Evoked potential correlates of visual item recognition during memory-scanning tasks

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Visually evoked potentials elicited by tachistoscopically displayed alphabetic stimuli were recorded at vertex from six human subjects during a series of item recognition tasks. When presented with a test stimulus, the observer had to decide whether it had been memorized previously (i.e., whether it belonged to the positive as opposed to the negative set) and made a choice reaction time response accordingly. P_{300} amplitude was unequivocally greater following positive letter presentations than it was following negative letter presentations. This result is consistent with a "template-matching" model of P_{300} enhancement, but, more importantly, it extends the potential generality of this theory beyond the detection of simple sensory stimuli to complex cognitive tasks and stimulus events. The latency of the second positive peak remained essentially invariant across all positive set sizes, a fact which suggested that it reflected the minimum time required to register or encode the stimulus input. In contrast, P_{300} latency increased as positive set size was increased, i.e., as information processing took longer to complete.

There have been numerous reports that the late positive (P_{300}) component of the vertex average evoked potential (AEP) is more prominent when elicited by a task-defined relevant stimulus than by a physically similar yet operationally irrelevant stimulus (Chapman & Bragdon, 1964; Corby & Kopell, 1973; Donald & Goff, 1971; Donchin & Cohen, 1967; Ford, Roth, Dirks, & Kopell, 1973; Sheatz & Chapman, 1969; Wilkinson & Lee, 1972). Several investigators, most notably Donchin and his colleagues (cf. Donchin, Kubovy, Kutas, Johnson, & Herning, 1973; Rohrbaugh, Donchin, & Eriksen, 1974), have attributed this finding to information processing differences associated with each class of signal. In a related approach, Hillyard and his associates (cf. Hillyard, Hink, Schwent, & Picton, 1973; Hillyard, Squires, Bauer, & Lindsay, 1971) have suggested that the enhancement of P_{300} for a stimulus event designated as relevant is dependent upon a cortical match between that particular input and the template of the critical stimulus stored in memory. Support for their position has been derived almost exclusively from signal detection studies of perceptual judgments. In this context, relative to P_{300} activity observed during trials when a signal is correctly detected, the P_{300} component is either absent or greatly diminished on trials when misses, false alarms, or correct rejections occur (Hillyard et al., 1971; Jenness, 1972; Ritter & Vaughan, 1969; Squires, Hillyard, & Lindsay, 1973b).

With the exception of Chapman's use of number and letter characters in simple problem solving situations [cf. review by Chapman (1973)], the reports cited above have utilized relatively low-level pure tones, noise bursts, or white light flashes to determine how P_{300} is affected by the subject's evaluation of stimulus significance. The influence that psychological variables such as this have on the AEP should be examined during more complex cognitive tasks in which the stimulus events are readily discernible and performance measures are maintained at acceptable levels.

The techniques developed by Sternberg (1969a, b) to study the retrieval of information from memory represent a precisely controlled procedure that is directly applicable to this general problem area. In Sternberg's item-recognition task, the subject is presented with a target set of items (e.g., letter characters) short enough to store in immediate memory. When subsequently presented with a test stimulus, he must decide whether or not this letter has been memorized previously (i.e., whether it belongs to the positive as opposed to the negative set) and make a choice reaction time response accordingly. We believe that by recording AEPs to positive and negative test stimuli while varying the number of items in the memorized list, we may be able to observe differences in waveform as a function of stimulus class (positive or negative) and/or as a function of the complexity of information processing required (number of stored items).

METHOD

Subjects

Four men and two women, ranging in age from 21 to 37 years, took part in the experiment. Three had participated in previous AEP studies of a similar nature. Five had normal visual acuity and one wore corrective lenses.

Recording Apparatus and Stimulus Presentation

Electroencephalographic activity was recorded at vertex (C_z) and referred to right mastoid (left mastoid ground) with Beckman silver/silver chloride electrodes. The scalp was abraded before the start of each test day to insure that the measured

impedance between electrodes did not exceed 1.5K ohms. Signals were fed through high-impedance probes into ac pre-amplifiers (Grass P511) with a bandpass of .1 to 100 Hz. The outputs to positive and negative test stimuli were segregated and fed into separate channels of a summing computer (Nicolet 1072 signal averager). Each AEP was a compositive of 96 responses, 730 msec in duration. Average waveforms were written out with an X-Y plotter, and all AEPs were recorded on digital magnetic tape for subsequent off-line computer analysis of component amplitudes (peak to trough) and latencies. Data were reduced to 512 word outputs, with a digitizing rate of 1.43 msec per computer point.

