Evoked Potential Correlates of Signal Recognition between and within Modalities

Abstract. *Electrical responses evoked by clicks, flashes, changes in noise level, and changes in light level were recorded from the scalps of human subjects set to detect one of the stimuli. An early negative component of the evoked responses reflects selection between sensory modalities, whereas the later positive component reflects a more complex intramodal discrimination.*

In order to study information-processing in man, we asked subjects to detect a particular signal from an array of signals of both the same sensory modality and also another sensory modality. In similar experiments, typically, a subject is asked to make only one of those discriminations (*1, 2*); for example, he must discriminate between two auditory signals (the intramodal situation) or he must discriminate between two signals of different sensory modalities (the cross-modal situation). Using the more complex array of signals, we were able to demonstrate clearly differential physiological effects at successive stages of signal analysis.

One objective physiological index of signal relevance is the amplitude of the electrical activity it evokes in the cerebral cortex as recorded from the scalp. For example, the amplitude of the evoked response to a stimulus is attenuated when it is made irrelevant and another signal from the same (*1*) or a different modality (*2*) is made relevant. In this experiment, the variation in amplitude at the different peaks of the evoked response was used to gain information about the different stages of signal analysis during a signal-recognition task in which stimuli competed within, as well as across, modalities.

We paid 12 male volunteers between the ages of 19 and 26 for participating in this experiment. They sat in a comfortable chair in a darkened audiometric testing booth. Subjects were instructed to fixate on an asterisk in the center of the visual field while being presented with a random sequence of four possible stimuli, two auditory (via an overhead loudspeaker) and two visual (via a tachistoscope): (i) a click, (ii) a change in the steady background noise level, (iii) a flash, or (iv) a change in the background light intensity (*3*). The intervals between the stimuli varied randomly from 1 to 5 seconds (*4*). We instructed the subject to press a button as soon as possible upon detecting a specified relevant stimulus, while ignoring the other three, irrelevant stimuli (*5*). The stimulus series, consisting of 50 stimuli of each type, was presented to each subject four times, with the subject detecting a different stimulus each time. Each subject had a brief practice session before each condition. Order of conditions was counterbalanced across subjects, and no two subjects received the same ordering of conditions. Only 12 of the possible 24 counterbalanced orders were used, selected randomly. Each condition was in each position in the order at least twice.

During stimulus presentation, we recorded the electrical activity from the subject's scalp. Electrodes placed at the vertex and referenced to the linked mastoids were used for recording auditory evoked responses, and electrodes placed at the right occiput and also referenced to the mastoids were used for recording visual evoked responses. Amplification band-pass was 0.03 to 100 hertz. Recordings of eye movement potential were made from electrodes placed on the inferior and superior orbital ridges. We recorded the amplified signals on magnetic tape and averaged the responses with a signal-averaging computer. Evoked responses to all stimuli were averaged for each of the four conditions, yielding four averaged evoked responses (AER's) to the click, four to the noise change, four to the flash, and four to the light change for each subject. Each AER is the composite of 50 responses, each of 800-msec duration. The AER's were plotted and measured. Careful inspection of eye movement potentials showed negligible involvement of eye movement in the AER's.

Typical morphologies of the averaged responses evoked by the click, the noise change, the flash, and the light change are seen in Fig. 1. Prominent peaks are an early positive (P2), an early negative (N2), and a late positive (P3) (*6*).

There are three types of AER's for each stimulus:

1) The AER to the relevant stimulus (called *Rel.* in Fig. 1), for example, the AER to the click when the click is the relevant stimulus.

2) The AER to the irrelevant stimulus in the same modality as the relevant stimulus (called *Irrel./Intra*), for example, the AER to the click when the noise change is the relevant stimulus.

3) The AER to an irrelevant stimulus in the other modality from the relevant stimulus (called *Irrel./Cross*), for example, the AER to the click when the flash or the light change is the relevant stimulus. Because of the lack of statistical differences for a given modality between AER's when the rapid (that is, click or flash) and slow (noise change or light change) cross-modal signals are irrelevant, no further distinctions will be made between them except in Fig. 1 and Table 1.

