

## Implications of a Transient-Sustained Dichotomy for the Measurement of Human Performance

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Recent evidence suggests that the human visual system has two components: a sustained system that will respond to static contrasts and a transient system that will only respond to rapid changes over time. The present article provides further support for a transient-sustained dichotomy of visual information processing by examining the effects of abrupt changes in visual stimulation in a variety of situations. Several experiments are reported in which stimuli are presented both with and without abrupt onsets. The results of these experiments, together with other evidence, suggest that the overall effects of abrupt changes in visual stimulation may be more extensive than has previously been suspected.

William James (1950) once noted that the perception of movement is the most delicate of all our senses:

movement is the quality by which animals most easily attract each other's attention. The instinct of "shamming death" is no shamming of death at all, but rather a paralysis through fear, which saves the insect, crustacean, or other creature from being noticed at all by his enemy. It is paralleled in the human race by the breath-holding stillness of the boy playing "I spy" to whom the seeker is near; and its obverse side is shown in our involuntary waving of arms, jumping up and down, and so forth, when we wish to attract someone's attention at a distance. (pp. 173-174)

As was observed by William James almost a century ago, an object that is rapidly undergoing change is somehow more perceptually salient than an object that is stationary. Indeed, there is a growing amount of evidence that change and nonchange are distinct psychological entities for which our visual systems have evolved separate processing mechanisms.

In the area of electrophysiology, for example, it is generally acknowledged that there are at least two classes of retinal gan-

glion cells that have been observed in a variety of mammalian species (e.g., cats and monkeys). One group of neurons, called Y-cells (Enroth-Cugell & Robson, 1966) or transient cells (Cleland, Dubin & Levick, 1971), will only respond to abrupt changes in visual stimulation, such as onset, offset, or movement. These neurons are equally distributed at all portions of the retina (Fukuda & Stone, 1974), and they have fast conduction velocities (Stone & Fukuda, 1974), so that abrupt changes can be quickly detected regardless of their location within the visual field. Stationary objects cannot stimulate the transient cells, but must instead be detected by a second class of neurons, called X-cells (Enroth-Cugell & Robson, 1966) or sustained cells (Cleland et al., 1971), which have slow conduction velocities (Stone & Fukuda, 1974) and are heavily concentrated in the fovea (Fukuda & Stone, 1974).

Although it is not possible to compare single cells in humans, there is considerable evidence that transient and sustained cells may also exist within the human visual system. With selective adaptation procedures, it can be demonstrated that the visual system is composed of many independent channels, each maximally sensitive to a fairly

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narrow range of spatial frequencies (Blake-more & Campbell, 1969). These channels can be subdivided into two classes—transient and sustained—whose properties relate closely to the visually responsive neurons in the cat retina. The transient channels have rapid response latencies (Breitmeyer, 1975; Tolhurst, 1975). They are especially sensitive to low spatial frequencies (less than three cycles per degree) and will only respond to movement (Tolhurst, 1973), flicker (Kulikowski & Tolhurst, 1973), or the abrupt onset of stimulation (Breitmeyer & Julesz, 1975; Tolhurst, 1975). The sustained channels have longer response latencies (Breitmeyer, 1975; Tolhurst, 1975). They are most sensitive to high spatial frequencies and are effectively stimulated by visual displays that do not change over time (Kulikowski & Tolhurst, 1973).

There have been a number of attempts in recent years to incorporate a transient-sustained dichotomy into theories of visual information processing (e.g. Breitmeyer & Ganz, 1976; Weisstein, Ozog, & Szoc, 1975). The most common argument is that the visual system is composed of two semi-independent subsystems: a transient system that orients an organism and directs its attention to locations in visual space and a sustained system that is highly specialized for the analysis of pattern information. More recent evidence suggests, however, that the perceptual effects of movement or other types of abrupt change may be more extensive than originally suspected. There have been several demonstrations that objects can be correctly identified solely on the basis of their patterns of movement (Bassili, 1978; Cutting, Proffitt, & Kozlowski, 1978; Johansson, 1973, 1975; Kozlowski & Cutting, 1977). There are also reports in the clinical literature of patients who are blind to stationary objects but can easily identify the same objects under dynamic transformation (Botez, 1975). This latter finding provides especially strong evidence that there is an isolable component of the visual system that is exclusively sensitive to dynamic aspects of visual stimulation and is sufficiently powerful for object identification.

### *Onset and No-Onset Stimuli*

A transient-sustained dichotomy of visual information processing could have important implications for any experiment in which observers must respond to visually presented materials. Consider, for example, a typical experimental procedure. An observer is required to stare at a fixation point in the center of an otherwise blank display screen. Following a brief interval, a new stimulus appears suddenly, and the observer must initiate a correct response as quickly as possible. This type of *onset presentation procedure* is usually taken for granted by most psychological researchers. However, if the visual system contains a specialized processing structure that is specifically sensitive to transient inputs, is it not possible that abrupt changes in visual stimulation could significantly alter the processing strategies by which a given activity is performed? If so, then results obtained using onset presentation procedures may not always be generalizable to other situations outside the laboratory.