The stimuli were white letters, .8 cm in height, centered on a 2.5 x 2.2 cm background. They were front illuminated by two mercury-argon lamps and were presented tachistoscopically within a 7.0 x 11.4 cm diffuse ambient field for a duration of 2 sec and with a fixed 3-sec interstimulus interval. Each letter subtended a visual angle of 0 deg 22 min at a viewing distance of 120 cm and was displayed with a luminance of 10.6 fL. Figure surround luminance during stimulus onset was 1.4 fL. The outline of the ambient field was visible between stimulus presentations.

Procedure

Before the experimental sessions were initiated, two pretraining sessions were devoted to familiarize each subject with the fixed-set item-recognition task. All letters of the alphabet comprised the set of potential test stimuli. During pretraining, two letters (B, F) were arbitrarily designated positive-set items, and they were shown to the subjects on a card. The subjects were instructed to commit these items to memory before the test series began. All remaining letters constituted the negative set.

The subjects were told to fixate at the center of the ambient field between presentations. While they viewed the test stimuli through the tachistoscope, subjects were seated with their heads supported by a chin rest and with each index finger positioned over a response key on a table in front of them. The subjects had to decide whether or not the letter character was a member of the positive set and make the appropriate keypress. A correct press produced immediate auditory feedback (2.9 kHz tone, 70 dB SPL) through a speaker mounted next to the response keys. For half of the subjects a left response was positive and for half a right response was positive. Reaction times (RTs) were recorded to the nearest millisecond, and subjects were instructed to respond quickly but to maintain, as nearly as possible, error-free performance levels. Each pretraining session included 192 random stimulus presentations, half of which were positive letters.

By the end of pretraining, reaction times for positive and negative stimuli were relatively stable and performance was virtually error free. The main experiment was then conducted within the framework of a 4 by 2 by 6 repeated measures design representing: size of the positive set (one, two, four, or six items); class of the test stimulus (positive vs. negative); and subjects (N = 6). Two days of two sessions per day were allotted for completion of the four memorized sets. Each session again included 192 random stimulus presentations, with the probability that a positive letter would appear remaining .5. Furthermore, a session was divided into three blocks of 64 stimuli, and 2-min rest periods were interposed between blocks to reduce fatigue effects. Thus, the total time required to complete a single positive set was approximately 25 min. The order of positive-set testing was varied randomly for each subject.

RESULTS

AEPs recorded from three subjects are shown in Figure 1 for each positive set evaluated. As described below, changes in specific component amplitudes and/or latencies occurred within subjects as a function of either the number of items in memory or the class of letter character viewed. While differences existed among individuals in overall morphology of the waveforms,
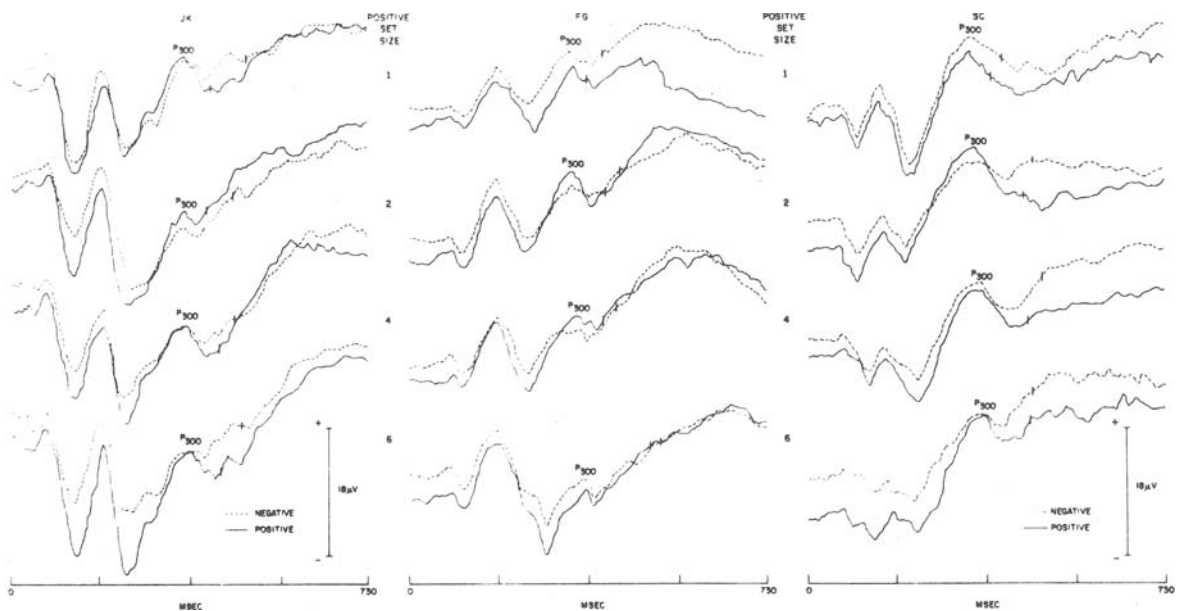

