Evoked Potential Correlates of Some Complex Psychological Variables

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Much of my research in evoked potentials over the last few years may be summarized in the following statement: certain components of the sensory evoked potential are altered in amplitude and latency by the significance of the sensory stimulus to the organism. Now "significance" is a large and amorphous concept and there are many ways in which stimuli may be more or less significant to a subject. For example, we have presented randomly ordered clicks and light flashes and instructed the subject to guess before the presentation of each stimulus whether it will be a light or a sound. We have found that the evoked response to these stimuli is different when the occurrence of the stimulus informs the subject that his guess was right and when the occurrence of the same stimulus informs the subject that his guess was wrong. There are also cumulative effects. The response to a stimulus which has been guessed correctly is also affected by whether the previous trial was correct or incorrect. Similarly for incorrect guesses. If we ask the subject to stake money on his guesses, there are larger effects associated with higher stakes than with lower stakes.

Some of these data have been presented at other conferences, and I do not want to dwell on these points. What I would like to concentrate on today are manipulations which alter the information content of the stimulus. I would like to present data to support the following statements:

1. A stimulus whose identity is known in advance conveys no information. In response to such a stimulus, certain components of the waveform are smaller than when the identical physical stimulus resolves some doubt or uncertainty, i.e., when the stimulus delivers information.

2. The non-occurrence of a stimulus which might have occurred can deliver information and corresponding waveform alterations can be found.

3. The waveform alterations occur in a fixed relationship to the point in time at which information is delivered.
4. The amplitude of these alterations is quantitatively related to the amount of information delivered by the stimulus.

5. The waveform alterations obtained when the non-occurrence of a stimulus delivers information are different from the waveform alterations obtained when the occurrence of a stimulus delivers information.

Now as to the data! In a previous publication I have presented evidence that in all subjects the response to a predictable stimulus is different from the response to the same stimulus when it cannot be predicted in advance. For example, for a random sequence of clicks and light flashes, in one experimental condition we can tell the subject before each stimulus whether the next one will be a light or a sound, in the other, we can ask him to guess prior to the occurrence of each stimulus whether it will be a light or a sound. In the FIRST SLIDE (1) is an example of the waveforms obtained. In the upper pair, the solid line represents the average response waveform to clicks in the certainty condition, the dashed line represents the average response waveform to identical clicks in the guessing condition. We record with the active electrode on vertex and the indifferent electrode on earlobe. Note the large positive deflection, down in these curves, which reaches peak amplitude at about 300 milliseconds in the upper curve when the clicks are uncertain. The lower pair of waveforms are for the same subject and are responses to clicks which are identical in every way. However, they are different in that the alternative stimulus in this experiment is not a flash of light but a double click. There are no responses shown on this slide to either light flashes or double clicks. Everything on this slide is an average response to single clicks. Note the alteration in the positive process as a function of the difference in the alternative stimulus. The only point I want to make about these data is that the response to a stimulus is a function of
the stimulus which it is not, in other words the response to a stimulus is a function of the alternative stimulus. For amplification of this concept, I would like to go on to the NEXT SLIDE (2).

Again every tracing on this slide was obtained as an average response to single clicks. Here we have shown on the top line the waveform to single clicks which are predictable or, certain. The next tracing is the waveform to single clicks when the alternative stimulus in that experiment was a double click with a 180 millisecond interval. In the third tracing, is the waveform to single clicks when the alternative stimulus was a double click at 580 milliseconds. Note the shift of the positive process to a longer latency. This shift in latency can be thought of in the following way: When the subject hears a click he does not yet know whether it will be single or whether it is the first member of a pair and will shortly be followed by a second click. When a double click at 580 milliseconds is the alternative stimulus, then this doubt cannot be resolved until at least this much time after the first click has elapsed. When a double click at 180 milliseconds is the alternative stimulus, then the doubt can be resolved at an earlier point in time. In other words, the positive deflection is a function of the point in time that the second click might have, but did not, occur. This point in time is indicated by the open triangle. Another way of describing what is happening is to view the physically absent stimulus as an endogenous stimulus.