The obvious solution to this problem is to design a presentation procedure that does not involve abrupt change, such as presenting stimuli with gradual onsets (Breitmeyer & Julesz, 1975; Tolhurst, 1975). The problem with this approach is in interpreting reaction time data. Response latencies can be measured from any point within the gradual period of onset (Tolhurst, 1975), but in no case are they directly comparable to the reaction time data for stimulus presentations whose period of onset is effectively instantaneous. This problem can be avoided by adopting a less obvious technique called the *no-onset presentation procedure*. At the beginning of each trial, all possible stimulus alternatives are displayed simultaneously, and following a brief interval, a single stimulus is presented in isolation by the instantaneous removal of all other items. This latter technique for presenting stimuli has two essential properties. The timing on each trial is well specified by abrupt transitions in the overall structure of the display, yet there is no change in the one stimulus alternative to which the subject must respond.

In the experiments described below, the relative effects of onset and no-onset presentation procedures are examined in a variety of experimental tasks. The goal of this research is to examine the significance of abrupt changes in visual stimulation in experimental situations that do not involve masking.

### Experiment 1

Experiment 1 is designed to demonstrate that onset and no-onset stimuli have different effects on performance that are analogous to the known differences between transient and sustained retinal ganglion cells. It is generally acknowledged that transient neurons have fast conduction velocities and are equally distributed across the retina, whereas sustained neurons have slow conduction velocities and are heavily concentrated in the fovea. Thus, it is hypothesized that two effects should be evident when onset stimuli are replaced by no-onset stimuli in a reaction time experiment. Response latencies should increase, and the relationship between reaction time and the angular displacement of a stimulus should be significantly altered.

Eye movement reaction time is used as the response measure for testing these hypotheses. Moving the eyes toward an abruptly presented stimulus is a highly compatible act, frequently studied by experimental psychologists. Of particular interest are a number of studies on the relationship between reaction time and the angular displacement of a target. In general, it has been reported that the latency of a saccade increases with target displacement (Bartz, 1962; White, Eason, & Bartlett, 1962), but the increase is usually negligible within the range of  $5^{\circ}$ – $20^{\circ}$  (Bartz, 1962; Becker, 1972; Cohen & Ross, 1977; Miller, 1969; White et al. 1962). Another issue that has appeared in the literature concerns whether or not the latency of a saccade is significantly affected by stimulus/response uncertainty. Some investigators have reported that the difference between simple and choice reaction time is significant (Hackman, 1940; Ohtani, 1968), and others have reported that it is not sig-

nificant (Miller, 1969; Saslow, 1967). In either case, there is generally no additional increase in reaction time when the number of target alternatives is increased above 2 (Megaw & Armstrong, 1973; Ohtani, 1968; Saslow, 1962), provided that direction uncertainty is held constant and the subject is not required to make some other response in addition to an eye movement (e.g., Leushina, 1965). This high degree of stimulus/response compatibility is also revealed by Becker's (1972) finding that the accuracy of a saccade is not related to its initial latency. Experiment 1 extends these findings by comparing eye movement response latencies to both onset and no-onset stimuli.

### Method

*Apparatus.* Stimuli were presented on a Tektronix 602 cathode ray tube (CRT) display, refreshed every 5 msec by a Nova minicomputer via a stroke generator, which drew lines on the face of the CRT (Van Gelder, 1972). A fast P15 phosphor insured the rapid onset and offset of all displays (luminance decay to .1% in 50  $\mu$ sec). The displays were viewed binocularly at a distance of 11 in. (27.94 cm) from a  $3.25 \times 4.25$  in. ( $8.26 \times 10.80$  cm) display screen. Head movements were restricted through the use of a Tektronix viewing hood.

The horizontal eye movement response was measured by placing a Beckman skin electrode at the outer margin of each eye. The difference between the two voltages, alternating current coupled and amplified, gave a positive voltage excursion for movement in one direction and negative voltage excursion for movement in the opposite direction. The signal was sent to an analog-to-digital converter, which the computer sampled every millisecond, starting with target display onset.

The criterion for initiation of a saccade was the beginning of a period of 16 successive monotonic samples, in which the last sample differed from the first by a predetermined minimum voltage. Completion of a saccade was taken as the first non-monotonic sample. In preliminary testing all samples were typed out to compare the computer's decision with manual analysis. This conjunctive decision rule (monotonicity and criterion voltage difference) was found to accurately separate signal from noise. No false positives were seen, although an occasional small saccade was missed.

In an adjacent room with the computer and teletype were an oscilloscope to monitor the eye movement waveforms, and a duplicate CRT display to monitor each stimulus presentation. Summary statistics were typed after each block of trials, and all raw data were punched for later analysis.