Figure 1. Average evoked potentials generated by positive (continuous trace) and negative (discontinuous trace) letter presentations are shown as a function of positive-set size (one, two, four, or six items) for six subjects. Each waveform reflects 96 summations and is labeled to indicate the relationship between P_{300} occurrence and mean reaction time (vertical slash marks). Negativity at vertex electrode is downward.
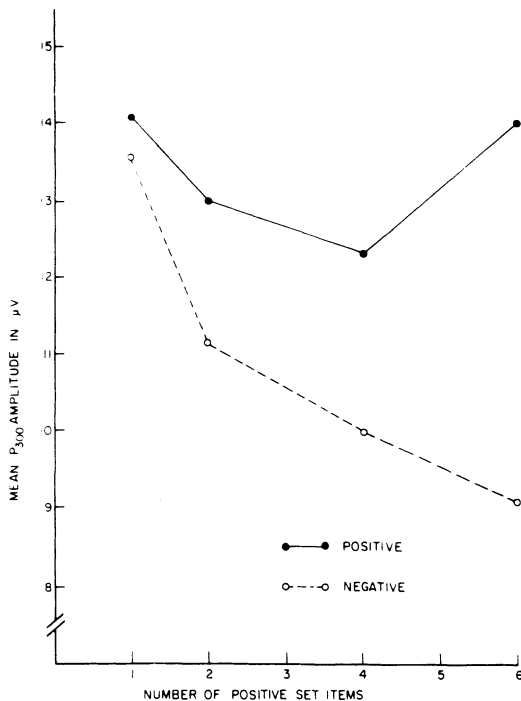
Figure 2. Mean amplitude of P_{300} component in microvolts for positive and negative test items as a function of positive-set size.

there were consistencies across subjects in the number and latencies of identifiable components. [Due to the relatively high intensity levels of equipment noise that were present during test runs (approximately 74 dB SPL) and due to the variable nature of RT responses, no clear auditory EPs to the feedback tones were observable in the data.] In this regard, there is good agreement with the vertex data reported by Sutton (1969).

P_{300} amplitude was measured relative to the second negative deflection. Similarly, voltage levels for the other components were measured in relation to the immediately preceding peak or trough. Analyses of variance revealed no significant influence of positive-set size or stimulus class on the amplitude measures for any component prior to P_{300}. With respect to P_{300} magnitude. a highly reliable main effect of stimulus class (F = 83.4, df = 1/5, p < .01) as well as a significant interaction of Stimulus Class by Positive-Set Size (F = 5.5, df = 3/15, p < .01) were found. Figure 2 shows while the amplitude of the P_{300} component evoked by positive items remained fairly constant across all positive sets, the amplitude of the P_{300} component associated with negative test stimuli declined as set size was increased. Thus, the difference in P_{300} magnitude for positive relative to negative letter characters, which was significant when the positive set contained one item (p < .05), increased substantially as a function of set size.

