

## Stimulus Processing During Eye Fixations

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A curious discrepancy exists between current estimates of the time needed to process simple visual stimuli (i.e., about 100-150 msec) and the average duration of the fixation between successive saccadic movements of the eyes (i.e., about 300 msec). Two hypotheses are proposed to account for this discrepancy as follows: (a) Saccadic suppression reduces the functional duration of the stimulus during an eye fixation by approximately 100-150 msec; and (b) previous estimates of stimulus processing time are misleading because of failure to incorporate higher level cognitive processes in the duration estimates. The saccadic suppression interpretation was rejected in Experiment 1 by the finding that all segments of the fixation were equally effective at mediating stimulus identification. The higher level processing interpretation was supported in Experiments 2 and 3 by the finding that a change in the fixated stimulus increased fixation duration (an index of higher level processing) at temporal intervals in which identification accuracy (an index of low-level processing) was asymptotic. This result was interpreted as indicating that higher level processing of a visual stimulus continues for 100-200 msec after it has been initially registered in the nervous system.

Although it is commonly assumed that the function of the pauses between saccadic movements of the eye is to allow visual stimuli to be processed, researchers have generally overlooked the discrepancy between existing estimates of stimulus processing time and the average duration of an eye fixation. Most estimates of stimulus processing time have been based on tachistoscopic experiments using a backward masking paradigm. A number of experimenters (e.g., Eriksen, Becker, & Hoffman, 1970; Eriksen & Collins, 1964; Eriksen & Eriksen, 1971; Liss, 1968; Spencer, 1969; Spencer & Shuntich, 1970) have reported that simple visual stimuli can be identified accurately if an interval of approximately 100-150 msec elapses between the presentation of the target stimulus and the presentation of a disrupting masking stimulus. With the as-

sumption that processing can only occur prior to the presentation of the mask, it can be inferred that stimulus processing requires about 100-150 msec. Typical fixation durations are at least two to four times greater than this, however, generally ranging from 200-400 msec.

It is possible that stimulus processing is not the only determinant of the duration of an eye fixation. For example, Salthouse and Ellis (1980) have recently concluded that a component labeled *minimum pause time* (i.e., the minimum time required to stop the eyes, recover from a past saccade, and prepare for a future saccade) was responsible for approximately 200 msec of the total fixation duration. A question remains, however, about what the visual processing system is doing in the 100-300 msec of the fixation duration that is not occupied by stimulus processing. From an evolutionary perspective it might seem unreasonable to suggest that the visual processing system is essentially idle for 50%-75% of the duration of an eye fixation, yet that seems to be the implication of the evidence currently available.

The interpretation that the visual processing system is unoccupied for one half to

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three fourths of the fixation time would also seem to lead to the possibility that visual processing rate could be dramatically increased by a method of stimulus presentation that would eliminate the need for saccadic eye movements. For example, reading speed might be doubled or tripled with a visual display system that presented successive segments of information in the same spatial location, rather than requiring the reader to move his or her eyes between each new information source. (Gilbert, 1959, has actually presented some evidence in support of this view, finding that word pairs presented sequentially every 167 msec were better identified when presented in the same spatial location than when presented in different positions, as in a normal printed sentence.) For practical reasons, if no other, therefore, it is important to investigate the causes for the apparent discrepancy between the 100-msec estimates of stimulus processing time and the 200- to 400-msec values of actual fixation duration.

At the present time there appear to be two plausible explanations that might account for this discrepancy. One possibility is that saccadic suppression reduces the functional duration of a fixated stimulus by suppressing perception prior to and following a saccadic eye movement. This interpretation suggests that fixations exceed the duration of stimulus processing in part because processing is not possible during periods at the beginning and the end of the fixation. Because the fixation durations are assumed to be limited by factors related to the movements of the eyes, the saccadic suppression explanation of fixation durations is consistent with the notion that visual processing rate could be increased by eliminating eye movements.

A second possibility is that the 100-msec stimulus processing estimate only represents the initial registration or detection phase of processing and that further (higher order) processing continues for an additional 100-300 msec. Since this explanation assumes that processing continues throughout the entire fixation duration, visual processing rate presumably could not be substantially increased by eliminating eye movements if this alternative were to be supported.

The three experiments discussed in this

article examine these two possibilities and lead to the conclusion that stimulus processing in one form or another occupies nearly the entire duration of a fixation.

### Experiment 1

Saccadic suppression or attenuation is a phenomenon in which the threshold for detecting brief low-intensity flashes of light is elevated for a period beginning as early as 40 msec before the onset of a saccadic eye movement and ending as late as 80-100 msec following the termination of a saccade (e.g., Latour, 1962; Volkman, 1976). If this phenomenon operates in normal viewing situations, one might infer that stimulus information is functionally unavailable for processing for the first 80-100 msec and the last 40 msec of an eye fixation. However, two characteristics of saccadic suppression experiments may limit the generalizability of these findings in normal viewing situations. First, the test flashes used as targets in saccadic suppression experiments are typically quite brief, ranging in duration from 50 microsec (e.g., Latour, 1962) to 5 or 10 msec (e.g., Chase & Kalil, 1972; Mitriani, Yakimoff, & Mateef, 1970). Second, the stimuli are generally at near-threshold levels of intensity (e.g., Beeler, 1967; Chase & Kalil, 1972; Latour, 1962; Starr, Angel, & Yeats, 1969).