*Procedure.* Subjects were instructed to maintain a steady gaze toward a fixation triangle at the center of the CRT display. For onset presentations, the fixation triangle appeared by itself. After a short countdown to eliminate time uncertainty, the fixation triangle was turned off and a small target stimulus appeared suddenly at a randomly selected location. For no-onset presentations, the fixation triangle appeared together with all possible target alternatives. After a short countdown, everything was turned off, with the exception of the single target stimulus. In either case, the target stimulus was a small cross, whose diameter was .5° of visual angle. Subjects were told to look at the cross (by moving their eyes) as quickly as possible.

To prevent anticipations, the experiment was programmed so that catch trials occurred with a 20% probability. For catch trials, the fixation triangle remained on following the countdown, and no target stimulus was presented. Subjects were instructed to remain fixated whenever this occurred.

Immediately following their response (or lack of response), subjects were given immediate feed-

back about their performance. If they made a correct response, their reaction time in milliseconds was flashed on the screen for 1 sec. To improve performance, the feedback message included the word *slow* whenever a response latency was slower than 300 msec. If a subject made an incorrect response, the reaction time for that trial was not recorded and the feedback message included a short error statement. All errors were differentiated into three types: movement errors, anticipation errors, and response errors. A movement error was recorded whenever the computer failed to detect an eye movement within 500 msec from the beginning of a target presentation. The feedback message for these errors was the word *move* presented by itself. For any trial in which the reaction time was faster than 80 msec, it was assumed that the subject had anticipated and an anticipation error was recorded. The feedback message consisted of the reaction time together with the word *wait*. Response errors occurred on those trials in which the eyes were moved in the opposite direction of the target. The feedback message for these errors was the word *wrong* presented by itself.

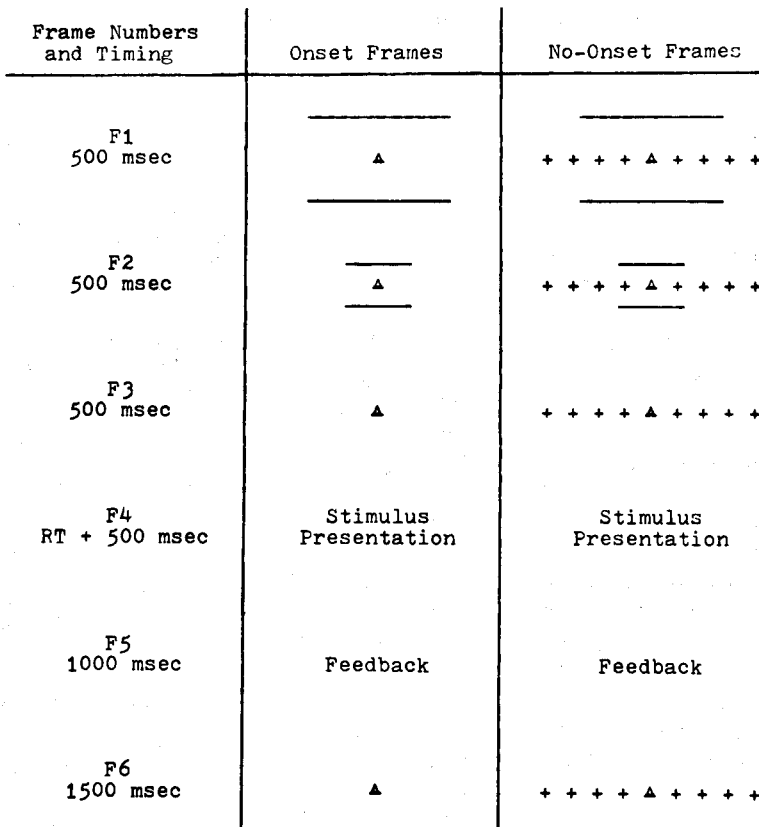


Figure 1. A typical sequence of successive frames for both the onset and no-onset presentation procedures.

Table 1  
Number of Trials per Block for Each Condition of Experiment 1

Condition	Angular displacement				Catch trials	Presentation procedure	Blocks per session
	2.5°	5.0°	7.5°	10°			
A	6	6	6	6	6	Onset	4
B	6	6	6	6	6	No onset	4
C	24	0	0	0	6	No onset	1
D	0	24	0	0	6	No onset	1
E	0	0	24	0	6	No onset	1
F	0	0	0	24	6	No onset	1

Each experimental trial consisted of a sequence of six presentation frames (F1 through F6), which are represented in Figure 1. The first three frames provided a countdown, which for most subjects, appeared as two lines converging over time to a single point. This tended to draw their attention toward the fixation triangle and prime them for optimal performance. F4 and F5 were used for stimulus presentations and response feedback. These frames are not represented in Figure 1, since they were varied on each trial. F6 was used to control the pace of the experiment. A duration of 1,500 msec was found to provide a comfortable pace for most subjects. They were able to withstand 1-hr sessions at this rate without becoming overly tired.

In general, most subjects seemed to enjoy this procedure. The immediate feedback provided a gamelike atmosphere to the experiment, and subjects often bragged about their best response times.