Because of the nature of the responses recorded, we analyzed the AER amplitude data for each modality separately. Within each modality, the AER

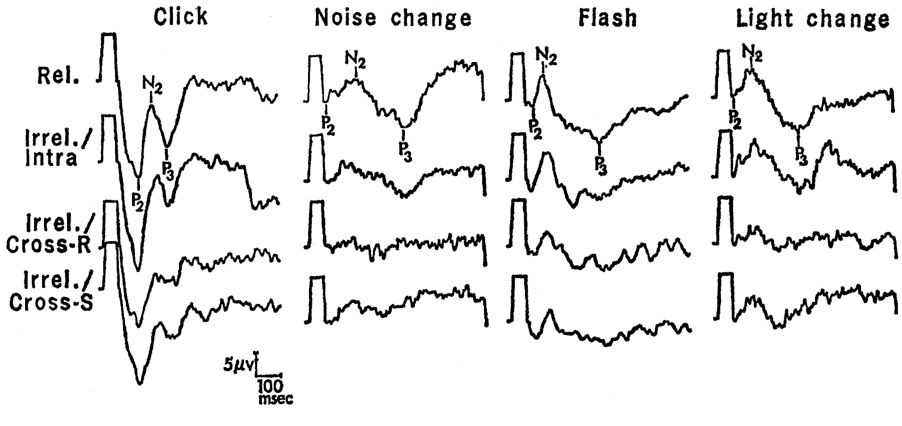

Fig. 1. Typical morphologies of the averaged electroencephalographic responses evoked by the click, the noise change, the flash, and the light change during each attention condition; *Rel.*, the stimulus eliciting the response is relevant; *Irrel./Intra*, the other stimulus in the same modality is relevant; *Irrel./Cross-R*, the "rapid" stimulus in the other modality is relevant; and *Irrel./Cross-S*, the "slow" stimulus in the other modality is relevant. The AER's to the click and flash are from one subject, and the AER's to the noise change and light change are from another subject. (Stimulus occurs at the beginning of the record.)

Table 1. Mean response amplitudes (in microvolts) of the AER's to the auditory and visual stimuli during each condition; Rel. (the stimulus eliciting the response is relevant), Irrel./Intra (the other stimulus in the same modality is relevant), Irrel./Cross-R (the "rapid" stimulus in the other modality is relevant), and Irrel./Cross-S (the "slow" stimulus in the other modality is relevant).

Waveform component	Rel.	Irrel./Intra	Irrel./Cross-R	Irrel./Cross-S
		Auditory stimuli		
P2	10.91	10.12	9.06	9.57
N2	12.67	12.29	9.49	8.69
P3	14.84	10.43	8.58	7.24
		Visual stimuli		
P2	1.55	1.90	1.19	0.96
N2	9.69	9.61	6.34	5.57
P3	17.34	12.64	6.42	4.65

amplitude data were grouped according to the relationship between the evoking stimulus and the relevant stimulus. For example, we grouped the peak amplitudes of the AER's to the click, when the click was relevant, with the peak amplitudes of the AER's to the noise change when the noise change was relevant.

The means of the amplitudes of the combined auditory and combined visual AER's are presented in Table 1.

Statistical analysis clearly shows identical trends for both auditory and visual AER's (*7*). There were no significant effects on the amplitudes of the P2 component (*8*). The N2 and P3 components were both strongly, but differentially, affected by the relevance of the stimulus, $P < .01$ (*9*). The principal findings are the following: (i) for relevant stimuli: a large N2 and a large P3; (ii) for irrelevant stimuli in the same modality: a large N2 and a medium amplitude P3; and (iii) for the irrelevant stimuli in the different modality: a small or nonexistent N2 and a small or nonexistent P3. In other words, a large N2 is elicited by stimuli in the relevant modality regardless of their specific relevance, while P3 is large if the stimulus is relevant, medium sized if the stimulus is irrelevant but in the relevant modality, and virtually nonexistent if the stimulus is in the irrelevant modality.

The results at N2 are consistent with two different theoretical approaches. The N2 data may imply gating of stimuli from the irrelevant modality, although our data offer no direct evidence regarding whether the gating is central or peripheral. [However, Picton *et al.* (*10*) strongly urge that gating does not occur as peripherally as the cochlea.] Alternatively, the results at N2 may imply that a preliminary decision based on modality parameters precedes the ultimate decision which is reflected at P3. In either case, the data presented here for N2 do not rule out the possibility that the preliminary process may not be based on modality per se, but rather on the fact that sensory modality is, in our case, the most salient feature for discrimination purposes.

