

On the selection of signals*

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In a previous paper, it was argued that alertness, selectivity (set), and processing capacity (consciousness) could be identified and studied as separate components of attention. The current paper develops this theme by showing that alertness does not affect the buildup of information within the memory system but only the rate at which a later system responds to that information. Thus, in standard reaction-time tasks, increased alertness produces a reduction in reaction time but no decrease in errors. In contrast, providing a model of the signal the S is to process improved both speed and accuracy. The presence of a model of what the S is to process varies the vertex neural response to that specific signal as compared to a mismatching signal in the first 200-300 msec after its presentation. Three accounts of this effect are: speeded processing of a matching stimulus, habituation of the electrical response to a matching stimulus, and prolonged or enhanced processing of a mismatch. Evidence favors the first of these explanations, but the other two cannot be dismissed as possible contributors to this effect.

The study of attention has assumed a central role in modern cognitive psychology (Broadbent, 1971; Kahneman, 1973; Keele, 1973; Mackworth, 1969; Moray, 1969). It is generally acknowledged that the term has several distinct meanings. These include an attentive state of the organism (alertness or arousal) as well as an ability to select or classify aspects of the input (set). Both alertness and set affect the ability of Ss to select signals from the environment.

A recent paper (Posner & Boies, 1971) tried to study the relationship of alertness and set (called selectivity in that paper) in a letter-matching task. It was found that both alertness, as introduced by a warning signal, and set, introduced by providing the S with one of the two letters, improved reaction time to the task. When the same signal was used both to alert and set the S, the improvement in reaction time was the sum of the individual improvements.

While alertness and set combine to improve reaction time, they are by no means identical in their effects upon behavior. For example, alertness improved reaction time to matching and mismatching letter pairs by the same amount, while providing the S with one letter (set) improved his reaction time to the occurrence of a second letter more when it matched the first than when it did not (Posner & Boies, 1971, Fig. 7).

The current experiments were designed to provide a more detailed account of the ways in which changes in alertness and set affect the processing of signals. The first series of experiments dealt with variations in alertness and used mainly reaction-time techniques. The

second series dealt with the problem of set and involved mainly the use of electroencephalogram measures.

ALERTNESS

Posner and Boies (1971) showed that alertness and set both led to marked improvements in reaction time. The size of their effects depended upon the time between the warning signal or the first letter and the second stimulus. It took about .5 sec for either the warning signal or the first letter to have its full effect. When a single item was used both to alert and set the S, improvement in reaction time was exactly the sum of the individual improvements and the time course of improvement remained the same. This finding implies that the efficiency with which the first letter served to "set" the S for the match was equal regardless of the level of alertness at the time the letter was presented. Put another way, the buildup of information from the first letter was equally rapid whether the S was alert when it arrived or not.

If the rate of buildup of information is constant regardless of the level of alertness, rapid responses must be made on the basis of information which is at least of no higher quality than would be obtained if responding was slowed. It follows from this idea that the reduction in reaction time due to improved alertness cannot be accompanied by reduction in errors. If the buildup of information is slow relative to response time, errors will increase with alertness, while if the buildup is fast, errors will tend to remain constant as reaction time is reduced.

In order to check on this idea, we combined information from several letter-match experiments reported previously (Posner & Boies, 1971). These involved physical, name, or vowel-consonant matching. The results are shown in Fig. 1. It is clear that providing Ss with the first letter (set) decreases errors just as it

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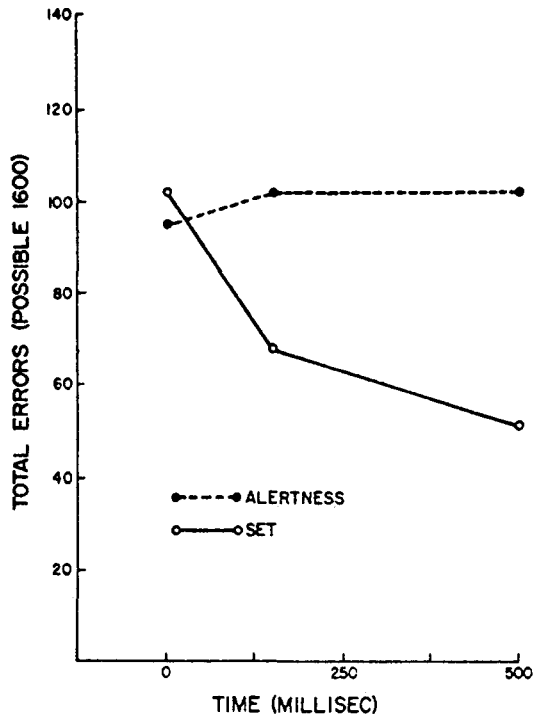


Fig. 1. The change in errors as a function of the time following a warning signal (alertness) or one of the letters in a matching task (set).

does reaction time ($p < .01$ by sign test). However, providing Ss with a warning signal has no reliable affect upon errors.

This finding was encouraging for our view of alertness. However, there were relatively few errors in the tasks shown in Fig. 1 and only three points on the alertness function. It was thought best to replicate the effect of alertness on speed and accuracy in a new situation where manipulations in compatibility could be used to assure a reasonable error rate.

EXPERIMENT I

Method

Subjects

The Ss were nine students obtained through the employment service of the University of Oregon and paid \$1.50 per hour. Each S was run individually for 1 h on 3 consecutive days.