An experimental session consisted of 12 randomly sequenced blocks, where each block contained 30 randomly arranged stimulus presentations. These blocks were divided into three presentation groups: an eight-alternative onset group (Condition A), an eight-alternative no-onset group (Condition B), and a two-alternative no-onset group (Conditions C through F). Target stimuli could appear with angular displacements of 2.5°, 5°, 7.5°, or 10° on either side of the fixation triangle. All positions were included with equal frequency for each presentation group. At the beginning of every session, subjects were given one block of Condition A and one block of Condition B for practice, and prior to each block they were informed of the presentation method that would be used. Table 1 provides a summary of the different conditions.

*Subjects.* Six unpracticed subjects participated in the experiment to fulfill the requirements of an introductory psychology course. Each subject participated in two sessions.

### Results and Discussion

Figure 2 shows eye movement response latencies as a function of target displacement

for each presentation group. The data were analyzed by partitioning the sums of squares with a set of orthogonal comparisons. As expected, there was a large difference between the overall response latencies to onset and no-onset stimuli,  $F(1, 55) = 263.45$ ,  $p < .001$ . The effect of target displacement was negligible for onset presentations but highly significant for no-onset presentations,  $F(3, 55) = 10.03$ ,  $p < .001$ .

These results are closely paralleled by the known differences between transient and sustained retinal ganglion cells. Transient neurons have fast conduction velocities and are equally distributed across the retina, whereas sustained neurons have slow conduction

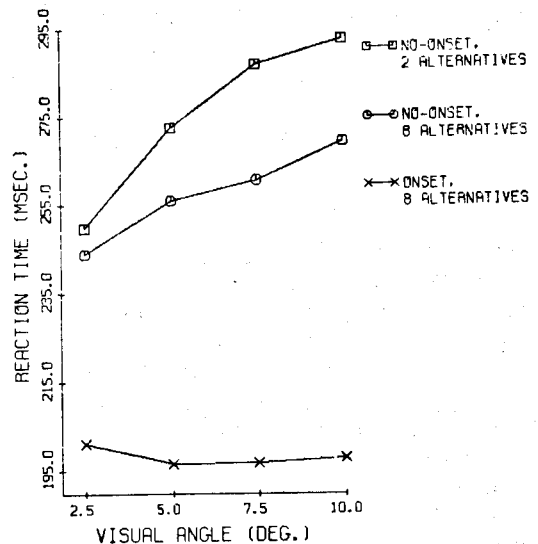


Figure 2. Eye movement reaction time as a function of target displacement for the three presentation groups of Experiment 1. (Deg. = degrees.)

Table 2  
*Percentage of Errors for Each  
 Presentation Group of  
 Experiment 1*

Group	Angular displacement			
	2.5°	5.0°	7.5°	10.0°
Onset, 8 alternatives	21.9	6.3	5.2	6.6
No onset, 8 alternatives	28.1	10.8	7.3	8.7
No onset, 2 alternatives	30.9	19.1	12.5	19.4

velocities and are heavily concentrated in the fovea. When onset stimuli were used in the present experiment, the results corresponded with the above properties of transient neurons. That is to say, the response latencies were consistently fast and were relatively unaffected by target displacement. When no-onset stimuli were used, the results more closely resembled the properties of sustained neurons. Response latencies increased with target displacement and were consistently slower than would otherwise be expected with onset stimuli.

An analysis of the error data (see Table 2) revealed that the onset presentations produced proportionately fewer errors than the no-onset presentations  $F(1, 55) = 12.21$ ,  $p < .001$ . Movement errors were by far the most frequent of the three types. These errors were recorded when an eye movement was not detected within 500 msec from the beginning of a target presentation. There are at least two reasons for this occurrence. On some trials, the subjects may have responded with a latency greater than 500 msec, whereas on other trials, their eye movements may have been mistaken for noise. This latter possibility would have occurred most frequently for smaller saccades, and probably accounts for the large number of errors at the innermost target positions.

It is important to keep in mind that the error criteria did not require subjects to look directly at the target stimulus. Any eye movement would be recorded as correct as long as it was made in the appropriate direction and its latency fell between 80 and

500 msec. Nevertheless, all of the subjects reported that they looked directly at the target stimulus on every trial, and this was confirmed by visual examination of their eye movement waveforms. While monitoring subjects' performance during the experiment, it was also observed that the amplitudes of the waveforms increased proportionally with target displacement. Since the magnitude of a saccade is directly proportional to the amplitude of its resulting waveform, this suggests that the subjects were indeed performing as expected.

The most surprising aspect of this experiment was the effect of number of alternatives for the no-onset stimulus presentations. It has been previously demonstrated by several investigators (e.g., Megaw & Armstrong, 1973; Ohtani, 1968; Saslow, 1967) that eye movement reaction times are generally unaffected by varying stimulus/response uncertainty in the manner employed by our present procedures. This observation apparently does not apply to no-onset stimulus presentations. In the present experiment, the subjects showed a significant increase in performance—that is, shorter latencies and fewer errors—when the number of no-onset target alternatives was increased from two to eight,  $F(1, 55) = 16.34$ ,  $p < .001$ , for the reaction time data, and  $F(1, 55) = 6.83$ ,  $p < .05$ , for the error data.