The P3 data support the contention that P3 reflects some special cognitive processes which are invoked by certain psychological operations, independent of physical characteristics of the stimulus (*11*). Our results confirm and extend the finding of Hillyard *et al.* (*12*), who offer the explanation that P3 activity is triggered by a "definitive match" between a sensory event and a neural template. If this hypothesis were logically extended, one would not expect P3 to be enhanced for trials where the signal and the template are mismatched. Thus, our moderate amplitude P3 to the Irrel./Intra stimulus may represent a partial template match.

Thus, it appears that N2 and P3 either reflect different types of processes *or* different stages of one type of process. Typically, peaks earlier than our N2 are more affected by sensory factors, while late peaks in our P3 latency range (often termed P300) are more affected by cognitive evaluation of stimulus significance (*13*). Thus, our N2 may reflect sensory gating based on modality parameters, or it may reflect a preliminary decision regarding the stimulus significance, based on modality parameters. In either case, P3 reflects the subsequent decision based on specific features within a modality (*14*).

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References and Notes

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2. P. Spong, M. Haider, D. B. Lindsley, *Science* **148**, 395 (1965); J. B. Satterfield, *Electroencephalogr. Clin. Neurophysiol.* **19**, 470 (1965).
3. Technical details are available from J.M.F. upon request.
4. Subjects were not able to anticipate relevant stimuli, vitiating any alternative explanation of the results based on differential prior arousal [R. Nätäänen, *Acta Psychol.* **33**, 178 (1970).]
5. The motor response involved in pressing the button has been shown to be equivalent to a counting response in its effects on the amplitude of the AER for the components of interest in the study reported here [Harter and Salmon (*1*)].
6. The prominent peaks common to records for both modality AER's were P2 (measured relative to prestimulus baseline), N2 (relative to P2), and P3 (relative to N2). For the auditory AER peaks, P2 was taken to be the most positive peak between 80 and 190 msec, N2 was taken to be the most negative peak between 190 and 270 msec, and P3 was taken to be the most positive peak between 270 and 500 msec. For the visual AER peaks, P2 was taken to be the most positive peak between 80 and 170 msec, N2 was taken to be the most negative peak between 170 and 280 msec, and P3 was taken to be the most positive peak between 280 and 600 msec. The few ambiguous cases were compared to the subject's other responses in an attempt to identify the more consistent of the possible peaks with regard to latency. The individual who scored the data was ignorant of the hypothesis.
7. An analysis of variance on repeated measures was performed on the data. Orthogonal comparisons based on the estimate of error from the analysis of variance were made between means. All data statements made in the text are true at the $P < .05$ level or much better.
8. The lack of attentional effects for the P2 components is consistent with earlier data [L. R. Hartley, *Quart. J. Exp. Psychol.* **22**, 531 (1970); Smith *et al.* (*1*)].
9. Statistical analyses are available upon request.
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14. It should be noted that the latency of P3 is extremely labile and can occur anywhere between 200 and 500 msec after the stimulus presentation (*11*). Our P3 is quite late, perhaps because signal-processing itself is slowed owing to the large number of stimuli to be discriminated. S. Sternberg [*Science* **153**, 652 (1966)] has shown that the number of items to discriminate is positively correlated with the behavioral reaction time to the target stimulus. Perhaps P3 latency is similarly correlated with the number of items to be discriminated. If so, this partially explains our late P3 latencies. The mean reaction times to the discriminanda are quite long and exceed the P3 latencies by at least 150 msec. For the four relevant signals, the mean reaction times (MRT) and P3 latencies (both in milliseconds) were: click: P3, 316; MRT, 513; noise change: P3, 377; MRT, 702; flash: P3 379; MRT, 529; light change: P3, 394; MRT, 750. This indicates that although the P3 might represent the neural recovery from events associated with the penultimate signal evaluation, it probably is not contaminated with the ultimate motor response. Furthermore, the moderate P3 amplitudes in the conditions where no motor response was made further indicates that the P3 component does not rely solely on motor preparedness or response for its amplitude.

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