The primary goal of this experiment was to determine whether visual attenuation is evident in fixations on targets of moderate duration and relatively high intensity. The procedure involved comparing the relative effectiveness of different segments of the fixation period in mediating the identification of alphabetic characters. An asterisk was briefly replaced by the target stimulus at various times before, during, and after the subject fixated in the target location. It was assumed that postsaccadic visual attenuation, if present, would be reflected in a reduced probability of correctly identifying visual targets presented shortly after the beginning of fixation. In a similar fashion any presaccadic attenuation should be evident as a reduced probability of target identification when targets are presented close to the end of fixation.

## Method

**Subjects.** Two subjects, aged 25 and 35 years, with normal or corrected-to-normal vision, participated in 5 practice and 30 experimental sessions of approximately 50 min. each.

**Apparatus.** A PDP 11/34 computer interfaced with a Narco-Biosystems Model 200 eye movement monitor was used to present stimuli and to record eye movements and keyboard responses. Stimuli, presented on a Mini-Bec cathode-ray tube (CRT), consisted of the uppercase alphabetic characters V and Y, each approximately  $.6^\circ \times .3^\circ$  of visual angle at a viewing distance of 46 cm. The target letters were easily visible, with a luminance of approximately  $.4 \text{ cd/m}^2$  on a background of  $.1 \text{ cd/m}^2$ .

A computer program identified the beginning of an eye movement as the point in time beyond which the right eye position differed by at least  $.2^\circ$  in the same direction on three consecutive samples spaced 10 msec apart. Similarly, beginning of fixation was identified when the right eye position differed less than  $.2^\circ$  on three consecutive samples. Neither a movement nor a fixation was identified if eye position differed by more than  $.2^\circ$  but less than  $.6^\circ$  for a period of 30 msec. Temporal relationships between eye movements and stimulus presentations were measured with 5-msec accuracy.

**Procedure.** Each experimental session consisted of 10 practice trials followed by four blocks of 50 trials each. Within a session the first and the last experimental blocks involved eye movements to the right, and the second and the third involved movements to the left.

The experimental task began with fixation on the word *READY*, located at the left or right of the CRT depending on the direction of movement. The subject continued to fixate while the ready signal was replaced with an asterisk displayed for 1 sec. The disappearance of the asterisk signaled the subject to initiate a  $10^\circ$  eye movement to the target location marked by another asterisk at center screen. After fixating as briefly as possible, regardless of the presence or absence of a target character, the subject moved  $10^\circ$  to a final asterisk at the opposite side of the display.

At some random time between the signal to begin the first eye movement and the final fixation, the center asterisk was replaced by one of two possible target characters. The target was displayed for 40 msec, and 40 msec after the target offset, another asterisk was presented to minimize iconic persistence. Thus, the asterisks were absent for a total of 80 msec—40 msec of target presentation followed by a 40-msec blank interval. The time of target presentation was rectangularly distributed within the range of 50–400 msec after the initiation of the trial. A target could therefore be presented before, during, or after fixation on the target location. Each trial was completed with a two-choice keyboard response indicating which of the target characters had been presented on that trial.

## Results

Approximately 95% of the trials were included in the analyses. Excluded trials were those in which the subject anticipated the

signal to begin the first saccade, failed to fixate on the target location, or made eye movements too short or too long, requiring additional eye movements to bring the target location into foveal vision.

Each trial included in the analyses was categorized according to the temporal relation between the beginning and end of the target fixation and the stimulus onset. Because there were no apparent differences related to direction of eye movement, all data reported are collapsed across direction. Data points in Figures 1, 2, and 3 are based on an average of 50–60 trials, with mean standard errors of slightly less than 7% for the percentage of correct data and approximately 40 msec for the fixation duration data.

Figure 1 illustrates the percentage of correct target identifications as a function of the delay between target onset and the beginning of eye fixation. The paradoxical finding that target identification is high during the 40 msec immediately preceding the beginning of fixation is probably attributable to the fact that the targets were 40 msec in duration (followed by a 40-msec blank interval). Hence a target whose onset was, for example, 20 msec prior to the beginning of the fixation would actually still be present for 20 msec after the saccade had ended, and an iconic representation might be available for an additional 40 msec.

The most important feature of the results displayed in Figure 1 is that little or no visual attenuation was apparent during or after the saccadic movement that moves the eyes to the target location. Under the present conditions, therefore, the point in time at which the ability to pick up visual information becomes greatest coincides closely with the beginning of the eye fixation.

Figure 2 illustrates the percentage of correct target identifications as a function of the interval between stimulus onset and the end of eye fixation. It is apparent that little or no presaccadic attenuation was evident during the final 100 msec of fixation for Subject 1. The data for Subject 2 might be interpreted as suggesting some attenuation; however, an alternative interpretation is that this subject simply had a higher duration threshold. That is, as targets are presented

