148

Evoked Potential Correlates of Stimulus Uncertainty*

Samuel Sutton, Ph.D.[1], Margery Braren, M.A.[1], E. R. John, Ph.D.[2], and Joseph Zubin, Ph.D.

Presented at the meetings of the American Psychological Association, September 1964, Los Angeles, California.

* This work was supported in part under Grant MH 07776 and MH 08579 from the National Institute of Mental Health, United States Public Health Service. The authors are indebted to Mr. Robert Laupheimer and Mr. Ray Simon for assistance with instrumentation and to Dr. Gad Hakerem, Miss Marjorie Goldman, Mrs. Jo Roberts, Miss Paula Adams and Miss Hansook Ahn for assistance with other aspects of the work. The authors are indebted to Dr. Nathan Beckenstein, Director of Brooklyn State Hospital for providing the facilities for carrying out this research.

1 Biometrics Research, New York State Department of Mental Hygiene and Columbia University.

2 Brain Research Laboratories, Department of Psychiatry, New York Medical College.

The possible functional relevance of sensory evoked potentials recorded from the scalp of conscious human subjects is a problem of continuing interest. We approached this problem by searching for correlates between these potentials and manipulations of the experimental situation which were intended to alter the expectancy or attitude of the subject with respect to our stimuli.

The present study is an extension of previous reaction time work where we showed that when the subject had no prior knowledge whether the stimulus was to be a sound or a light, his reaction time was longer than when the modality of the stimulus was known in advance.[3] Furthermore, reaction time was lengthened in direct proportion to the degree of probability, or rather improbability of occurrence of a given type of stimulus.

In the experimental situation, the subject sat relaxed while flashes of lights or clicks were presented. The stimuli were all at a comfortable intensity level substantially above threshold. All recordings to be reported today were taken with the active electrode placed 1/3 of the distance on a line from the vertex to the external auditory meatus. The reference electrode was attached to both earlobes.

Stimuli were delivered in pairs; the first member of the pair was a cueing stimulus and the second was a test stimulus. There were two kinds of pairs. One kind consisted of a cueing stimulus which was always followed by a test stimulus of a particular sensory modality. The subject could thus be certain about the quality of the test stimulus before it occurred. The second kind of pair had a different cueing stimulus which indicated the subsequent delivery of either a sound or a light. The subject thus was uncertain about the sensory quality of the

---

[3] Sutton, S. and Zubin, J. Effect of sequence on reaction time in schizophrenia. In J. E. Birren and A. T. Welford (Eds.), Behavior, aging and the nervous system: biological determinants of speed of behavior and its change with age. 1964, Charles C. Thomas, in press.

test stimulus. The sequence of the two kinds of pairs was random. The cueing and test stimuli were separated by a random interval of 3 to 5 seconds' duration. During this interval, the subject stated his guess as to the sensory modality of the test stimulus.

In Figure 1 are presented average response curves for 5 subjects to test stimuli which were sounds. The number of responses averaged varied from 30 to 360, 90 or more being typical. But since these are normalized, that is to say, averages and not sums, direct amplitude comparisons can be made. Negativity is upwards. The solid tracing is the average response curve to sound stimuli which the subject was certain would be sounds; the hatched tracing is the average response curve to identical sound stimuli of which the subject was uncertain. There are, as always, marked individual differences, but there are also marked similarities in the change brought about by uncertainty. There are differences between the waveforms evoked by certain and uncertain stimuli in each of five components we chose to measure. Because of time limitations, I will concentrate on only two of these components: one, the large negative deflection which for sound has an average latency of about 110 milliseconds, and two, the large positive deflection which for sound has an average latency of about 300 milliseconds. The late positive component was larger for the uncertain stimulus in 34 out of 34 experiments in 6 subjects. The earlier negative component was larger for the uncertain stimulus in 28 out of the 34 comparisons.