Procedure

Each trial consisted of either no warning or a warning tone of 50 msec followed after constant intervals of 50, 100, 200, 400, or 800 msec by an X which appeared to the left or right of a vertical line at the center of an oscilloscope. In the compatible condition, S pressed the left key when the X was left of center and otherwise pressed the right key, while the incompatible condition was reversed. The S's response terminated the display, which was replaced by a visual feedback of time and error information. A variable intertrial interval of 2-5 sec was used.

Each S performed six compatible and six incompatible blocks, one block at each foreperiod on each experimental day. The

blocks were 20 trials, 10 for each stimulus position. The order of compatibility conditions was counterbalanced, and the order of foreperiods was controlled by a random Latin square.

The Ss were encouraged to respond as rapidly as possible without regard to any particular level of accuracy. Speed was stressed throughout the experiment.

Results

The median reaction time for correct responses and error rate was computed for each S and day at each foreperiod for both compatible and incompatible conditions. The means of these values combined for Days 2 and 3 are shown in Figs. 2 and 3. An analysis of variance of the reaction-time scores showed a significant effect of foreperiod [$F(5,40) = 18.8, p < .01$] and of compatibility conditions [$F(1,8) = 37.1, p < .01$] and no significant interactions. The ANOVA of the error scores also showed significant effects of foreperiods [$F(5,40) = 7.8, p < .01$] and of compatibility [$F(1,8) = 24.9, p < .01$], with no significant interactions.

The most striking aspect of the data was the clear inverse relation between reaction time and errors. While the two functions are not quite mirror images of each other, it is clear that errors tend to be highest where reaction time is fastest (e.g., foreperiods of 50-200 msec) and lowest where reaction time is slowest (e.g., 0 and 800 msec).

The reaction times shown in Fig. 2 are only for

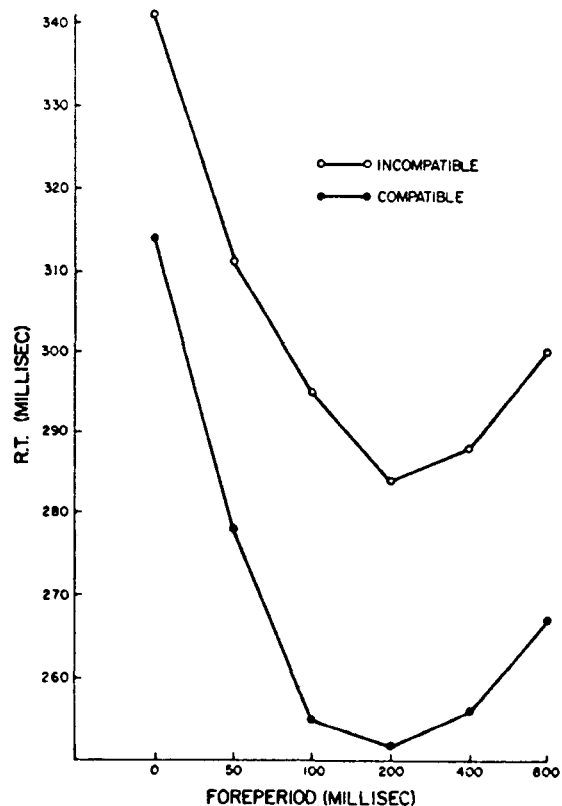


Fig. 2. Reaction time as a function of foreperiod for a spatial choice reaction-time task.

correct responses. The error reaction times are also of interest. Table 1 provides a comparison of the mean correct and error reaction times at each foreperiod for both compatible and incompatible conditions.

Discussion

In general, this experiment confirms the idea that rapid responding introduced by a warning signal does not reduce the likelihood of error. In this task, Figs. 2 and 3 illustrate a marked speed/accuracy tradeoff over foreperiods.

The data of Table 1 are consistent with the view that alertness produces rapid responding without improving the buildup of information about the signal. Without a warning signal errors had about the same reaction time as did correct responses. However, with a warning signal, error reaction times were systematically faster.

The increase in errors with foreperiod is consistent with other studies using this task. While there is no specific discussion of this speed/accuracy tradeoff with foreperiod, the literature is consistent with it (e.g., Bertelson, 1967; Bertelson & Tisseyre, 1969). What seems to have happened in these studies is that the errors

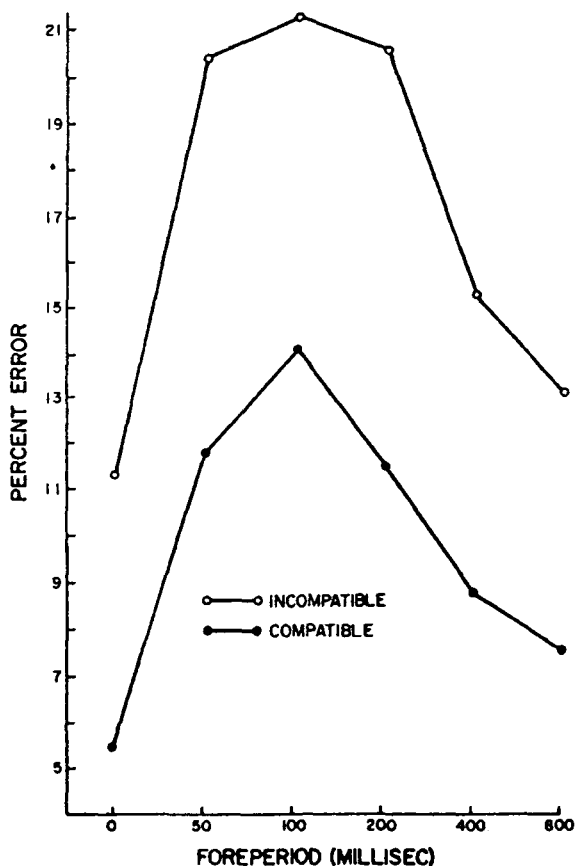


Fig. 3. Error rate as a function of foreperiod for a spatial choice reaction-time task.