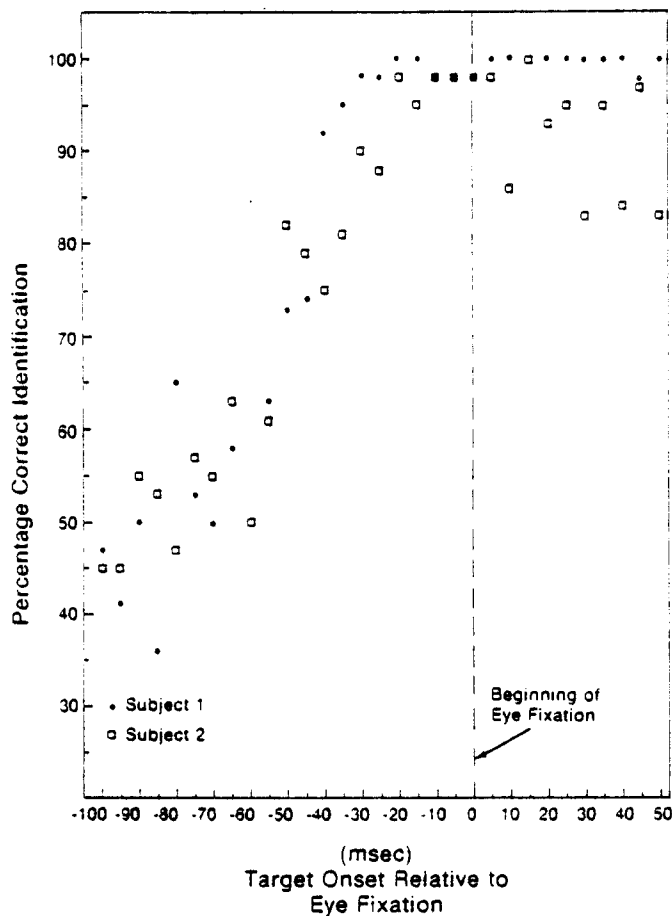


Figure 1. Percentage of correct target identifications as a function of the interval between the beginning of eye fixation and the onset of the stimulus, Experiment 1.

later in the fixation and closer to the next movement, the effective duration of the target decreases. This interpretation suggests that the exposure time required to identify a target was greater for Subject 2 than for Subject 1, and informal measurements of duration thresholds with tachistoscopic stimulus exposures confirmed this implication. It therefore seems reasonable to conclude that neither subject exhibited attenuation effects that can be unequivocally traced to saccadic suppression phenomena. Even if the results of Subject 2 were interpreted as a reflection of saccadic suppression, it is noteworthy that the effect occurred only at the end of the fixation and occupied less than 50 msec of the total duration of 300 msec. A considerable discrepancy between the estimates of stimulus processing time and ef-

fective fixation duration would therefore still exist, and some mechanism other than saccadic suppression would apparently be necessary to account for this remaining difference.

The relationship between fixation duration and the delay between the beginning of the fixation and the presentation of the target is shown in Figure 3. Notice that fixation durations increased in a roughly linear fashion, with delays up to approximately 170 msec, but then became increasingly variable and began to decrease.

#### Discussion

Taken together the data from Figures 1 and 2 suggest that under the conditions of this experiment, all segments of the fixation

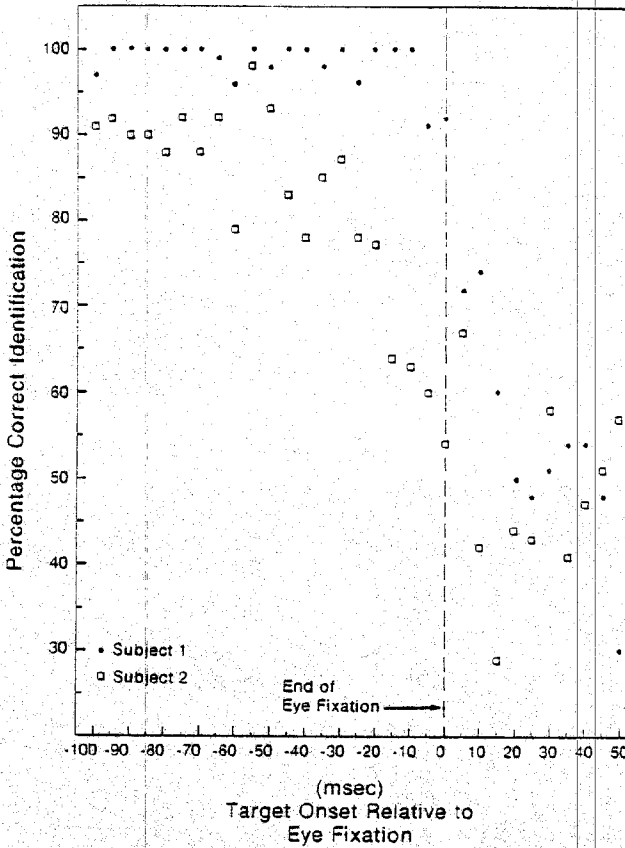


Figure 2. Percentage of correct target identifications as a function of the interval between the end of eye fixation and the onset of the stimulus, Experiment 1.

period are uniformly effective in mediating the registration of stimulus information. A target stimulus is apparently identified accurately whether it is presented in the first or last few milliseconds of a fixation or in the middle of the fixation. This finding suggests that saccadic suppression does not reduce the functional availability of a fixated stimulus in normal viewing and that stimulus processing can be initiated with equal effectiveness at all points throughout the fixation.

The fixation duration data of Figure 3 seem to suggest an increase with stimulus onset delay until about 170 msec. This increase is apparently an involuntary inhibitory phenomenon, since the subjects were instructed to fixate as briefly as possible and to attempt to "preprogram" their fixation durations by setting a maximum duration

for their fixation regardless of the presence or absence of the target. Neither subject reported being aware of a relation between fixation duration and stimulus onset delay while participating in the study.

