought about by uncertainty. There are differences between the waveforms evoked by certain and uncertain stimuli in each of five components which were measured. However, the most dramatic difference is in the large positive deflection whose latency at peak amplitude is about 300 msec. The amplitude of this late positive component was larger for the uncertain stimulus in 36 out of 36 experiments with eight subjects.

The degree of uncertainty was manipulated in a number of subsequent experiments. In one of these there were again two kinds of pairs, but now both of these were uncertain. For one kind of pair, a cueing stimulus was followed in one-third of the trials by sound stimuli and in two-thirds by light stimuli; for the second kind of pair, a different cueing stimulus was followed by the inverse ratio; that is, in one-third of the trials by light stimuli and in two-thirds of the trials by sound stimuli. The average-response curves for one subject are presented in Fig. 2. The upper pair of waveforms compares the effect of the two stimulus probabilities on the evoked potentials to sound stimuli; the lower pair compares the effect of the two stimulus probabilities on the evoked potentials to light stimuli. All four curves show the "late" positive deflection, but it is of greater amplitude for the lower probability stimulus. The occurrence of a larger amplitude in the positive deflection for the lower probability stimulus was found in 22 out of 29 comparisons with eight subjects.

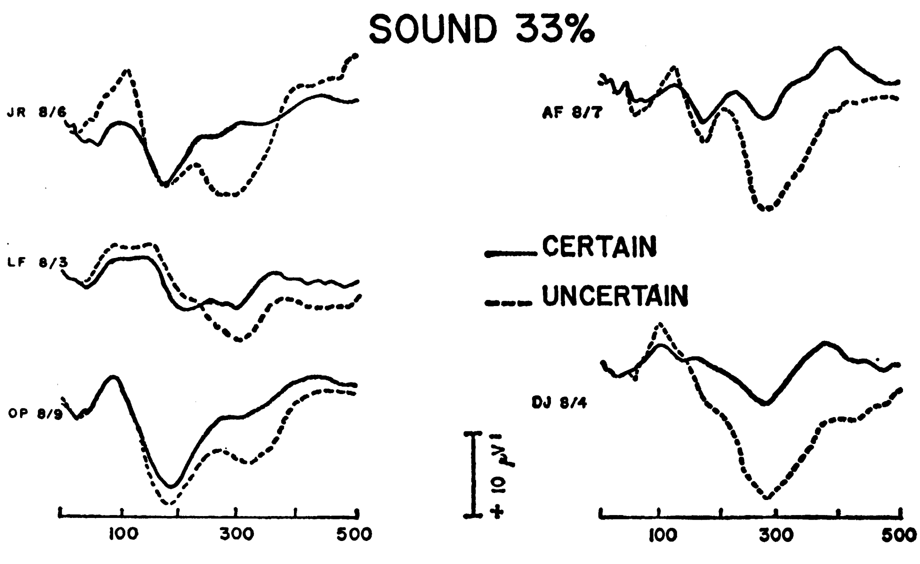

Fig. 1. Average waveforms for certain and uncertain (*P* = .33) sounds for five subjects.

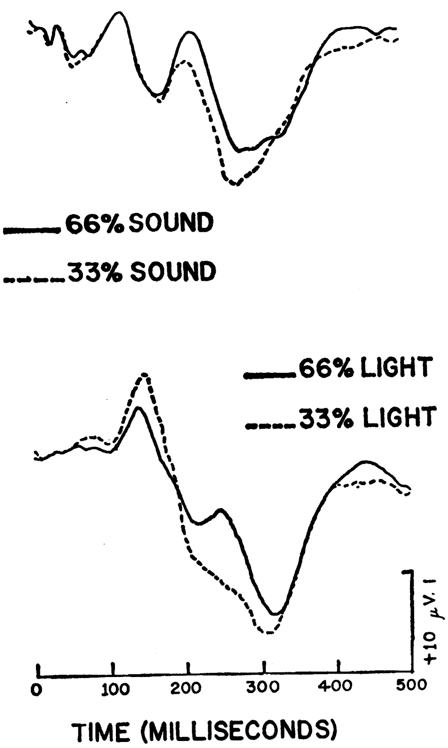

Fig. 2. Average waveforms for different probabilities of sound and light. The 33 percent sound and the 66 percent light had one cueing stimulus while the 66 percent sound and the 33 percent light had a different cueing stimulus.