In the next tracing, the fourth from the top, we have the results of an experiment which tests our assertion that the large positive process is related to the resolution of uncertainty. In this experiment, there were three stimuli: a single click, a double click with a 180 millisecond interval, and a double click with a 580 millisecond interval. The subject was asked to guess only whether the stimulus would be single or double. The interval in
the double click has no effect on whether his guess was considered right or wrong. It should be noted that this waveform is not the sum of the previous two waveforms but rather it resembles more closely the waveform where only the 580 millisecond double click was the alternative. Our interpretation is that in this experiment, the non-occurrence of a click at 180 milliseconds does not resolve uncertainty since the stimulus may still be a double if a second click occurs at 580 milliseconds.

The last waveform on the slide represents a pair of electrodes so placed as to pick up several major sources of movement artifact. This tracing suggests that muscle activity is not significantly involved in the deflections with which we are concerned.

We have presented evidence so far with respect to the fact that there are correlates in the evoked potential of the non-occurrence of stimuli, and further, that the latency of certain components is a function of the point in time at which non-occurrence delivers the information. I would like next to turn to the question of the amount of information delivered. We can manipulate this by altering the relative probability of the two stimulus alternatives. It should be clear that the occurrence of an event which is highly probable delivers less information than the occurrence of a relatively rare event. In the NEXT SLIDE (3) we have the results of such an experiment. For a change, I am also showing the responses to the double clicks. These are the two tracings on the right. The double clicks have a 380 millisecond interval. On the left, are the responses to single clicks as before. The two upper tracings represent one experimental condition in which single clicks were a common event, they occurred in two thirds of the trials. In this condition, double clicks were relatively rare, they occurred in only one third of the trials. The lower two tracings represent the exact opposite condition...
presented in alternate blocks of trials. Here double clicks are frequent, and single clicks are infrequent. The point is to compare vertically. Note the larger amplitudes for the low probability clicks than for the high probability clicks. This is consistent with the concept that the amplitude of the positive process we have been describing is a function of the amount of information delivered.

The final set of data I want to present are the results of an experiment which was done to answer a somewhat different question. But the findings are quite germane to the inferences I have been making. At the beginning of this presentation, you may remember I said the waveform for stimuli which signalled a correct guess were different from the waveform for identical stimuli which signalled an incorrect guess. We became intrigued with this question of rightness and wrongness. We wondered if we created a situation where there was more than one way of being wrong whether the waveforms associated with the different ways of being wrong would be similar or different. The experimental design is best explained by reference to the NEXT SLIDE (4). In this situation there were no single clicks presented, but rather three kinds of double clicks. We presented in random order either a double click with a 180 millisecond interval between the members of the click pair, a 580 milliseconds interval, or a 980 millisecond interval. The subject was asked to guess prior to each stimulus whether the interval would be "short," "medium," or "long." As the slide shows, there are only three ways of being right, but six ways of being wrong. If we postulate that all right guesses should yield similar waveforms, we can test this by examining the waveforms along the diagonal from the upper left to the lower right. As you can see they are not strikingly similar nor uniformly different from all the wrong guesses. Further, note for example the second column when the subject was presented with a medium, or 580 millisecond, interval. The waveform for the two ways of being wrong,
when he had guessed short and when he had guessed long, are quite different. Furthermore, it is quite striking that neither the physical stimuli, looking down the columns, nor the guesses, looking across the rows, impose uniformity on these waveforms. These findings can however be understood by considering the question of the delivery of information. There are two ways in which information is delivered in this situation. The occurrence of the second click may be the first signal to the subject that he has guessed right or wrong. This would be the case, for example, when the subject had guessed "long" and receives a short interval. The actual occurrence of the second click at 180 milliseconds is the first inkling he receives that he is wrong. This is also true for the case when the second click is at 180 milliseconds and he has guessed short and is therefore right. The occurrence of the second click is again the first point in time that he discovers that he is right. By contrast, let us consider the situation when he has guessed short and obtained a long, or 980 millisecond, interval. This is the cell in the upper right. Here, long before the actual occurrence of the second click at 980 milliseconds, the subject may note its absence at 180 and at 580 milliseconds. The same logic applies to the case when he has guessed long and gets long -- the cell in the lower right. Here he may note the absence of a click at 180, but this is not yet conclusive. When he notes the click is absent at 580, it is conclusive, he must be right. The second click must appear at 980 milliseconds.