So much for certain vs. uncertain: What about the effect of different degrees of uncertainty? In Figure 2, are the findings when 4 rather than 2 proportions were used in one experiment. Again, only the evoked responses for sound are shown. Note that the amplitude of the late positive component is in the same rank order as that of the proportions of sound as test stimuli. Again, the solid tracing is the certain waveform. The dashed tracing indicates sound occurred as the second member of the pair 75% of the time, the dotted 50%, and the hatched 25%.

When we obtained these data, we thought we had succeeded in quantifying the effect of stimulus probability. Unfortunately, in subsequent experiments we did not always obtain this degree of linearity. Nevertheless, in 18 out of 23 comparisons the late positive component has a larger amplitude for the lower probability stimulus. For the early negative deflection, the lower stimulus probability gave a larger amplitude in 17 out of 23 comparisons.

Perhaps our inability to obtain consistent linear changes as a function of stimulus probability was related to the fact that the subject did not always reproduce the objective probabilities in his guessing pattern. While we may have presented sound as test stimuli in 25% of the trials, the subject may, for example, have given sound for only 10% of his guesses. This led us to examine the effect of being right or wrong on the evoked response curves.

Figure 3 is an example of the effect on the average curves of the correctness of the subject's guess. The upper pair of curves are evoked responses to sound stimuli; the lower pair of curves are responses to light stimuli. The solid tracings are average curves for correct guesses; the hatched tracings are average curves for incorrect guesses. Note that amplitude is larger for incorrect guesses. For the late positive component this increase in amplitude held in 20 out of 24 comparisons; for the early negative component in 17 out of 22 comparisons.

Let me stress a few points before I proceed. We have found clear differences in the time domain between 80 and 400 milliseconds. The differences in the early portion of this time domain are of short enough latency to be relevant to our reaction time studies. Interestingly enough, the differences observed are increases in the amplitude of both positive and negative components, while the effect of the variables we have manipulated is to lengthen reaction time. The largest.

most consistent, and most dramatic differences are in the late positive component at a latency of about 300 milliseconds for sound and 340 milliseconds for light. Here we are presumably dealing with more complex elaborations of the response to our stimuli. These changes in waveform occur after a motor reaction would normally be completed. Yet they are clearly stimulus linked.

This last statement can be supported in the following way: In Figure 4, are shown the evoked responses to uncertain lights and sounds for 5 subjects. We have displaced the sound waveform in order to align on the peak of the large negative component as indicated by the arrow. This component has an average latency of 110 milliseconds for sound and 150 milliseconds for light, so our displacement approximately 40 milliseconds. When so aligned, the large late positive deflection occurs at the same latency for both light and sound. In averaging all our data, we find that this time distance between the large negative component and the late positive component is 193 milliseconds for sound and 190 milliseconds for light, or approximately identical. This identity for light and sound demonstrates that the late positive process is independent of the modality of the stimulus and is time locked to the early consequences of stimulation.

Certain aspects of our results are in line with the recent findings reported by Hallowell Davis[4] in Science in which the evoked response showed an increase in amplitude when the subject was asked to make a difficult discrimination but not when he was asked to make a simple discrimination. In a related vein are the results reported by Dr. Hakerem and myself at another symposium at this conference. We reported there, that the pupil responds to threshold intensity light stimuli

4 Davis, H. Enhancement of evoked cortical potentials in humans related to a task requiring a decision. Science, 145, 1964, 182-183.

with a long latency dilation (not contraction) when the subject is asked to report whether or not he sees the simulus, but no such dilation occurs when the subject is asked to observe but to make no report.

However, we do not think that the results we have reported today can be explained either by overall level of difficulty or by the notion that a particular cueing stimulus is associated with a particular level of arousal. We think both of these factors are relevant, but the reasons for our reservation are as follows: First, the most difficult, or uncertain, proportion we used is the 50% proportion, while the 25 and 75% proportions are of equal uncertainty. This is supported both by a priori calculation of stimulus information for the different proportions and also by the degree of guessing accuracy obtained by the subjects. Yet we have shown that the 50% proportion does not yield the greatest enhancement, while the 25% proportion yields a greater enhancement than the 75% proportion.