At first blush, this is an anomalous result. How could an increase in stimulus/response uncertainty facilitate performance? The peculiarity of this finding suggests the presence of a confounding variable, which is easily revealed on reexamination of the no-onset presentation procedure. For each no-onset stimulus presentation, a single target is displayed by turning off the other items in a fixed set of possible alternatives. As the number of alternatives is increased, so is the number of offsets. In the absence of other evidence, it would probably be expected that the sudden offset of the irrelevant alternatives would distract subjects and impair their performance. However, since performance is superior when the number of offsets is increased, it is more reasonable to conclude that the effect of offsets is facilitative. In

Experiment 2, an attempt is made to verify this conclusion by independently manipulating the number of target alternatives and the number of offsets.

### Experiment 2

#### Method

The apparatus and general procedure were the same as those used in Experiment 1. There were three no-onset conditions. For Condition A, there were seven offsets on each trial and eight possible target alternatives at 2.5°, 5°, 7.5°, and 10° on either side of the fixation triangle. For Condition B, there was a single offset on each trial and two possible target alternatives, each of which had an angular displacement of 7.5°. Condition C was a combination of the first two. During the count-down, all eight crosses were displayed, but only two of these crosses could ever appear as targets. Thus, there were seven offsets as in Condition A but only two possible target alternatives as in Condition B. An experimental session consisted of eight blocks of Condition A and two blocks each of Conditions B and C. Prior to each block subjects were informed about the upcoming condition.

Six naive subjects were paid \$2 per hour for their services. Each subject participated in two sessions.

#### Results and Discussion

The data are presented in Table 3. A Treatment  $\times$  Subject analysis of the reaction times revealed that the three treatments were significantly different,  $F(2, 10) = 26.00$ ,  $p < .001$ .

The effect of offsets was examined separately by comparing Conditions B and C in a post hoc test. In Condition B, there were two possible target alternatives and a single offset on each trial. In Condition C, the number of target alternatives was unchanged, but the number of offsets was increased from one to seven. These additional offsets provided no information about the correct stimulus or the correct response, yet they significantly reduced reaction time ( $p < .01$ ). This finding suggests that an abrupt change in visual stimulation can have a generalized, facilitative effect on performance, perhaps by increasing arousal (cf. Elnor, 1974). Moreover, an additional implication of this result is that the overall differences in reaction time to onset and no-onset stimuli, which

Table 3  
Mean Response Latencies for  
Experiment 2

No. offsets	No. alternatives	
	2	8
1	277.07 (B)	
7	260.00 (C)	254.00 (A)

Note. Letters in parentheses refer to the appropriate condition involved.

were observed in Experiment 1, cannot be due to any type of interference or interruption such as visual masking that might have been caused by the abrupt offset of the distractor elements. Since the effect of offset facilitates performance, it *reduces* the differences in reaction time to onset and no-onset stimuli. The primary effects of Experiment 1 must therefore require some other explanation.

A post hoc comparison of Conditions A and C revealed that the effect of stimulus/response uncertainty was insignificant ( $p > .05$ ). This comparison may not have been appropriate, however, because of differences in the effects of offsets. In Condition A, all of the crosses that were turned off could also appear as target stimuli and may therefore have had a greater effect on performance than the majority of crosses in Condition C, which could not appear as target stimuli. If the effect of offsets is not identical in each case, then the effect of stimulus/response uncertainty cannot be ascertained. Experiment 3 attempts to clarify this issue by employing a cuing technique to measure the effects of stimulus/response uncertainty for both onset and no-onset stimuli.

### Experiment 3

#### Method

The apparatus and general procedure were basically similar to those described for the earlier experiments. There were four possible target positions at 2.5° and 10° on either side of the fixation triangle, but unlike our earlier designs, the target stimuli did not appear at each position with equal frequency. At the beginning of each trial, the first two presentation frames (F1 and F2) con-

Table 4  
Number of Trials per Block for Each Condition of Experiment 3

Condition	Angular displacement		No. catch trials	Cue	Presentation procedure	Blocks per session
	2.5°	10.0°				
A	18	6	6	Inside	Onset	2
B	18	6	6	Inside	No onset	2
C	6	18	6	Outside	Onset	2
D	6	18	6	Outside	No onset	2
E	12	12	6	—	Onset	2
F	12	12	6	—	No onset	2

tained a small cue just above the fixation triangle, indicating where the target stimulus was most likely to appear. There were three possible cuing conditions, and all were used for both presentation procedures. In some blocks, the cue consisted of a small letter *i* (inside cue), which indicated that the target stimulus would have a 2.5° displacement on 75% of the trials. In other conditions, the cue consisted of a small letter *o* (outside cue), and the target stimulus would appear with a 10° displacement on 75% of the trials. Finally, there was also a no-cue condition, in which the target stimuli appeared at each position with equal frequency. A summary of the different conditions is given in Table 4.