#### Experiment 2

Potter (1975, 1976) recently presented evidence that visual stimuli may be subjected to at least two distinct types of processing. She reported that subjects could accurately detect the presence of a particular picture if a series of pictures were exposed for 100 msec each, but they required durations of approximately 400 msec each to achieve comparable accuracy in an immediate test of recognition memory. Potter's interpretation was that stimuli continue to be pro-

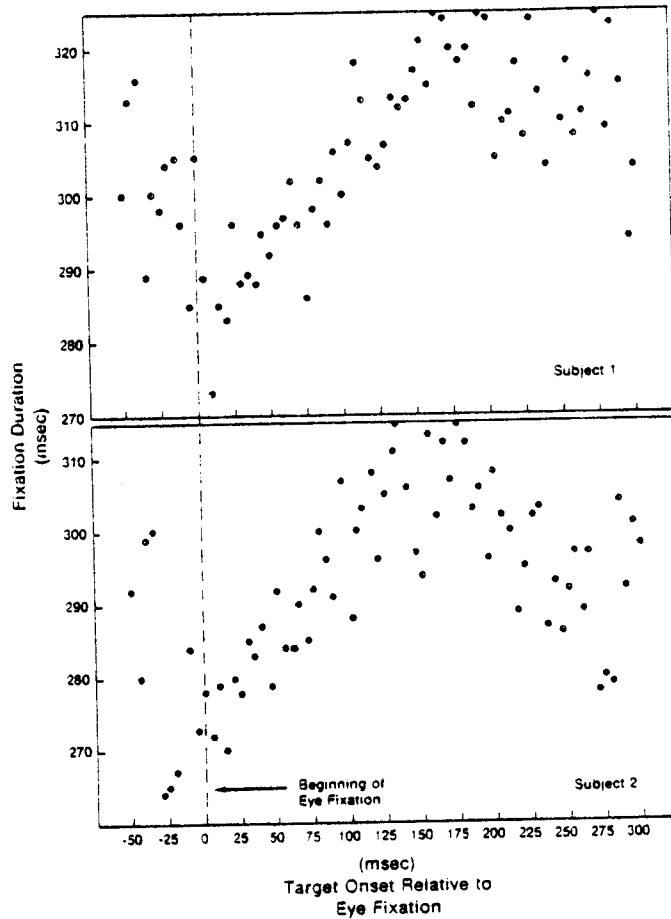


Figure 3. Fixation duration as a function of the delay between the beginning of eye fixation and the onset of the stimulus, Experiment 1.

cessed at a conceptual level after the initial visual detection or registration and that conceptual processing is necessary for subsequent recognition. In speculating about the relevance of her findings to eye fixations, Potter (1976) suggested, "The normal rate of eye fixations, three a second, represents a reasonable compromise between the need for rapid monitoring of the environment for significant events and the need to remember some portion of what one has seen" (p. 521).

The hypothesis that there is a higher level of processing after visual detection may account for fixation durations greatly exceeding the 100-msec estimates of visual processing, but thus far there is no evidence from eye movement studies to support such an interpretation. One of the problems with

obtaining evidence for multiple levels of processing concerns the availability of an index of higher level processing. Reaching a high, asymptotic level of accuracy can be interpreted as indicating that the initial visual processing has been completed. Once accuracy reaches an asymptotic level, however, it can no longer serve as an index of any higher level processing. A second dependent variable is necessary, therefore, to obtain evidence of processing that extends beyond the initial visual level.

The trend in the previous experiment for fixation duration to increase after decision accuracy had reached an asymptote (cf. Figure 3) led to the possibility that these two measures might provide suitable dependent variables for exploring multiple levels of pro-

cessing. Identification accuracy could be used to measure the lowest level of processing, and the delay in fixation duration could serve as a measure of later processing levels.

The task for the subjects in the present experiment was to move their eyes to a target location where one of two possible stimuli (i.e., < or >) was located. If a < was presented, the subjects were to move their eyes to the left, and if a > was presented, they were to move them to the right. At a randomly selected interval after the presentation of the first stimulus, a second stimulus appeared in the same spatial location as the first. On half of the trials, the second stimulus was the same as the first stimulus, and on the other half of the trials, the second stimulus was a different stimulus. Subjects were always instructed to respond to the first stimulus that they perceived.

Initial visual processing was indexed by the probability of responding to the first stimulus as a function of interstimulus interval, in the same manner that tachistoscopic masking experiments use the probability of correct stimulus identification as a reflection of stimulus processing. A measure of higher level processing was obtained by examining fixation duration at interstimulus intervals in which the probability of first stimulus responding has reached an asymptote. It was assumed, on the basis of the pattern exhibited in Figure 3, that a second stimulus arriving while a first stimulus was being processed would temporarily interfere with the processing and cause a lengthening of the fixation duration. The period of increased fixation duration might thereby provide an estimate of the time course of higher level processing that extends beyond the initial registration of the stimulus.

### Method

**Subjects.** Six subjects, aged 23 to 36 years, with normal or corrected-to-normal vision participated in four practice and four experimental sessions of approximately 30 min. each. None of the subjects participated in the previous experiment, but two subjects had extensive experience (i.e., over 50 hours) in other eye movement studies.