Table 1
Mean RTs for Correct and Error Responses for
Conditions of Experiment I

Fore-period	Compatible		Incompatible	
	Correct	Error	Correct	Error
0	325	346	351	340
50	293	255	322	267
100	265	200	312	252
200	262	200	305	219
400	274	215	307	271
800	273	263	332	264

were always few enough so that the effects were not significant, while the reaction-time effects were.

An indication of this general effect of alertness is also found in Broadbent's (1971) summary of vigilance. He argues that time on task usually produces a β change rather than a change in d' . As alertness declines, Ss require more information to report a signal. Since a warning signal presumably produces a high level of alertness, while time in a vigilance task presumably produces a low level of alertness, it appears consistent that alertness should manifest itself in both types of studies in fast but more risky responses.

Additivity between independent variables such as was found between foreperiod and compatibility in Experiment I has sometimes been used to suggest independent processing stages (Sternberg, 1969). One view consistent with this stage notion is that compatibility affects the rate of buildup of information in the memory units corresponding to the motor program of pressing the key (Keele, 1973), while alertness affects the rate at which the central processor can initiate the response.

While both the task studied in this experiment and the letter-match task (see Fig. 1) show reduced reaction time with warning and no reduction in errors, there are major differences between them. First, in the spatial task, the optimal reaction times were obtained at about 200 msec warning, while in the letter-match task, the fastest reaction times were obtained with foreperiods of 500 msec (Posner & Boies, 1971). Second, in the letter-match task, error rate remained flat over foreperiods, while in the spatial task there was a marked increase in errors. Third, even with low compatibility, the speed at which Ss responded in the spatial task was greater than for the letter-matching task. The next experiment examined the role of alertness in the matching task.

EXPERIMENT II

One effect of a warning signal is desynchronization of the electroencephalogram and the production of a negative shift called the contingent negative variation (Walter, 1964). There are similarities between the electroencephalogram changes due to a warning signal and those which occur as organisms shift from sleep to

wakefulness. Since the latter phenomenon has often been identified with stimulation of the reticular activating system (Milner, 1970), it seems reasonable to suppose that the behavioral alerting which we are studying by the introduction of a warning signal is related to that which would be obtained by reticular activation. Indeed, textbooks on physiological psychology suggest this relationship (Milner, 1970). The one study which is usually cited as relating performance changes to reticular activation is that of Fuster (1958). Fuster showed that reticular stimulation produces a decrease *both* in reaction time and in errors when compared to a nonstimulated control. An objection to the Fuster study has been that the animal might have used the stimulation as a warning signal. In any case, Fuster's finding of improvement in both speed and accuracy seems to contradict our view that errors do not improve with alertness in reaction-time tasks.

One difference between our letter-matching technique with humans and Fuster's study of monkeys is of special interest because it shows how a single view of alertness can make opposite predictions about errors, depending upon stimulus conditions. In Fuster's study the stimulus terminated after a brief interval, while in our study the stimulus remained present until the S responded. If the stimulus remains present, there is no way for the information to be of higher quality when the S responds faster, as he does under conditions of high alertness. However, if the stimulus disappears, and in particular when it is present for only a brief interval, a faster response may allow the S to use information which is less decayed and thus more accurate. Since alertness allows the S to respond faster, it could result in a reduction in errors when exposure duration is short.

Method

Subjects

A total of 15 Ss were run, each obtained from the student employment service and paid \$1.50 per hour for their services. The first 9 Ss served in Experiment IIA and the remainder in Experiment IIB.

Procedure

Each trial consisted of a warning interval (of 0 or .5 sec) followed by a pair of letters which remained present for either 40 or 400 msec in Experiment IIA or 500 msec in Experiment IIB. The Ss were required to respond "same" if the letters were identical and otherwise to respond "different." After each trial, Ss received feedback on errors and reaction time. A variable intertrial interval of 2-5 sec was used. The warning interval was introduced by a plus sign which remained present during the interval (if the interval was zero, no sign appeared).

In Experiment IIA, Ss ran in eight blocks of 30 trials on each of 3 days. Two blocks were run at each of the four combinations of exposure duration and warning. Within each block, half of the trials were same and half were different. Experiment IIB was identical except that only one exposure duration was used and there were twice as many blocks run at each warning interval.

Results

The mean of the median reaction times and the mean error rates were calculated for Days 2 and 3 for Experiment IIA. These are shown in the two upper curves of Fig. 4 and the two lower curves of Fig. 5. The reaction-time data show only a significant effect of foreperiod [$F(1,8) = 20.5, p < .01$]. The error data show significant effects both of foreperiod [$F(1,8) = 10.1, p < .05$] and of exposure duration [$F(1,8) = 21.6, p < .01$]. The interaction is not significant [$F(1,8) = 4.2, .1 > p < .05$]. However, sign tests of the difference in error at the two exposure durations show a significant improvement in error ($p < .05$) for the short duration and no significant improvement for the long duration. For the short duration, only one of the nine Ss failed to show an improvement in error with foreperiod, while at the long duration four Ss improved and four got worse.

Because the error rate at the long duration was much lower than at the short duration, it is possible that the failure to show a reduced error with alertness is due to the difference in overall performance rather than to exposure duration per se. In Experiment IIB, the overall reaction times (lower curve, Fig. 4) were faster and the error rate higher (upper curve, Fig. 5). An analysis of variance shows a significant effect of alertness on reaction time [$F(1,5) = 52.8, p < .01$], but once again no significant effect of alertness on errors and a trend which is opposite to that found with short exposure duration.