Figure 3 presents the relationship between positive-set size, choice RT, and peak P_{300} latency. Analysis

of variance performed on the RT data revealed that a significant increase in RT occurred with increasing positive-set size, regardless of stimulus class (F = 8.0, df = 3/15, p < .01). In addition, when pooling across set size, RTs were reliably longer following presentations of negative test stimuli (F = 44.7, df = 1/5, p < .01). Absence of an interaction effect between these factors precluded the existence of slope differences with respect to the positive and negative RTs. This was verified subsequently in regression analyses (see Figure 3 for slope values).

With regard to the latencies recorded for various components of the AEP, no differentiation could be made between positive and negative waveforms. There was, however, a significant increase in P_{300} latency as a function of increasing positive-set size (F = 19.6, df = 3/15, p < .01). A similar, yet not as substantial, shift in latency occurred for the second negative wave (F = 3.8, df = 3/15, p < .05), whereas the other component latencies remained essentially invariant across all positive sets.

Finally, it should be noted that trend analyses conducted on the RTs and P_{300} latencies shown in Figure 3 indicated that a significant deviation from linearity (F = 4.5, df = 1/15, p < .05) accounted for 20% of the variation in RT across positive-set size, while, in contrast, 99% of the variation in P_{300} latency across positive-set size was attributed to a linear trend.

DISCUSSION

A significant enhancement of the P_{300} component was observed for positive letter presentations in each of the item-
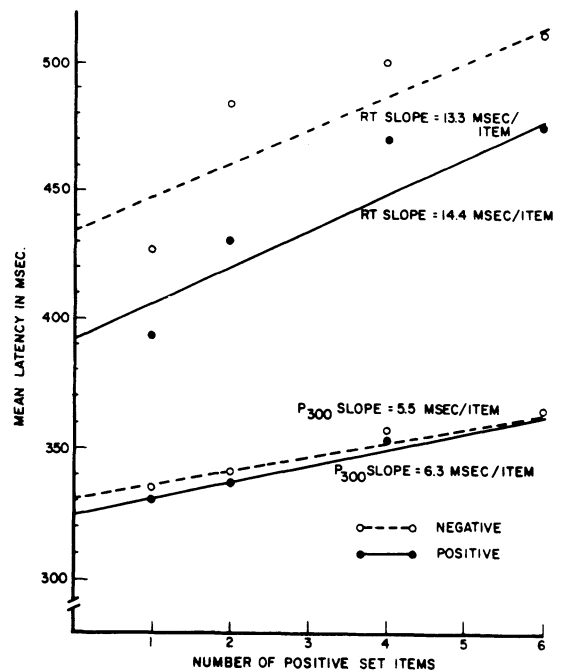

Figure 3. Mean reaction time (top) and P_{300} latency (bottom) in milliseconds for positive and negative test items as a function of positive-set size.

recognition tasks. Moreover, the difference in P_{300} amplitude between positive and negative letter characters increased as the number of items in the positive set was increased. This was due to the fact that the P_{300} associated with negative test stimuli declined in magnitude as a function of set size.

Given the randomization in displaying the letter characters, it is unlikely that the differences in P_{300} amplitude for positive and negative test items can be ascribed to selective attention (Tecce, 1970) or shifts in general arousal (Eason, Harter, & White, 1969). Similarly, since the positive and negative P_{300} components appeared earlier in time than their associated RTs for each of the positive-set sizes evaluated and since successive presentations of up to eight positive or negative stimuli were encountered, an explanation of these P_{300} differences calling for a reactive change in preparation *after* positive stimulus occurrence (Karlin, 1970) may also be discounted. We choose instead to relate our AEP results to cognitive behavior in general, and specifically to those tasks in which there is precision in controlling the particular thought processes that occur.