Secondly, in Figure 5 is presented evidence on the basis of which we reject the notion that a particular cueing stimulus has a particular level of arousal associated with it. In this type of experiment, we used two cueing stimuli, one which was followed in 1/3 of the trials by sound and in 2/3 of the trials by lights, the other cueing stimulus was followed in 2/3 of the trials by sounds and in 1/3 of the trials by lights. The figure shows that the response to the 1/3 sounds has a larger amplitude than the response to the 2/3 sounds and that the response to the 1/3 lights has a larger amplitude than the response to the 2/3 lights. The point is that these effects are occurring across the two cueing stimuli. It is not that one cueing stimulus produces a larger level of alerting than the other cueing stimulus.

Let me at this point summarize the conclusions and mention briefly some pilot data which might bear on the interpretation of these results.

With respect to attention and arousal I would like to make three points.

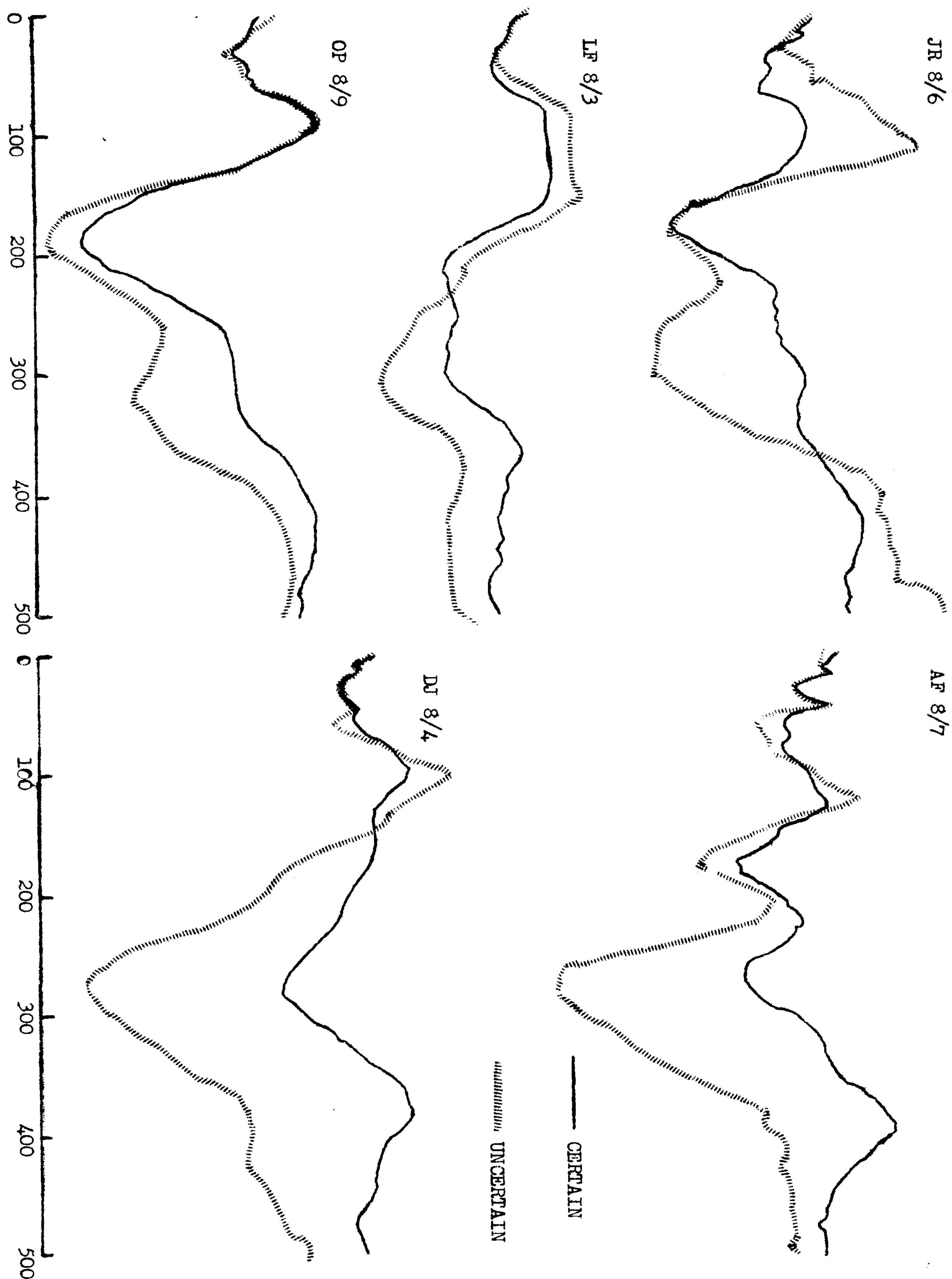
When we present a random sequence of lights and sounds and ask the subject to count all stimuli, instead of passively attending to all stimuli, there is a small increase in the amplitude of the late component. When the subject is asked to count only one of the two stimuli, there is a further increase in the amplitude of the late component. Therefore, it does not seem to be attention per se in the sense of arousal, but something like differential attention. We have also shown in the last figure that the increased amplitude of the late component can not be attributed to the notion that a particular cueing stimulus establishes a particular level of arousal.