Discussion

Generally speaking, there have been two views about how alertness works. One view is that there is a shift in the threshold of sensory or memory system units. This shift is usually thought to be due to reticular stimulation improving the responsiveness of the cortex. A second view has been that alertness works primarily upon the motor system, increasing the rate at which motor output can be produced.

Our data are clearly inconsistent with the first view of alertness. We have shown a marked reduction in error when encoding is varied by providing Ss with the first letter (Posner & Boies, 1971). If alertness worked by improving encoding, one would also expect decreases in error under the same conditions. Instead, error either remains constant or increases except when the signal is terminated quickly. This dependence of error performance on exposure duration is predictable from our view that alertness does not affect encoding but only the time for a later system to respond to encoded information.

However, we do not feel that a motor view, as that term is usually used in psychology, is necessarily correct. There is reason to believe that the effects of alertness are similar whether or not an overt response is

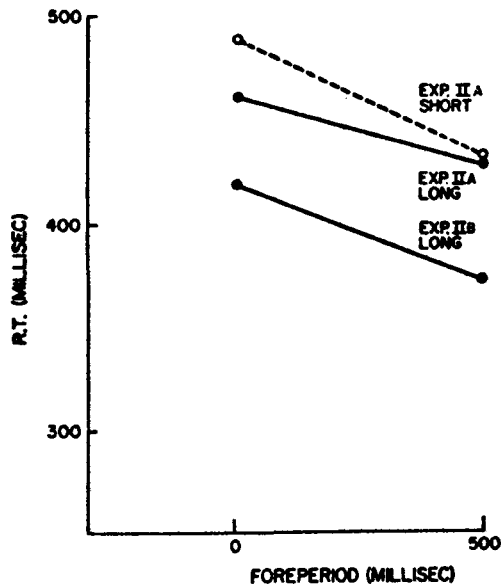


Fig. 4. Reaction time with and without a warning signal for short and long exposure durations in a letter-matching task.

required. On the behavioral side, similar foreperiod functions have been shown in number estimation tasks (Leavitt, 1969) as are found in reaction time. Moreover, the contingent negative variation and electroencephalogram desynchronization occur in much the same way regardless of whether an overt motor response is required. Finally, there is evidence that a warning signal affects the time between the stimulus and the first change in the electromyogram (premotor time), not the time between the electromyogram change and the response (motor time) (Botwinick & Thompson, 1966). Thus, the effects appear to be central and not peripheral.

The effects of alertness seem to us best described as reducing the time for some central limited-capacity system to respond to the buildup of information about the signal. The central processor of an alert organism reacts more quickly. If the task requires detection of a transient signal, this may improve all aspects of performance. If the task requires a rapid response about a steady signal, the increased speed of the central system will reduce reaction time, but at the risk of responding to poorer quality information. This view of alertness may be close to the physiological sense of the term "motor," since the limited-capacity system may be related to the control of motor mechanisms.

A different way to study the relation of the central system to information buildup is to provide the S with specific details about the signal he is to receive. In some studies, this is done by information about the modality or frequency of the input. We shall turn now to studies which provide a highly specific model of the expected input.

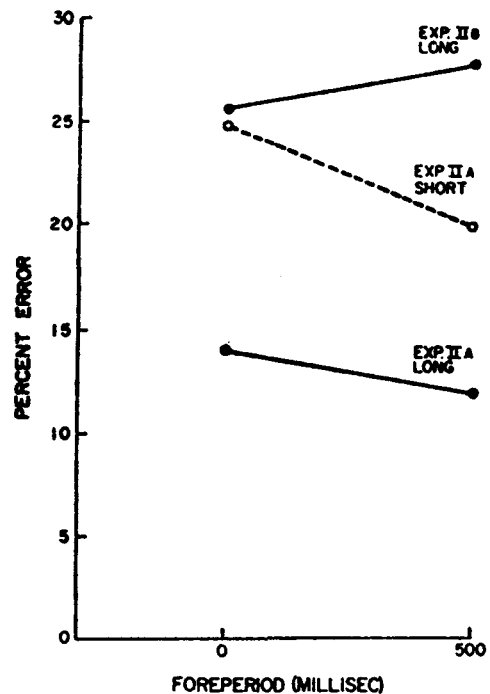


Fig. 5. Error rate with and without a warning signal for short and long exposure durations in a letter-matching task.

SET

The effect of alertness is to speed the processing of matching and mismatching letter pairs equally and not to improve errors. Showing the S one of the two letters improves reaction time more to a match than to a mismatch (Posner & Boies, 1971) and also reduces error (see Fig. 1). These findings suggest that the incoming stimulus is handled more efficiently if it matches the preceding stimulus.

In previous work, we have attributed this increase in efficiency to the activation of the internal representation of the first letter (Posner & Boies, 1971). When the second letter contacts an already-activated representation, it is handled differently than when it reaches units which are not activated.

It would seem useful to examine in detail the interaction between the stored letter and new input. To do this, we compare evoked potentials to matches and mismatches.

EXPERIMENT III

Method

Subjects

The Ss were 20 students obtained from the University of Oregon employment service and paid \$1.50 per hour for their services. Ten Ss were run in Experiment IIIA and 10 in Experiment IIIB.