I have indicated the actual occurrence of clicks by filled triangles, and the point in time at which information is delivered by open circles. In the five cases where the occurrence of the second click delivers the information, the triangle is inside the circle, the positive-going waveform has a larger amplitude and is relatively peaked. These have all been labeled "a," at the right of the waveform. In the four cases labeled "b," the circle occurs
earlier than the triangle, the waveforms appear more squashed. I have also used the subscripts 1 and 2 to mark subgroups which are more alike with respect to the relationship between the delivery of information and the occurrence of the second click.

In the "a1" group, information delivery and the occurrence of the second click are both at 180 milliseconds. In the "a2" group, the second click and information delivery also correspond, but this point in time is now 580 milliseconds. Therefore these should, and do, resemble the "a1" group except for a time displacement. The "b1" group both have information delivery at a short interval and they resemble each other more than they do the "b2" group which have information delivery at a medium interval.

In the NEXT SLIDE (5), is the same data but analyzed so as to give some estimate of the reliability of the averages. These are split half comparisons obtained from averaging separately alternate groups of trials.

It is conceivable that all these data reflect the same process. Perhaps the delivery of information via the occurrence and non-occurrence of stimuli release an identical waveform. However, when the occurrence of the second click delivers information, it can set large populations of cells into activity in synchrony. This would result in larger amplitude more peaked waveforms. When it is the absence of a click which delivers information, the point in time at which information is delivered can only be specified by the subject's internal time sense. Therefore time jitter of the same waveform would produce flattening in the average. Whether the process is the same or different can only be determined by finding an effective way of fractionating
populations of individual waveforms.

People have often asked me: Aren't these findings merely a reflection of generalized arousal or generalized activation? Both the long latency of the components I have been describing and the fact that they are best recorded from the vertex would certainly suggest that they are related to the activity of the diffuse projection system. Certainly all the conditions which produce larger amplitudes may also be described as in some sense reflecting a higher activation level. My objection to this interpretation lies not in the words activation or arousal but in the words generalized or diffuse. We are not creating situations in which the subject is at a higher arousal level and the occurrence of any stimulus releases higher amplitude activity. Rather, our experimental conditions are designed to attach specific significance to a particular type of stimulus, for example the occurrence of a single rather than a double click when the subject has guessed it would be double -- or the occurrence of a lower probability event rather than a higher probability event. If we think of an activation system which is capable of fine texture, which is capable of being preset for a particular kind of stimulus, which is in this sense released only by the meaning or significance of the stimulus, then the concept of activation is consistent with the present data.
SLIDE # 1
RESPONSES TO SINGLE CLICK
LIGHT ALTERNATIVE
DOUBLE CLICK ALTERNATIVE
--- CERTAIN
----- UNCERTAIN
MILLISECONDS

SLIDE # 2
SINGLE SOUND
--- CERTAIN
----- UNCERTAIN (180)
----- UNCERTAIN (580)
----- UNCERTAIN (180,580)
MILLISECONDS

SLIDE # 3
SINGLE
HIGH p.

LOW p.

MILLISECONDS

DOUBLE (S = 300 S)
HIGH p.

LOW p.

MILLISECONDS

SLIDE # 4
STIMULUS INTERVALS
GUESSES

GUESSES

GUESSES

MILLISECONDS

SLIDE # 5
STIMULUS INTERVALS
GUESSES

GUESSES

GUESSES

MILLISECONDS