Now with respect to guessing and uncertainty. When the subject is asked to guess whether sounds or lights will occur we obtain a larger late positive component than when the subject is asked to count only sounds or only lights. In programs in which the ratio of occurrence of sounds and lights is manipulated, the late component is larger for uncertain events than for certain events and among uncertain events larger for the rarer events.

Finally there is the effect of being right or wrong. I wonder if this last effect does not present the clue for bringing all the observations under one heading. We have rejected the terms attention, difficulty, and uncertainty as being capable of encompassing all the findings. I would like to suggest that all of the findings seem to be related to the process of evaluation of the significance of a stimulus. In all of our observations the evoked potential changed when the significance of the stimulus was changed. A stimulus to be counted has a different significance than a stimulus to be passively attended to. When only one of two stimuli is being counted a differential significance is established. Guessing establishes still another kind of significance, when the stimulus occurs one may evaluate whether one has been right or wrong. In such a context the occurrence of a stimulus of low probability has a different significance from the occurrence of a stimulus of high probability.

All of this suggests a relationship between the mechanisms which mediate conscious experience and the mechanisms which produce gross potentials. Some among you may voice distress at the fact that the most marked changes in electrical activity which we report here occur after the time at which motor reaction is known to occur. In this context we wish to point out that motor reaction may well occur prior to and independent of subjective awareness of the stimulus-caused reaction. Perhaps one can make a meaningful distinction between the reliable early electro-physiological events which precede reaction time as reflecting those processes involved in the perception of an event in an environment and the later components as reflecting those processes relating to the significance of these events.

Figure 1. Responses to certain and uncertain (p=.33) sounds for five subjects



JR 7/22

Figure 2. Responses to four different probabilities of occurrence of sound which were used in one experiment.