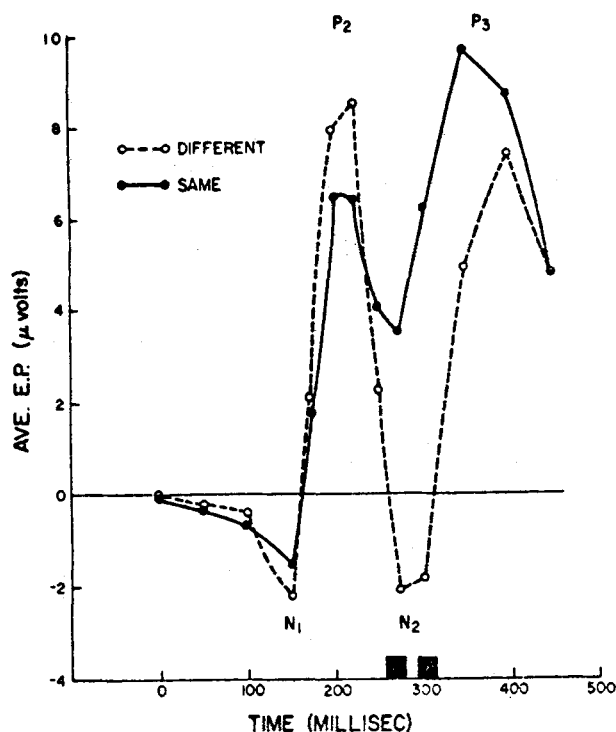


Fig. 6. Average evoked potential following the second letter when there is a match (solid line) and a mismatch (dotted line). Excursions on the x-axis represent significant differences between conditions.

Procedure

Electrical recording was from vertex electrodes (silver-silver chloride) referenced to the left mastoid with right mastoid as ground. The electrical signal was amplified by a Grass P₁ polygraph, sampled every 6 msec, converted to a digital reading by an A-D converter, and written on Dectape by a PDP-9 computer. Signals were displayed on-line by a scope display trial by trial and averaged later using an averaging routine developed for the PDP-9.

The stimulus display was controlled by the same PDP-9 computer. It consisted of a single letter which remained present for .25 sec in Experiment IIIA and until the Ss responded in Experiment IIIB. A second letter appeared in an adjacent position 1 sec after the presentation of the first letter and remained on until S responded. The display was foveal, subtending a visual angle of less than 2 deg. Ss were instructed to decide whether or not the second letter matched the first. They were not allowed to respond, however, until a plus sign appeared .5 sec following the second letter. They then pressed a left key if the letters were "same" and otherwise pressed the right key.

Each S was run in four blocks of 64 trials on each of 2 successive days. Each block consisted of 32 trials of matches and 32 trials of mismatches in a random order.

Results

The major results of the study consist of the average evoked potentials for matches and for mismatches for each S. Each of these evoked potentials is based upon the average of 128 trials. In averaging the data, the E eliminated trials in which obvious artifacts occurred.

In order to display the overall results, the data from

the Ss in each experiment were averaged together. The value of the average evoked potential was converted to microvolts by reference to a calibrating signal introduced at the start and finish of each S's session. In Experiment IIIA, the data from each S were set at zero at the time of the second letter. The amplitude averaged over Ss was calculated, at each of 10 points following the second letter, separately for the matches and mismatches. These results are shown in the form of the two averaged evoked potentials displayed in Fig. 6. In Experiment IIIB, the data for the full 3,072-msec time sample were averaged over Ss from the digital values sampled every 6 msec. A baseline was constructed from the first 1,000 msec (prior to the first letter), and the two curves were normalized around this baseline. These data are shown in Fig. 7.

The evoked potentials appear as a series of positive and negative waves. We have used the labels N₁, P₂, and P₃ to identify the successive negative and positive waves found in most of our data. The P₁ wave was not usually seen in the vertex recording we used.

Two types of statistical analysis were performed upon the data. First, an analysis was made of peak-to-peak differences in the evoked potentials. In Experiment IIIA, significant differences between match and mismatch conditions were found in the amplitudes of N₁ - P₂ ($p < .05$ by sign test) and P₂ - N₂ ($p < .01$ by sign test). In each case, the matching pairs showed a reduced amplitude. In Experiment IIIB, there were no differences in the N₁ - P₂ component, but there was a reduced amplitude for the matched pairs in both P₂ - N₂ and N₂ - P₃ components ($p < .05$ by sign tests). However, it was not entirely appropriate to analyze data by peak-to-peak measurements in this experiment, because there were clear shifts in the overall form of the evoked potentials. For example, many of the Ss showed no evidence of N₂ in the matched pairs. Instead of the dual positive peaks found for the mismatches, they showed only a single positive peak.

For this reason, another statistical analysis was performed (Wood, Goff, & Day, 1971). At each of the 10 points in Experiment IIIA and for all 512 points sampled in Experiment IIIB, a Wilcoxon matched-pairs signed-ranks test was run. Each S's value for match and mismatch at that point was ranked and the results summed to calculate the statistic. A cutoff point of .01 was established. Where these values are significant, an upward excursion is plotted on the x-axis of the graph.¹

There are significant differences in Experiment IIIA at 275 and 300 msec and in Experiment IIIB from 225 to 350 msec following the second letter. These differences coincide with the reduced amplitude of the P₂ - N₂ and N₂ - P₃ components of the matched pairs. In Experiment IIIB, a very clear difference between the conditions is found following the first positive peak. The matching pairs are relatively flat, while the mismatches show two separate positive peaks. These differences might be attributed to changing amplitude, but they