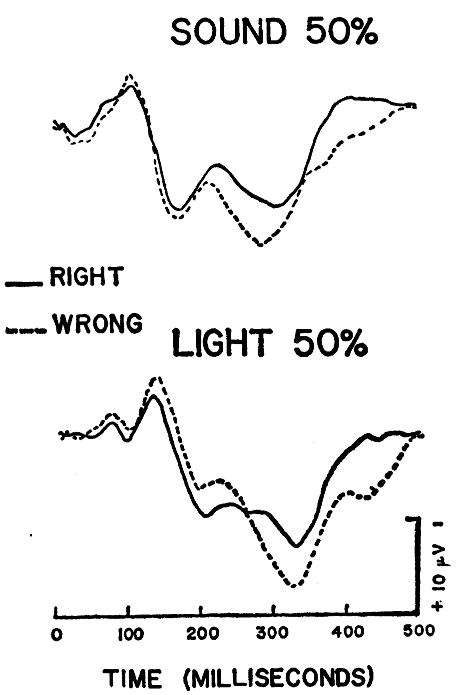

Fig. 3. Average waveforms to uncertain sound and uncertain light stimuli averaged separately as a function of the correctness of the subject's guess.

Since our procedure required the subject to make a guess with respect to the modality of the test stimulus, we were able to study the influence of the correctness of the subject's guess on the evoked potential. We used a program in which the probability of occurrence of sound and light was equally uncertain. Under these conditions the same late positive deflection (Fig. 3) that we have been considering has a larger amplitude for wrong guesses than for right guesses. While this finding was obtained in 33 of 40 comparisons (ten subjects), subsequent work has shown that the relative amplitude of the waveforms for wrong and right guesses is also influenced by at least four additional factors in complex interaction. These are the stimulus probabilities, the payoff structure of the guessing game, the sequence of correct and incorrect guesses, and the physical parameters of the stimulus alternatives.

While the late positive component with a peak at about 300 msec has been emphasized, only slightly less consistent effects of these psychological variables can be noted on several earlier components of the waveform. The differences are generally more pronounced in the later components. It is perhaps not an accident that studies which have not been concerned with systematically varied, complex, psychological variables have reported that later components were highly variable. The similarity of effects on the late component for light and sound stimuli can be demonstrated by aligning the two waveforms on some earlier component, for example, the large negative component which occurs at 110 msec for sound and at 150 msec for light. When so aligned, the large, late component reaches peak amplitude 190 msec later for both light and sound stimuli. Evidently these effects are related to the consequences of stimulation and are independent of the modality of the stimulus. While only the waveforms from the scalp area above sensorimotor cortex have been presented, the influence of these variables can be detected at any scalp locus, but the differences are generally smaller.

In one obvious but incorrect interpretation of our data the results are attributed to differences in generalized arousal value of the cueing stimuli. That this is not the case can be demonstrated by consideration of the conditions of the experiment which gave the results shown in Fig. 2. There the effect of stimulus probability operates across cueing stimuli: one of the cueing stimuli was associated with a smaller late component to the sound test stimulus but a larger late component to the light stimulus, whereas the other cueing stimulus was associated with the opposite effect. Therefore, the cueing stimuli do not define a level of arousal but rather specify the differential significance of the test stimuli. A sound test stimulus after one cueing stimulus has different significance from the identical sound test stimulus after a different cueing stimulus.

These data and the studies cited indicate that the evoked-potential waveform recorded from scalp of human subjects may reflect two kinds of influences. One of these is largely exogenous and related to the character of the stimulus. The other is largely endogenous and related to the reaction, or attitude, of the subject to the stimulus. The reaction of the subject is at least in part amenable to quantitative experimental manipulation. These conclusions are in accord with the results of animal studies (*3*).

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References and Notes

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