**Apparatus.** The equipment was the same as that described in Experiment 1. The stimuli were the characters < and >, each approximately  $6^\circ \times .3^\circ$  of visual angle and  $.4 \text{ cd/m}^2$  on a background of  $.1 \text{ cd/m}^2$ .

The computer program for identifying eye movements was modified to allow stimuli presentation to be contingent on the detection of an eye movement. The altered program detected a movement when the right eye position differed by  $1^\circ$  in the same direction on five consecutive samples separated by 1 msec each. Fixations were identified as occurring if the right eye position differed by less than  $.1^\circ$  on five consecutive 1-msec samples. Examination of tape-recorded data revealed that this new movement analysis routine yielded movement and fixation points nearly identical to those of the previous routine.

**Procedure.** An experimental session consisted of six blocks of 50 trials each. Subjects had the option of taking a short break after any of the blocks.

A trial began with subjects fixating on the word READY, located at the left edge of the CRT. An asterisk followed the ready signal, and when it disappeared the subjects moved their eyes to an asterisk located  $6^\circ$  to the right, in center screen. As soon as a movement was detected, the center asterisk was replaced with the target stimulus and additional asterisks were displayed  $6^\circ$  to the left and right of the target. At one of six randomly selected intervals (i.e., 25, 75, 125, 175, 225, and 275 msec), the first target stimulus was replaced by a second target stimulus. The possible stimuli, < and >, were equally likely, so the probability that the first and second target stimuli were identical was equal to the probability that the two stimuli were different, that is, .5. Target substitution was so rapid that the stimuli appeared continuous when a target was replaced by itself.

The subjects were instructed to move their eyes in the direction indicated by the first perceived target stimulus. That is, they were to move their eyes back to the left asterisk when a < was present and to the right asterisk when a > was present. The second target stimulus was replaced by an asterisk as soon as a movement from the target location was detected.

An editing segment was added to the computer program to reject trials with inappropriate eye movement patterns while the subject was performing in a block of trials. An experimental block therefore consisted of 50 trials with acceptable movement patterns, regardless of the number of additional unacceptable trials.

### Results and Discussion

The percentages of eye movement responses to the first stimulus as a function of the interstimulus interval between the first and second stimuli are displayed in Figure 4. The functions for trials in which the second stimulus was different from the first stimulus closely resemble visual masking functions, in that the first stimulus apparently was not perceived at a 25-msec interval, but was perceived nearly perfectly with interstimulus intervals greater than 125 msec. Following the reasoning of visual masking studies, the functions of Figure 4 can be interpreted as indicating that the initial reg-

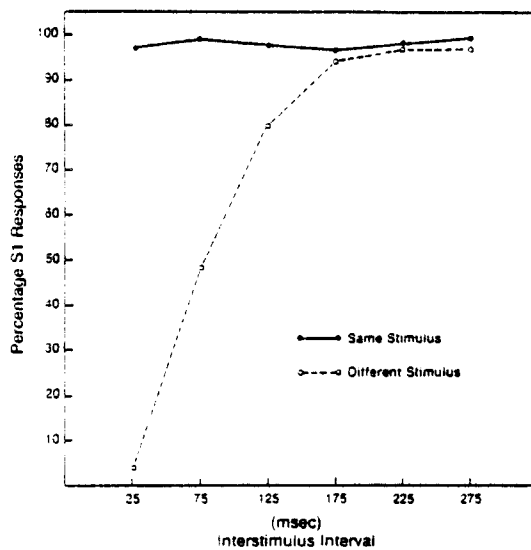


Figure 4. Percentage of responses to the first stimulus for same-stimulus and different-stimulus trials as a function of interstimulus interval, Experiment 2. (Each data point is based on approximately 600 observations.)

istration phase of stimulus processing is completed within 125–175 msec.

Average fixation duration for trials in which the first and second stimuli were the same and for trials in which they were different are plotted as a function of interstimulus interval in Figure 5. Fixation duration was roughly constant across all interstimulus intervals when the first stimulus was replaced with an identical second stimulus, but it was substantially greater at most interstimulus intervals when the first stimulus was replaced with a different second stimulus. These results were statistically evaluated with an analysis of variance on the mean fixation durations for each subject. The trial type,  $F(1, 5) = 14.15$ ,  $p < .05$ ,  $MS_e = 1.686.66$ , interstimulus interval,  $F(5, 25) = 3.43$ ,  $p < .05$ ,  $MS_e = 191.65$ , and Trial Type  $\times$  Interstimulus Interval interaction,  $F(5, 25) = 7.15$ ,  $p < .01$ ,  $MS_e = 172.35$ , effects were all significant in this analysis. The longer fixation durations when the first and second stimuli were different, compared to when they were the same, is consistent with the hypothesis that a different second stimulus disrupts or inhibits some aspect of stimulus processing. The discovery that this processing disruption occurs at interstimulus

intervals beyond those in which the percentage of first stimulus responses has reached an asymptote (i.e., 125 msec–275 msec) suggests that the stimulus processing indexed by this measure is not the same type of processing reflected in the percentage of first stimulus responses. Figure 5 also indicates that the time course of this second-level processing is generally between 75 msec and 225 msec after the beginning of the eye fixation, as the disruption is minimal with the 25-msec and 275-msec delays.