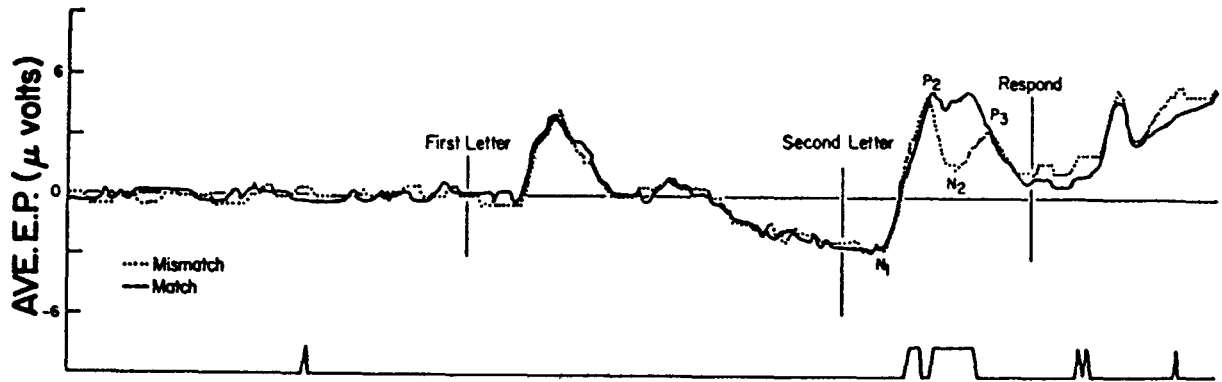


Fig. 7. Average evoked potential for match and mismatch for 3,072 msec from start of trial through response. Excursions on the x-axis represent significant differences between conditions. The interval between letters is 1,000 msec.

could also be due to a shift in latency. When a match occurs, the P_3 wave might be seen as moving forward in time so that the N_2 component is either reduced (Experiment IIIA) or eliminated (Experiment IIIB).

Another aspect of the data is the more rapid rise of the mismatched stimulus evoked potential in the $N_1 - P_2$ component. This is related to the tendency to find $N_1 - P_2$ smaller for matches than for mismatches in Experiment IIIA. Some Ss appear to show no distinct $N_1 - P_2$ component for matched stimuli. Rather, their evoked potential goes from a negative peak with the latency of N_1 directly to a positive peak whose latency is longer than P_2 and which may be identified as P_3 . Thus, peak-to-peak measurements are difficult for these Ss. The later peak of the first positive component for these Ss produces the significant difference between conditions from 160 to 200 msec in Experiment IIIB.

Discussion

The results of these studies indicate some difficulty in separating latency and amplitude differences in the evoked potentials for matches and mismatches. However, there is little question that the vertex evoked potential is significantly different for matches and mismatches in the range of 160-350 msec following the second letter. Because both amplitude and/or latency changes may be involved, at least three different theories of this effect seem possible.

(1) The difference might be characterized as a reduction in the amplitude of the second evoked potential when the signal matches. This view would square with the idea that a recognition unit which had just been activated would give a weaker signal when reactivated (Butler, Spreng, & Kneidel, 1969). Although there is some evidence for habituation of evoked potentials (Ritter, Vaughn, & Costa, 1968), none of the data suggest that a single presentation of an item would be sufficient to produce a specific habituation to that item. Moreover, all efforts on our part to find a behavioral analog of habituation such as a reduction in

luminance or an increased threshold of stimulation for matches were not successful.

(2) Another possibility is that Ss pay more attention to mismatches than to matches. This would suggest that the input is treated the same at a sensory level but that Ss rehearse or otherwise attend to a mismatch more than to a match. There is a great deal of behavioral evidence which suggests this possibility (see Posner & Warren, 1972, for a summary). However, it seems that the late positive wave for matches (P_3) would be the component affected if this were the case. Moreover, one would not expect the two evoked potentials to come together after 350 msec if the difference was due to more processing of mismatches.

(3) A third possibility is that the evoked potential components are shifted in latency for matches from their value for mismatches. Specifically, the late positive component has been related by researchers to a nonmodality specific association area effect which can be manipulated by such things as the probability of occurrence of a signal (Sutton, 1969) and other psychological operations. This description is close to what we have called the limited-capacity or conscious component of attention (Posner & Klein, 1973).

EXPERIMENT IV

Experiment IV was designed to test a dual hypothesis. First is that the system responsible for the P_3 will be influenced by instructions to attend closely to a stimulus. Second is that matches reach this system more quickly than do mismatches. Ss were given pairs of visual words which either matched or did not. In one condition, they were instructed to count only the matches and ignore the mismatches. In the other conditions, they were to count only the mismatches and ignore the matches.

Method

Subjects

The Ss were 14 students recruited from the student

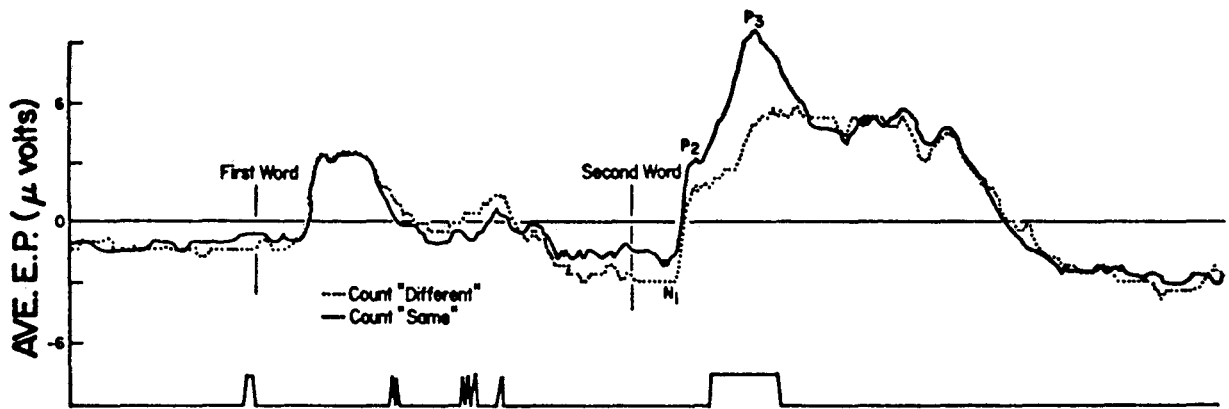


Fig. 8. Average evoked potential for matches when instructed to count "sames" or "differents." Excursions on the x-axis represent significant differences between conditions. The interval between words is 1,000 msec.

employment service and paid \$1.50 per hour for their services.