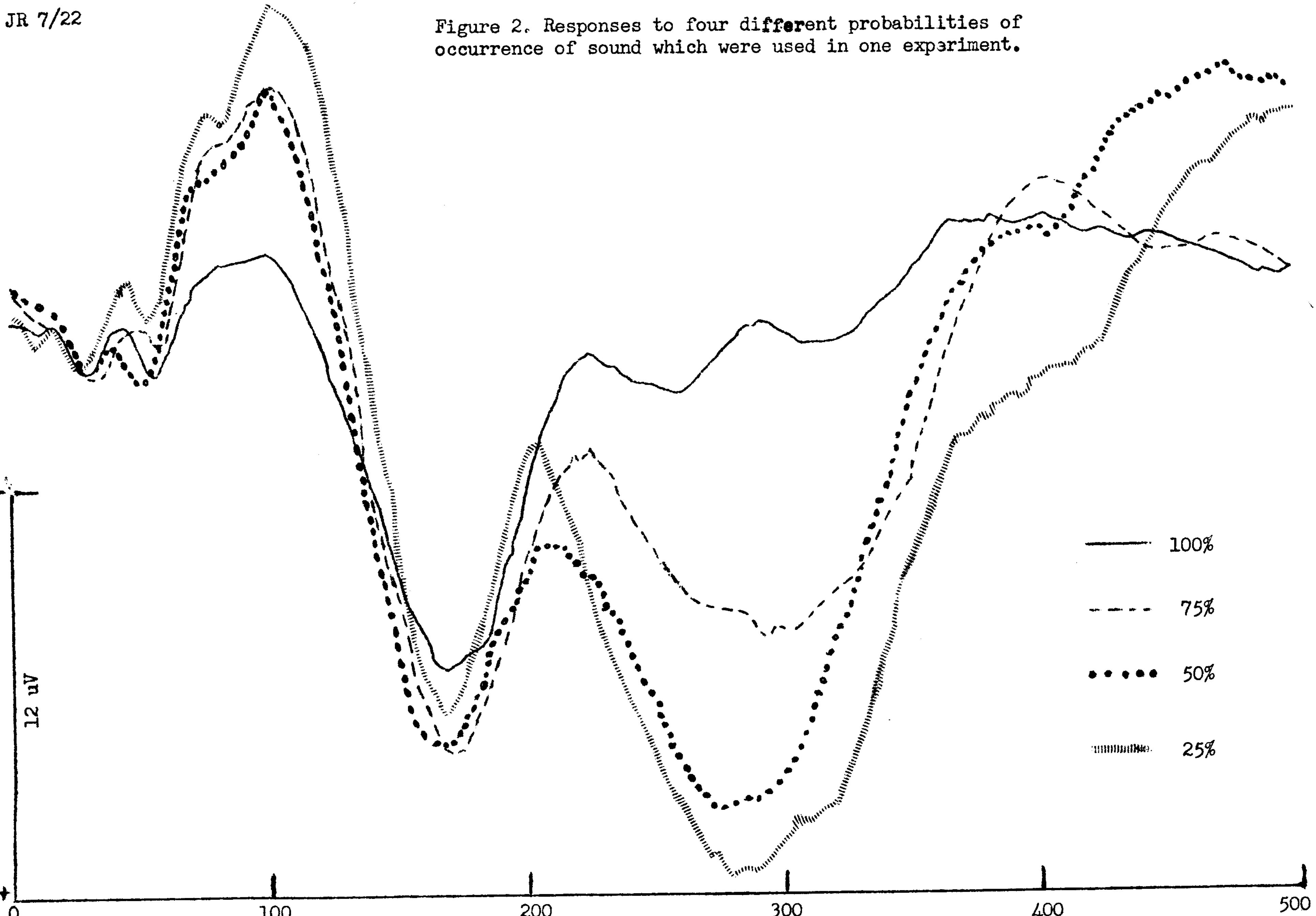


Figure 3. Responses to uncertain sound and uncertain light averaged separately as a function of whether the subject's guess was right or wrong.