Five experienced subjects were paid \$2 per hour for their services. Each subject participated in three sessions.

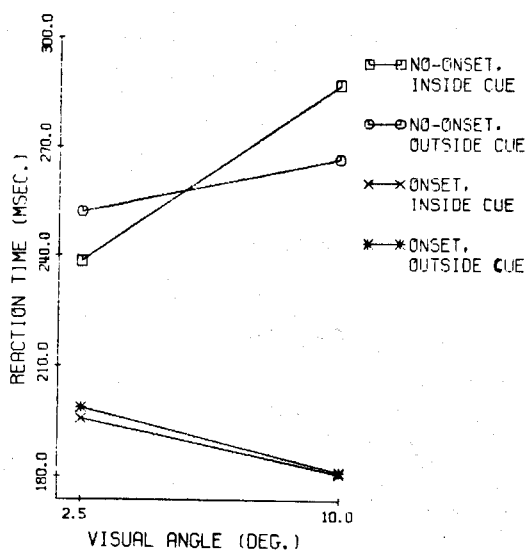


Figure 3. Eye movement reaction time as a function of target displacement for the four cuing conditions of Experiment 3. (Deg. = degrees.)

### Results And Discussion

Figure 3 shows the effects of target displacement for both the onset and no-onset cuing conditions. It should be noted that the different data points do not represent the same number of observations, since the target stimulus appeared at the expected (cued) displacement on 75% of the trials. Table 5 shows the average response latencies at each displacement for the cue and no-cue conditions. These data were obtained by averaging the individual reaction times at each displacement, so that the expected and unexpected presentations were automatically weighted according to their frequency of occurrence. All of these results were analyzed by partitioning the sums of squares with a set of orthogonal comparisons.

As expected, there was a significant difference between the overall response latencies to onset and no-onset stimuli,  $F(1, 44) = 698, p < .001$ . There was also a difference in their respective displacement functions. For onset presentations, reaction times were fastest for the 10° displace-

Table 5  
Mean Response Latencies for Experiment 3

Condition	Angular displacement			
	Onset		No onset	
	2.5°	10.0°	2.5°	10.0°
Cue	196.41	181.18	241.88	271.18
No cue	191.59	179.74	241.55	271.82



ments  $F(1, 44) = 14.69, p < .001$ ), whereas for the no-onset presentations, reaction times were fastest for the  $2.5^\circ$  displacements,  $F(1, 44) = 71.39, p < .001$ . These results are similar to those obtained in Experiment 1, and are closely paralleled by the known properties of transient and sustained neurons.

A comparison of the average response latencies for the cue and no-cue conditions (see Table 5) revealed no significant differences. This finding suggests that the displacement cues affect performance by biasing available resources. If a processing resource is biased in preparation for a particular event, the level of performance for that event may increase, but there should also be a decrease in performance for other less expected events. When all possible contingencies are taken into account, the average level of performance for a given presentation procedure should always remain the same.

The effects of the displacement cues for onset and no-onset stimuli are clearly revealed in Figure 3. For no-onset presentations, there was a highly significant Cue  $\times$  Displacement interaction,  $F(1, 44) = 13.53, p < .001$ ; in other words, the reaction times were fastest when the target stimuli actually appeared at the expected displacement. For onset stimulus presentations, the Cue  $\times$  Displacement interaction was negligible.

To summarize briefly, the experiments described thus far have revealed that eye movement responses to onset stimuli have shorter latencies and are less affected by target displacement and stimulus/response uncertainty than are identical responses to no-onset stimuli. In Experiments 4 and 5, an attempt is made to extend these findings to other experimental situations involving push-button responses based on pattern recognition and semantic judgments.

#### Experiment 4

##### Method

The apparatus and general procedure were similar to those used in Experiment 3. Instead of moving their eyes, however, the subjects were required to press one of two response keys whenever a target stimulus was presented. There were four possible target locations at  $2.5^\circ$  and  $10^\circ$  on

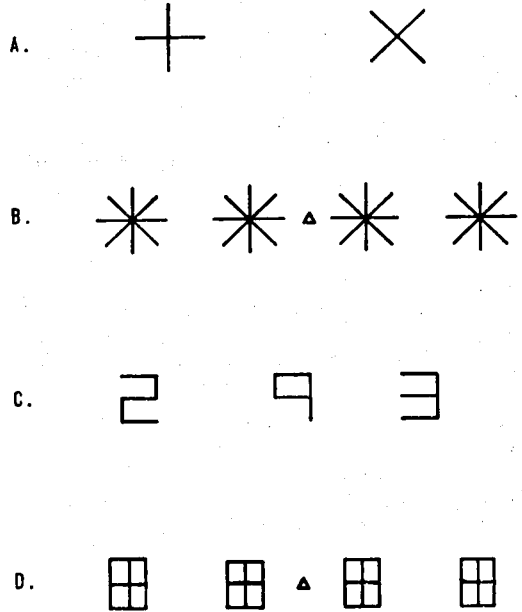


Figure 4. A sample of the display frames from Experiments 4 and 5. (The individual target stimuli [A], and a composite of all possible target stimuli [B] from Experiment 4. Selected target stimuli [C], and a composite of all possible target stimuli [D] from Experiment 5.)