Procedure

Vertex electrodes were used as in Experiment III. The recording and analysis were basically the same. They received pairs of visual words. The first word remained on for .4 sec and was followed after 1 sec by the second word. On half the trials the word was the same, and on half it was different. The E interrupted at variable times to ask S to report the number of "same" or "different" pairs. Each S was run through six blocks of 64 trials in one session. For half the blocks he was instructed to count "same" pairs and half "different" pairs.

Results

The basic result was the averaged evoked potential for matches and mismatches for both instruction conditions for each S. These in turn were averaged as described for Experiment IIIB. Figure 8 shows the overall average evoked potential for matches in the count "same" and count "different" conditions. The statistical tests which are significant beyond the .01 level by the Wilcoxon test are shown on the x-axis. The results show quite clearly that the instruction to attend to matches has an effect on the evoked potential by greatly enhancing the positive wave which peaks at 340 msec after the second word. The evoked potential for the count "same" instruction begins to depart from the evoked potential

for the count "different" instruction at about 200 msec. This is about the time the match and mismatch evoked potentials began to show their large divergence in Experiment IIIB.

Figure 9 shows the overall evoked potentials for mismatches in the two instruction conditions. The results are also in accord with our dual hypothesis. The count "different" instruction departs from the count "same" instruction by an enhancement of the late positive wave. Moreover, this difference occurs about 100 msec later than for the matches, starting at about 315 msec. This value is close to the point where the mismatches in Experiment III were at or near the peak of the positive wave.

Discussion

The results of Experiment IV lend substantial support to the dual hypothesis which arose at the end of Experiment III. Focusing the Ss' attention by instruction does affect the size of the late positive wave. This confirms previous results (Donchin & Cohen, 1967) of P₃ enhancement with instructions to attend. Since presentation of matches and mismatches is randomized, differences in background activity at the time the second word is presented cannot account for this enhancement. The time at which the enhancement begins is about

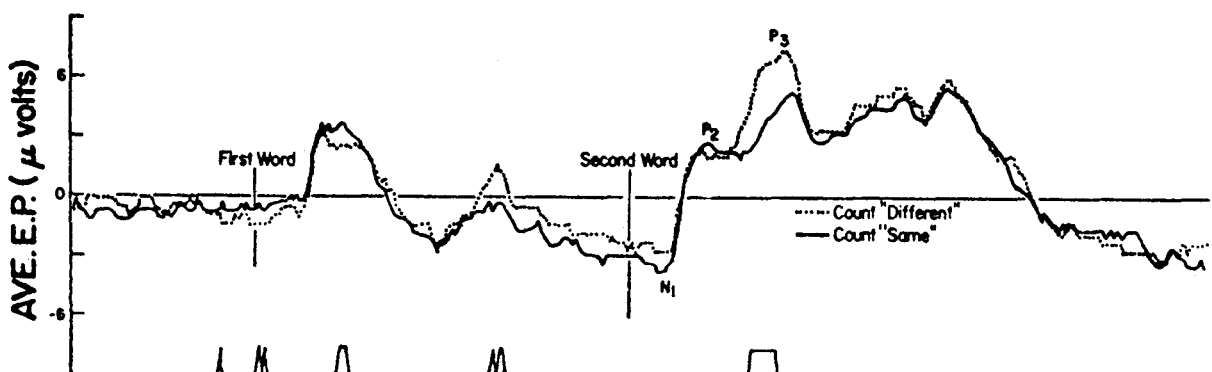


Fig. 9. Average evoked potential for mismatches when instructed to count "sames" or "differents." Excursions on the x-axis represent significant differences between conditions. The interval between words is 1,000 msec.

100 msec earlier for the matches than for the mismatches.

This result suggests to us that the evoked potential differences we have been discussing arise because when a stimulus matches a previous input, it starts to occupy the limited-capacity (conscious) mechanism at an earlier point. This point is about 200 msec following the occurrence of the input. About 100 msec later, this difference is reflected in the superiority in reaction time which matches have over mismatches for this kind of material (Posner & Boies, 1971).

Is the increase in the positive wave the cause of the change in reaction time or does the P_3 wave occur as the result of feedback from the response? In many situations, the positive wave occurs so late that it follows the overt response. In one study, however, a careful analysis of individual trials (Ritter, Simpson, & Vaughn, in press) suggests that elements of the P_3 complex can precede the response. In our study, we forced the S to delay overt responding by .5 sec following the second letter. Even if we had not done so, there is some reason to believe that the distinction between the matches and mismatches found in the electroencephalogram would precede overt behavior. In the most favorable of circumstances, the overt response to "same" takes from 300 to 350 msec, with only an occasional response occurring as early as 300 msec. The electroencephalogram effects appear to occur in the range from 200 to 300 msec and probably precede the overt response on a majority of trials. Thus, it seems fair to conclude that the electroencephalogram changes lead the overt changes and are not the result of them. This does not, of course, mean that the later reaction-time changes are a result of the earlier electroencephalogram change, but it does eliminate the reverse hypothesis.