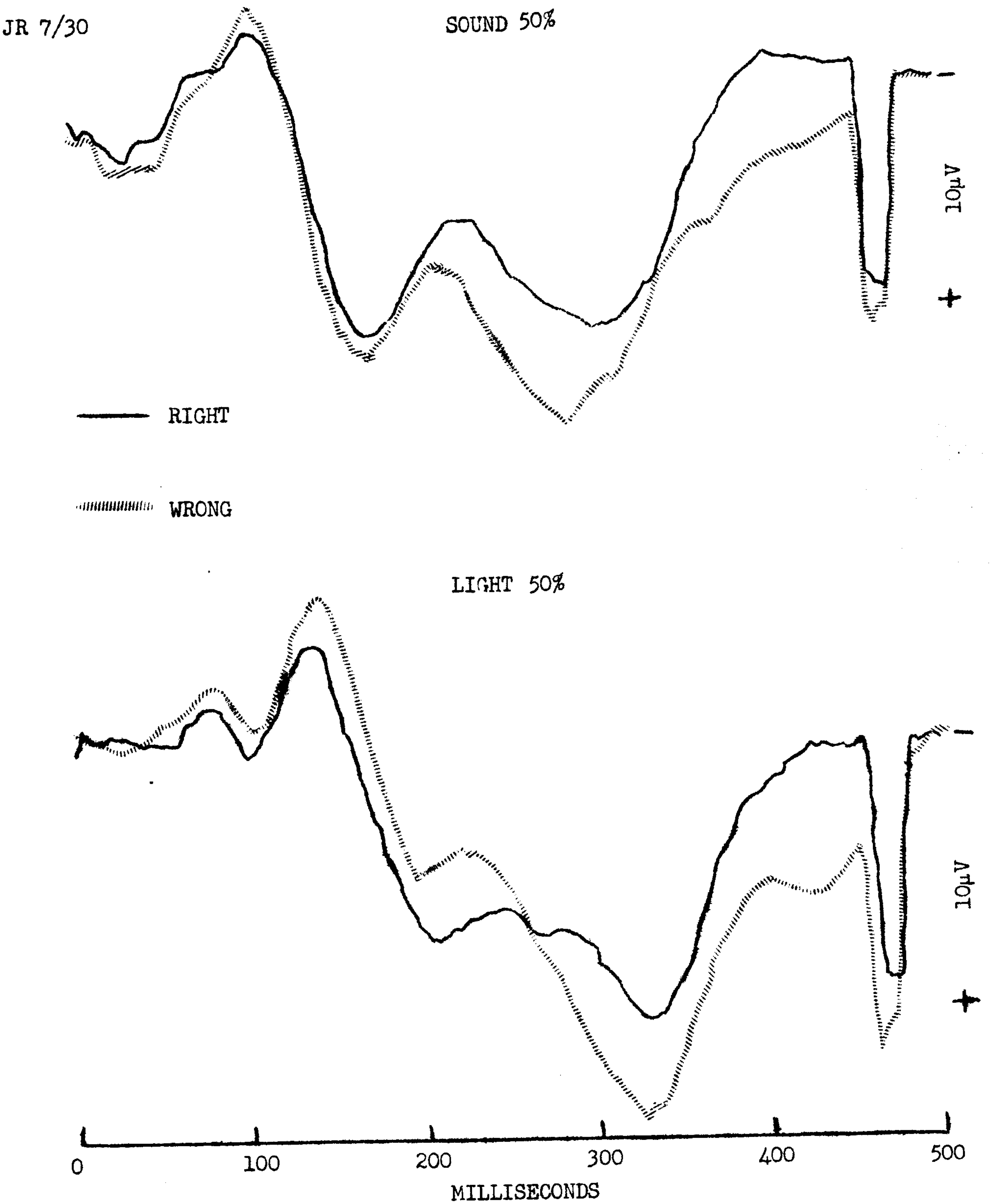


Figure 4. Latency comparison of responses to sounds (p=.33) and lights (p=.33). The curves for sound have been displaced so as to align on the large negative component as indicated by the arrows.