either side of the fixation triangle. Two different target stimuli could appear at each position, a vertically oriented  $2.75^\circ \times 2.75^\circ$  cross or an identical cross rotated by  $45^\circ$  (see Figure 4a). Subjects were required to press one key for the vertically oriented cross and another key for the rotated cross. Both crosses were presented with equal frequency at a given displacement, but the total number of presentations for each displacement was varied across conditions. For no-onset presentations, a composite of all possible target stimuli (see Figure 4b) was presented during the three countdown frames.

Our initial pilot work with this task revealed that it would not be possible to respond accurately within the 500-msec time limit used in our earlier experiments. The time limit was therefore extended to 1,000 msec, and the criterion for a "slow" feedback message was similarly extended to 500 msec. Catch trials were also eliminated to make the task easier and to increase the amount of data collected per session. It was decided that the anticipation and response error conditions were sufficient to prevent subjects from responding before the target stimulus was actually presented.

Because of the long response latencies for this task, there was more than enough time for subjects to make an eye movement before pressing the response key. To prevent this from occurring, a

**Table 6**  
*Number of Trials per Block for Each Condition of Experiment 4*

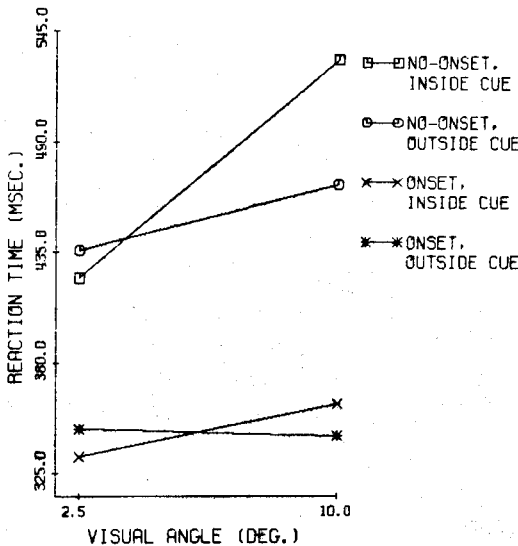
Condition	Angular displacement		Cue	Presentation procedure
	2.5°	10.0°		
A	48	16	Inside	Onset
B	48	16	Inside	No onset
C	16	48	Outside	Onset
D	16	48	Outside	No onset
E	32	32	—	Onset
F	32	32	—	No onset

new error condition was added to the experiment. On any trial in which an eye movement was detected prior to a push-button response, the error message "EM" was presented as feedback and no reaction time was recorded.

Three well-practiced subjects, who had not been used in earlier studies, participated in the experiment. All subjects were paid \$2 per hour for their services and participated in six sessions. An experimental session consisted of six different cue and no-cue conditions, each divided into two sub-blocks (see Table 6). The ordering of these conditions was randomly varied across sessions.

**Results And Discussion**

The reaction time data for the onset and no-onset cuing conditions are presented in



**Figure 5.** Push-button reaction time as a function of target displacement for the four cuing conditions of Experiment 4. (Deg. = degrees.)

Figure 5, and the average response latencies for the cue and no-cue conditions are presented in Table 7. As before, the data were analyzed by partitioning the sums of squares with a set of orthogonal comparisons.

The results were similar to those obtained in Experiment 3. Significant differences were obtained for the presentation effects,  $F(1, 22) = 874.12, p < .001$ , the displacement effect for no-onset stimuli,  $F(1, 22) = 153.08, p < .001$ , the cuing effect for no-onset stimuli ( $F(1, 22) = 33.00, p < .001$ , and the displacement effect for onset stimuli,  $F(1, 22) = 4.44, p < .05$ . A comparison of the average response latencies for the cue and no-cue conditions revealed no differences. Unlike our previous results, there was also a significant cuing effect for the onset stimulus presentations,  $F(1, 22) = 4.91, p < .05$ , although a post hoc comparison revealed that the no-onset cuing effect was significantly larger ( $p < .01$ ).