These results suggest an explanation for the fixation duration results from the previous experiment. A trial in Experiment 1 consisted of the subjects moving their eyes to an asterisk that was replaced by one of two target characters at some randomly determined interval. The trials were therefore analogous to the different stimulus trials of Experiment 2, albeit with some potentially important differences. (E.g., in Experiment 2 stimuli were not followed by a blank period and hence were susceptible to backward masking, both first and second stimuli were informative rather than just the first stimulus, and processing had to be completed before the next saccadic movement could be initiated.) Comparison of Figures 3 and 5 indicates that very similar inhibition trends are evident in the two experiments. In both

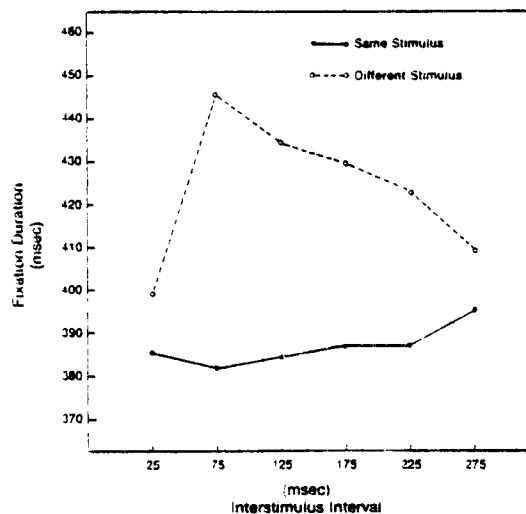


Figure 5. Fixation duration for same-stimulus and different-stimulus trials as a function of interstimulus interval, Experiment 2. (Each data point is based on approximately 600 observations.)



sets of data, the increase in fixation duration occurred between about 25 msec and 225 msec, with a maximal inhibition of approximately 40–60 msec. It therefore seems likely that the results of Figure 3 are attributable to the same type of processing disruption responsible for the increased fixation durations for different stimulus trials illustrated in Figure 5.

A similar interpretation might account for the relationship between fixation duration and stimulus onset delay reported by Vaughan and Graefe (1977). These investigators changed the fixation stimulus from a point to either an X or an O at intervals of 0–150 msec after the beginning of the fixation. They found that fixation duration increased from 371 msec at a 0-msec stimulus onset delay to 415 msec at a 150-msec delay. As with the current data, the disruption was at a maximum of approximately 40 msec at an interstimulus interval of 150 msec. These consistencies suggest that a common mechanism is responsible for all of these effects.

### Experiment 3

A third experiment was designed to investigate two additional issues. One issue concerns the component of stimulus processing that is influenced by task complexity. Movement decisions in this experiment were determined by an odd/even digit classification that was considered more complex than the directional arrow decision of Experiment 2. If this greater complexity influences the initial registration phase of processing, the function relating the percentage of first stimulus responses to the interstimulus interval should be shifted to longer interstimulus intervals relative to Experiment 2. If the increased complexity affects a later phase of processing, however, the shift attributable to the more complex task should be apparent in the function relating the interstimulus interval to the fixation duration on changed stimulus trials.

The second issue investigated in this experiment concerned whether the processing disruption reflected by the increased fixation duration was primarily a stimulus or a response phenomenon. In the previous exper-

iment there were only two stimuli and two responses, and thus a change in the stimulus necessarily indicated a change in the response. The disruption could have been the result, therefore, of a response-competition mechanism because the second stimulus always indicated the opposite response, or it could have resulted simply because the presence of any nonidentical second stimulus interfered with the processing of the first stimulus. By increasing the number of stimuli to 10 and keeping the number of responses fixed at two, Experiment 3 allows a change in stimulus to be examined independently of a change in response. For example, the first stimulus could be one odd digit (e.g., a 3) and the second stimulus a different odd digit (e.g., a 5), and yet the same response (i.e., moving the eyes to the left asterisk) would be indicated by both stimuli. Three types of trials can therefore be compared in this experiment: (a) the first and second stimuli can be identical; (b) the first and second stimuli can be different but from the same response category; and (c) the first and second stimuli can be different and from different response categories. Same-stimulus trials and different-stimulus-different-response trials are expected to yield functions similar to those of comparable trials from Experiment 2. The interesting question is whether the different-stimulus-same-response trials will be similar in performance to the different-stimulus-different-response trials (signifying that the disruption phenomenon is attributable to a change in stimulus) or to the same-stimulus trials (indicating that disruption occurs because of a change in the appropriate response, not just a change in the stimulus).

### Method

*Subjects.* The same subjects from Experiment 2 participated in the four experimental sessions of this experiment in a counterbalanced sequence with the four sessions of Experiment 2. Two of the practice sessions mentioned in the description of Experiment 2 were devoted to the conditions of the present experiment. This arrangement of sessions allowed the results of this experiment to be compared directly with those from the previous experiment, since there was no confound of experiment with amount of prior practice.

*Apparatus.* The apparatus was the same as that described in the previous experiments.