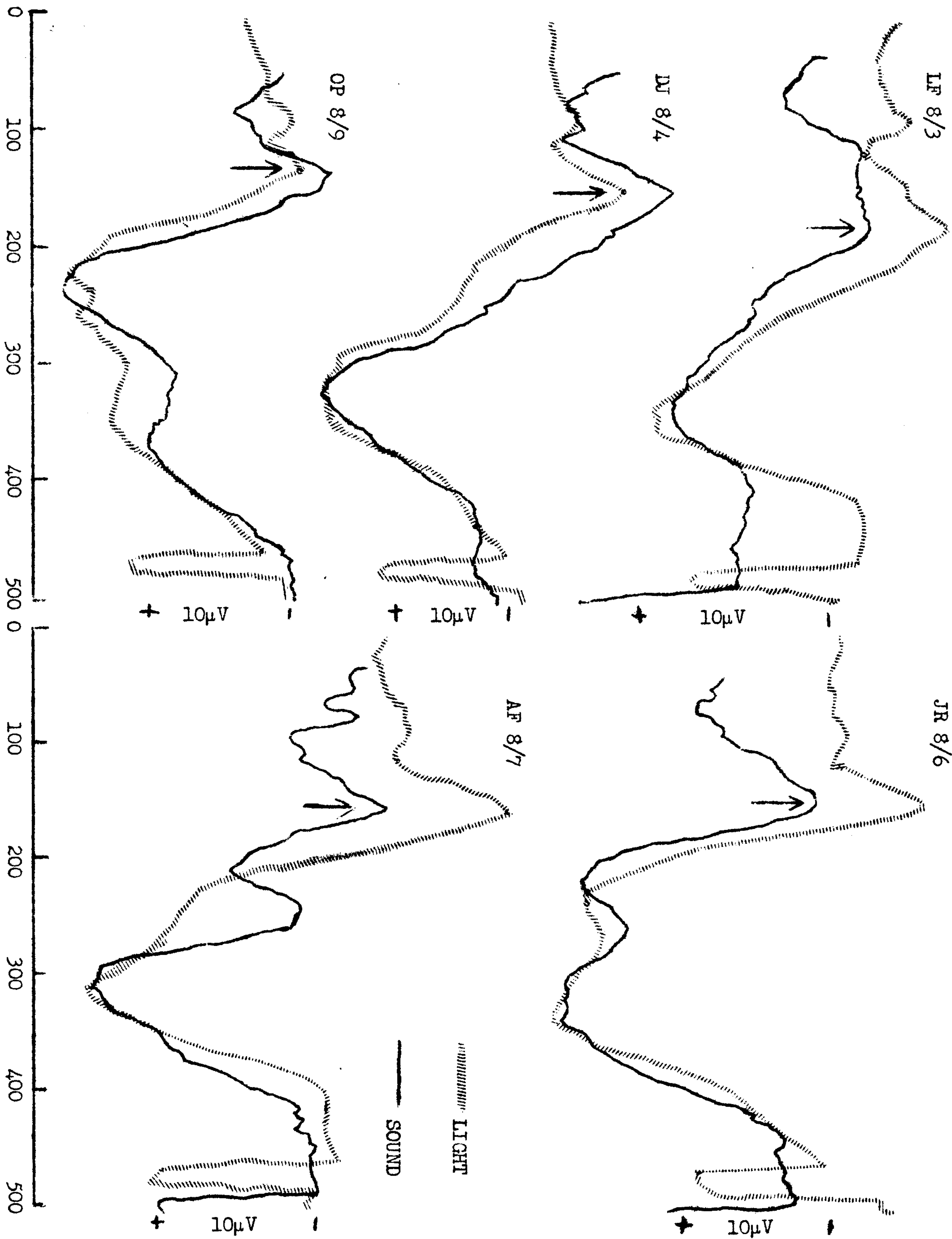


Figure 5. Responses to different probabilities of sound and light. The 33% sound and the 66% light had one cueing stimulus while the 66% sound and the 33% light had a different cueing stimulus.