OVERALL CONCLUSIONS

Alertness

Both alertness and set affect the rate at which a signal becomes available to a later processing mechanism. However, they do so in different ways. A warning signal does not affect the rate at which information builds up in the sensory-memory system. This conclusion follows from a number of different results. First, the ability of a letter to set the S for an oncoming stimulus does not vary as a function of the S's level of alertness at the time the letter occurs. Second, improvement in reaction time as a function of foreperiod is not accompanied by a decline in errors provided that the signal remains present during the reaction-time interval. In some tasks (see Fig. 3), there is an increase in error with foreperiod. This indicates that the information to which the S responds when alert is of no higher quality than that to which he responds when he is not alert. Third, errors when the S is highly alert are faster than correct reaction times, while this is not true at low levels of alertness. Fourth, reduced

alertness during vigilance tasks manifests itself in a decline in responses both to signals and to nonsignals as though the ability to respond has declined rather than the quality of information available (Broadbent, 1971).

These results lead to a rejection of the idea that alertness affects the basic sensitivity of sensory or memory units. One possible objection to this conclusion might be based on the role of alertness in producing changes in evoked potential. There have been reports of amplitude and latency changes in primary evoked potential at varying levels of alertness. However, since alertness is accompanied by desynchronization of the electroencephalogram, it would seem difficult to interpret changes in the evoked potential when it occurs against different backgrounds. Thus, it does not seem reasonable to dismiss the strong behavioral evidence on the role of alertness on the basis of evoked potential results.

There are many problems concerning the specific relation between buildup of information and responding which remain to be answered. In particular, it is difficult to know why some tasks produce flat error curves over warning intervals while others show clear increases in error. The view taken here relates this difference between tasks both to the rate of information buildup and to the minimum reaction time which one can obtain for the task. It will probably be necessary to achieve independent control over these factors before a more complete model is possible.

Set

On the other hand, we believe that the evoked potential components are meaningful when the level of alertness and thus the background electrical activity is held constant, as in our studies of set. In these experiments, the S cannot know whether the stimulus is a match until it occurs. Thus, the background is held constant. Nonetheless, there is a clear difference in the evoked potentials to matches and mismatches. The difference begins about 200 msec following the stimulus and continues for 100 msec. We proposed three theories concerning this shift. One of them supposes that the matching stimulus produces a smaller electrical output because of its recent activation. The second supposes that the mismatches receive more processing because of their novelty. The third supposes that the processing of a match is speeded in the sense that it reaches the limited-capacity mechanism more quickly. The third hypothesis led to specific predictions about the locus of the effect of instructions to count matches or mismatches, which were confirmed in Experiment IV. The other two views cannot be eliminated, however.

It should be borne in mind that the faster processing of the matches in the set paradigm must be different than that which occurs in alertness, since errors are reduced only with set. One reasonable hypothesis is to suppose that in the set paradigm, the buildup of the

information in the memory system about the second letter is affected by the prior stimulation of the first letter. Another possibility is that giving Ss the first letter allows the later mechanism not only to respond more quickly, but also to avoid competing tendencies which might lead to error. Unfortunately, none of our current work provides a clear answer to this problem.

Processing Capacity

There is a third component of attention for which the current results also have important implications. In a series of papers (Posner & Boies, 1971; Posner & Klein, 1973), we have tried to establish the relationship between nonmodality specific interference effects and the concept of conscious processing. The idea is that consciousness is identified with only those mental operations which require the use of a particular brain mechanism. This mechanism is of limited capacity such that any two signals which occupy it will tend to be processed less efficiently than when only one signal demands it. This mechanism serves to impose a serial order upon what are essentially widespread parallel processes initiated by a stimulus. Thus, interference between mental operations is used as a means of detecting the operation of the conscious processor. We have attempted to show the relationship between interference definitions of conscious processing and other intuitive functions of consciousness such as intention, awareness, and storage (Posner & Klein, 1973).

If our ideas of a specific brain mechanism related to conscious processing make sense, the current studies provide some techniques for its analysis. It seems likely that the mechanism whose activity we have been detecting by interference is also the one which releases the late positive wave (P_3). Some descriptions of P_3 in the literature fit with this idea (Goff, 1969; Hillyard, Squires, Bauer, & Lindsay, 1971; Sutton, 1969).

A fuller understanding of stimulus selection will probably require a study of the relationship of task interference and P_3 to alertness, on the one hand, and to set, on the other. Both alertness and set appear to be intimately related to the activity of the central processor, and such studies may help us understand why alertness acts to improve speed at the expense of accuracy while set improves both speed and accuracy.

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NOTE

1. There is reason to be somewhat cautious about the statistical analysis applied to these data. The exact confidence values of the Wilcoxon tests are dependent upon the existence of independent samples. Clearly, tests conducted at successive 6-msec intervals are not independent. Moreover, it would be difficult to determine how far apart tests would have to be to achieve independence. There appears to be little problem in Experiment III, because the data are sufficiently clean that very few significant differences occur outside the critical interval following the second letter. However, in Experiment IV there are

a fairly large number of significant differences found in the interval before the second word, even when the comparisons are from the same block so that these differences could occur only by chance. The problem is that once a single difference is found, there is an increased probability of further significant differences due to a lack of independence. None of the differences found outside the critical interval following the second letter approach the magnitude or consistency of those found in the critical

range. This is particularly true of the "match" evoked potentials where the effect of the instructions to count same holds for virtually every S. There is more doubt about the "mismatch" effects, but even there the tests which occur at P_3 show more and larger differences than any found outside this range.

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