*Procedure.* The procedure was similar to that of Experiment 2, except for a change in the stimuli and

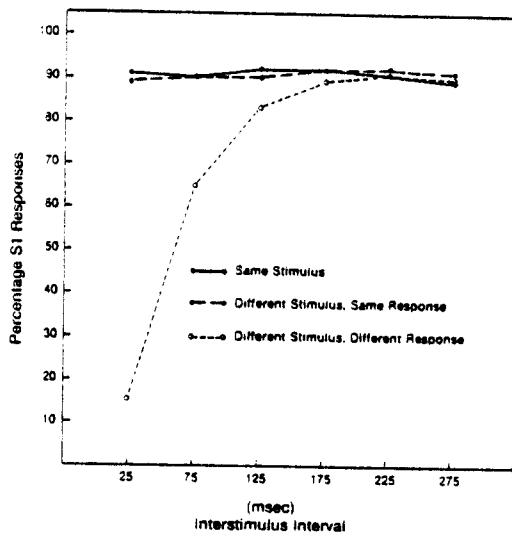


Figure 6. Percentage of responses to the first stimulus for the three trial types as a function of interstimulus interval, Experiment 3. (Approximately 600 observations are represented per data point for different-stimulus-different-response trials, 480 observations per data point for different-stimulus-same-response trials, and 120 observations per data point for same-stimulus trials.)

the movement decision rules. The digits 0-9 were equally likely as the first and second stimuli, and subjects were instructed to move their eyes to the left asterisk if an odd digit (i.e., 1, 3, 5, 7, or 9) was presented and to move their eyes to the right asterisk if an even digit (i.e., 0, 2, 4, 6, or 8) was presented. Because the stimuli were equally likely, 10% of the trials had identical first and second stimuli, 40% of the trials had different stimuli from the same response class (i.e., both odd or both even), and 50% of the trials had one odd and one even stimulus with conflicting responses indicated by the two stimuli.

### Results and Discussion

The percentages of first stimulus responses in the three types of trials are displayed in Figure 6. Notice that the masking functions for the different-stimulus-different-response trials are very similar to the functions from Figure 3. This indicates that the complexity of the decision task did not affect the initial registration phase of processing.

The fixation duration data are plotted in Figure 7. An analysis of variance on the mean fixation durations indicated that both main effects and the interaction were significant: for trial type,  $F(2, 10) = 37.68$ ,  $p < .01$ ,  $MS_e = 208.75$ ; for interstimulus

interval,  $F(5, 25) = 2.83$ ,  $p < .05$ ,  $MS_e = 240.96$ ; and for Trial Type  $\times$  Interstimulus Interval,  $F(10, 50) = 3.06$ ,  $p < .01$ ,  $MS_e = 267.99$ .

The first thing to be noted about these data is that the average durations were from 60 msec to 100 msec longer than those from Experiment 2 (cf. Figure 5). The greater complexity of the present task was thus reflected in the increased fixation durations. The second important aspect of these data is that unlike the previous results, they show no clear trend toward a reduction in the inhibition effect with increased interstimulus interval.

The data of Figure 7 allow conclusions to be drawn with respect to the two issues of primary concern in this experiment. First, average fixation durations were considerably longer than those observed in the simpler task from Experiment 2, and the time course of the disruption phenomenon was shifted to longer interstimulus intervals. These findings, in conjunction with the remarkable similarity in the masking functions (cf. Figures 4 and 6), indicate that task complexity exerts its influence on a second, higher order level of processing. Second, the patterns por-

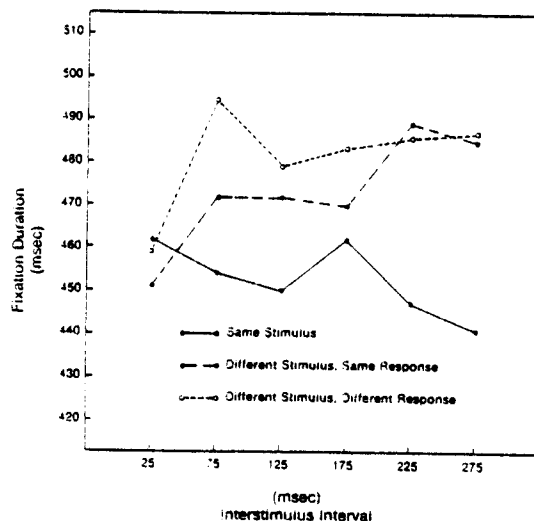


Figure 7. Fixation duration for the three trial types as a function of interstimulus interval, Experiment 3. (Approximately 500 observations are represented per data point for different-stimulus-different-response trials, 480 observations per data point for different-stimulus-same-response trials, and 120 observations per data point for same-stimulus trials.)

trayed in Figure 7 indicate that changing the stimulus caused a delay in the fixation regardless of the nature of the required response. This result suggests that the phenomenon is primarily caused by a disruption of stimulus processing and is not merely a reflection of competition between conflicting responses.

### General Discussion

This research was aimed at distinguishing between two plausible explanations for the discrepancy in the duration of eye fixations (i.e., about 200–400 msec) and the estimated duration of stimulus processing (i.e., about 100–150 msec). One possibility was that saccadic suppression reduces the effective duration of an eye fixation by limiting the time that the fixated stimulus is available for processing. This hypothesis was rejected in Experiment 1 on the basis of the following results: (a) Only one of the two subjects exhibited any indication of reduced visibility during the fixation; (b) the perceptual attenuation was only presaccadic, rather than both presaccadic and postsaccadic, as would have been predicted; and (c) the total duration of this attenuation was only 25% of the time discrepancy between the average fixation duration and estimates of stimulus processing time. Perhaps because the stimuli in these studies were of higher energy (i.e., exposed longer and at greater intensity) than those of previous saccadic suppression experiments, there was no clear evidence of visual attenuation either before or after the saccadic movements. The conclusion from the first experiment, therefore, was that saccadic suppression is probably not an important factor contributing to the duration of eye fixations in normal viewing situations.