AEP correlates of positive and negative letter presentations have been evaluated recently within the context of a Sternberg varied-set procedure in which positive-set size equalled one (Posner, Klein, Summers, & Buggie, 1973). In this situation, a new item was memorized before the initiation of each trial. These authors reported significant differences in $P_2 - N_2$ and $N_2 - P_3$ amplitudes for positive vs. negative test stimuli, in contrast both to our singular finding of P_{300} differences and to Hartley's (1970) observation that signal relevance does not affect components with a latency less than approximately 250 msec. They also concluded that the cognitive match created by positive letter presentation produced a substantial reduction in the size of the N_2 and P_3 components, a result in direct contradiction to the enhancement observed here and in studies cited earlier (e.g., Ford et al., 1973; Hillyard et al., 1971). It remains to be determined whether the use of a varied-set procedure by Posner et al., as opposed to the fixed-set procedure employed here, is responsible for the discrepant findings. However, the behavioral evidence available (cf. Sternberg, 1969a) suggests that this methodological distinction is not causally related to the orthogonal nature of the P_{300} data presented in the two studies.

In re-examining their earlier explanation (Hillyard et al., 1971), Hillyard's group (Squires, Hillyard, & Lindsay, 1973a) offered a two-stage model to account for the P_{300} enhancement seen in studies concerned with the detection of simple sensory stimuli. They argue that there is a "template-matching" stage in which the sensory input is evaluated with reference to specific memorized characteristics which define the critical stimulus dimension. An output proportional to the goodness-of-fit of the match is then sent to a second, "decision" stage. The received output is then added to a prestimulus "bias," the level of which is inversely proportional to the observer's expectancy that the relevant event will be displayed. Thus, the degree of P_{300} enhancement is seen to covary with the closeness of the template match but to be inversely related to the a priori or subjective probability of relevant signal occurrence. Our results provide corroborative evidence for the theoretical position taken with respect to the first stage, but, more importantly, they extend the potential generality of this hypothesis beyond the detection of simple sensory stimuli to complex cognitive tasks and stimulus events. Regarding the relevance of our data to the second stage, we did not observe an increase in P_{300} amplitude for positive letter characters as a function of increasing set size, despite the fact that the probabilities of occurrence for each individual item within the positive set were reduced.

Sternberg (1969a, b) has developed a theory to account for RT data graphed in the manner exhibited in Figure 3, which is also applicable to an interpretation of the present AEP latency data. He contends that the y intercept represents: (a) the time required to encode or preprocess the test stimulus into suitable form for content evaluation and (b) the time needed to organize and execute the motor response. The slope, on the other hand, reflects the time per unit item involved in scanning memory and retrieving information for comparator processing.

Ford et al. (1973) have remarked previously about the extremely labile nature of P_{300} latency and, as shown by our data, they correctly predicted that P_{300} latency would increase in a retrieval task as the number of memorized items to be processed increased. In addition, Ritter, Simpson, and Vaughan (1972) and Squires et al. (1973b) related delays in P_{300} occurrence with level of difficulty and decision latency in discrimination tasks. Moreover, consistent with the P_{200} data in the present experiment, the former researchers noted that this component appeared at essentially the same time across the various experimental conditions. This finding led them, and we concur, to suggest that vertex P_{200} latency reflects the minimum time required to register and conduct preliminary analyses of the sensory input. Furthermore, the graded positive displacement of P_{300} latency which we observed with increasing positive-set size (i.e., as information processing took longer to complete) provides direct evidence to tie P_{300} activity to cognitive function. It is interesting to note that Roth, Kopell, Tinklenberg, Darley, Sikora, & Vesecky (1975) did not find a significant effect of positive-set size on P_{300} latency during a series of similar item-recognition tasks. However, in contrast to our data, they were unable to identify P_{300} in many of the individual records. Finally, the functions relating P_{300} latency to set size in the present study were highly linear and almost identical in slope. This is indicative of a serial search of memory, however, whether the scanning process is exhaustive (Sternberg, 1969b) or self-terminating (Theios, Smith, Haviland, Traupmann, & May, 1973) remains unresolved.

With regard to RT, the small slope values reported are consistent with other findings when subjects are given considerable practice on the retrieval task (Burrows & Murdock, 1969). Further, a significant nonlinear trend in the RT data, which were better fitted to the logarithm of positive-set size (cf. Briggs, 1974), has been reported previously if the number of items to be memorized exceeded four (Ross, 1970). The reliably longer RTs for negative-set items are a common occurrence when the probabilities of presentation for individual nontarget stimuli are much lower than those for individual target characters (Theios et al., 1973) and are probably best explained by differential motor sets in stimulus-response translation (Teichner & Krebs, 1974).

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