The second hypothesis to account for the discrepancy between the average duration of a fixation and the estimates of stimulus processing time was based on the assumption that some form of stimulus processing continues beyond the initial registration phase. Experiment 2 supported this hypothesis with the finding that fixation duration was increased at periods in the fixation after which the probability of a particular response had reached an asymptotic level. The response

probability variable was assumed to be an index of the initial registration phase of stimulus processing, and the fixation duration variable was assumed to reflect a second, higher level type of stimulus processing. Additional support for this interpretation was provided in Experiment 3, in which an increase in the complexity of the decision required during the fixation did not affect the time course of the response probability variable indexing the registration phase of processing, but did extend the time course of the fixation duration increase that indexed the higher level of stimulus processing.

It is tempting to think of the two levels of processing in terms of successive stages concerned with registration and what might be termed comprehension (i.e., identification and interpretation). Given this stage concept the present data allow two further implications to be drawn. The first is that both stages seem to be influenced by the visual properties of the stimulus, since a change in the external stimulus affects measures reflecting the operation of both inferred stages. That is, both the percentage of Stimulus 1 responses function (cf. Figures 4 and 6) and the fixation duration function (cf. Figures 5 and 7) exhibit differences when the first and second stimuli are different, compared to when they are the same. Considerably more research is needed before this conclusion can be fully accepted, but it is particularly interesting because it may serve to explain the heretofore anomalous result that the quality of the visual stimulus appears to influence the same processing stage as the factor of semantic priming (i.e., Meyer, Schvaneveldt, & Ruddy, 1975).

The second implication about the hypothesized stages is that they do not appear to be organized in a strict discrete succession in which second stage processing does not begin until first stage processing has been fully completed. The evidence for this assertion is based on the apparent independence of the times to complete Stage 1 and to begin Stage 2. In both Experiments 2 and 3, the probability of a response to the first stimulus (reflecting the operation of the registration stage) did not reach an asymptotic level until 125–175 msec, yet the increase in fixation duration (signifying the operation

of the comprehension stage) was evident between 75 msec and 125 msec. The fact that the time of onset of the second stage does not correspond in a simple fashion to the time of completion of the first stage suggests that processing is not organized in a strict serial sequence with only one stage in operation at any time. Although specific details have not been worked out, an interpretation of processing as a continuous flow or cascade in which information is processed in all stages as soon as it becomes available (e.g., Eriksen & Schultz, 1979; McClelland, 1979) may be able to account for the present results, particularly if it is assumed that task complexity influences the rate of processing in the second stage.

It should perhaps be pointed out that the eye movement task in Experiments 2 and 3 was somewhat unusual, in that the direction of the following movement was determined by the stimulus in the current fixation. The subject was therefore required to process the stimulus completely during the fixation in which it was presented. Though it might be assumed that processing generally does take place during the current fixation in natural viewing situations, it is quite possible that processing could continue beyond the fixation in which the information was obtained. Indeed, the results from Experiment 1, in which identification accuracy was quite high even when the stimulus was presented in the last 50 msec or so of the fixation (cf. Figure 2), strongly suggest that processing can continue after the fixation, since it is unlikely that processing could be completed in such a brief interval.

Davidson, Fox, and Dick (1973) have also reported that stimulus letters presented within the last 70 msec of an eye fixation are generally identified accurately. A further result by Davidson et al., however, indicates that there must be a maximum limit on the interval in which processing can lag behind the fixated stimulus. These authors found that a stimulus presented during the second fixation had a masking effect, that is, lowered the identification accuracy, on the stimulus letter that occupied the same retinal location in the previous fixation. This suggests that the processing of one stimulus might be delayed up to the point that a sec-

ond stimulus, which would mask the first stimulus, begins to be processed. In other words, processing of the stimulus in Fixation 1 might continue during the eye movement between Fixation 1 and Fixation 2, but it is unlikely that it could continue after processing begins on the stimulus in Fixation 2.

Because the earlier estimates of stimulus processing time seem to be somewhat misleading in accounting for only low-level peripheral processing, it now appears that there is very little discrepancy between estimates of total processing time and average fixation duration. Gilbert's (1959) report that sentences were better identified without the necessity of saccadic movements is thus called into question. One possible explanation for his finding that identification was poorer when saccadic eye movements were required is that subjects simply could not make sequential movements of the eye in the 167-msec interval between stimuli. Salthouse and Ellis (1980) have shown that the minimum pause time of the eye between saccadic movements is approximately 200 msec. Subjects in Gilbert's (1959) experiment may therefore have made eye movements to a stimulus that was no longer present and, as a consequence, were forced to base their identifications on parafoveal or peripheral recognition processes, rather than foveal ones. It is noteworthy that the difference between the same-location and different-location presentation conditions was greatly reduced when the time between successive word pairs was increased to 250 msec, thus allowing subjects to fixate directly on each word pair. A practical implication of the present results and this interpretation of Gilbert's results, therefore, is that the tantalizing idea that rate of visual processing could be substantially increased by eliminating eye movements between successive presentations of information is probably not feasible.

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