It is important to note that the differences in response latency to onset and no-onset stimuli observed in the present experiment were quite large in comparison to those observed in Experiment 3 (see Figure 6). The other results described thus far have all been consistent with the known differences between transient and sustained retinal ganglion cells, but this increased latency effect cannot be explained so easily. Why should an abrupt change in visual stimulation have a greater effect on a push-button pattern discrimination task than on an eye movement localization task? There are several possible explanations for this finding. The differences in response latency to onset and no-onset stimuli might vary significantly for

**Table 7**  
*Mean Response Latencies for Experiment 4*

Condition	Angular displacement			
	Onset		No onset	
	2.5°	10.0°	2.5°	10.0°
Cue	336.82	348.00	425.91	485.64
No cue	341.55	353.41	424.65	486.67

different groups of subjects. They might also vary with different response measures, or they might reflect the overall cognitive complexity of the decision criteria for choosing a response. If the latter hypotheses were correct, then it would be difficult to argue that transient neurons in the initial stages of the visual system are exclusively responsible for the behavioral effects of abrupt change. Rather, the results would suggest that these transient neurons are part of a more global subsystem that can affect performance at many levels of processing.

### Experiment 5

Experiment 5 was an attempt to eliminate the alternative explanations to the data of Experiment 4. The same subjects were given a more difficult discrimination task, and the results were compared with those of the previous experiment.

### Method

The apparatus and general procedure were similar to those used in Experiment 4. There were four possible target locations at 2.5° and 10° on either side of the fixation triangle. A target stimulus could be any whole number from 0 to 9, and subjects were required to press one key if the number was even or a second key if the number was odd. (See Figure 4c for a sample of the different stimuli.) For no-onset presentations, a composite of all possible target stimuli was presented during the three countdown frames (see Figure 4d). Each of the four boxes in this composite was 2.0° tall and 1.35° wide.

Because of the many stimuli involved, it was impossible to vary the number of presentations for each displacement without exceeding the limitations of our computer program. The experiment, therefore, contained only two conditions: a no-cue onset condition and a no-cue no-onset condition. In either case, all possible target stimuli were presented once at each position, for a total of 40 trials per block. Both conditions were repeated six times during a session, and their ordering was randomly varied across sessions.

The same three subjects who participated in Experiment 4 were again paid \$2 per hour for their services. Each subject participated in two sessions.

### Results And Discussion

The data (see Table 8) were consistent with our earlier findings. Significant differ-

Table 8  
*Mean Response Latencies for Experiment 5*

Condition	Angular displacement	
	2.5°	10.0°
Onset	386.80	412.32
No onset	527.21	591.91

ences were obtained for the presentation effect,  $F(1, 6) = 403.23$ ,  $p < .001$ , and the displacement effect for no-onset stimuli,  $F(1, 6) = 31.36$ ,  $p < .005$ . The displacement effect for onset stimuli did not reach significance.

To compare results from the no-cue conditions of Experiments 4 and 5, a set of difference measures was obtained by subtracting the onset response latencies from the no-onset response latencies for each task and each value of angular displacement (see Figure 6). These difference measures were then compared using a three-way (Task  $\times$  Displacement  $\times$  Subject), repeated measures analysis of variance. Both the task and displacement effects were significant,  $F(1, 6)$

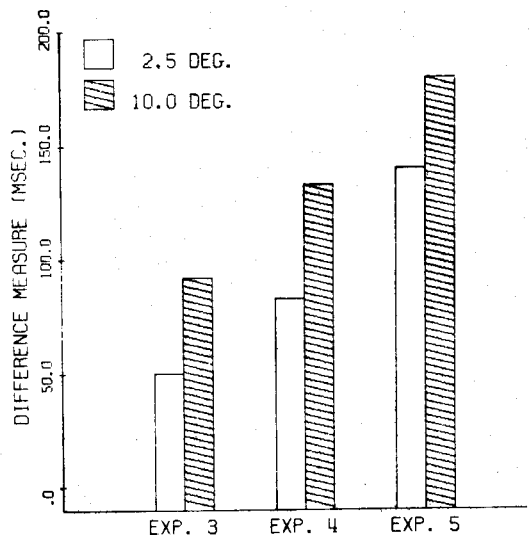


Figure 6. Differences in response latency to onset and no-onset stimuli for three experimental tasks at two values of angular displacement. (Deg. = degrees; Exp. = experiment.)

= 39.82,  $p < .001$ , for the task effect, and  $F(1, 6) = 32.74$ ,  $p < .005$ , for the displacement effect, and there was no significant interaction.

The significant task effect is especially important. Following Experiments 1 and 3, it was argued that the differences in response latency to onset and no-onset stimuli could be attributed to the known differences between transient and sustained retinal ganglion cells. Unfortunately, however, this cannot explain why the abrupt onsets of the target stimuli had a greater effect on performance in Experiment 5 than they did in Experiment 4. These experiments were similar in most respects except for their response criteria. In Experiment 4, the subjects were required to distinguish between a "+" or an "X," whereas in Experiment 5, the same subjects were required to distinguish between an even or odd number. In other words, the relevant differences between these tasks appear to have been restricted to abstract cognitive activities such as pattern recognition or semantic judgments, which must surely be far removed from the processing capabilities of the transient and sustained retinal ganglion cells.

One possible explanation for the combined results of Experiments 4 and 5 is that a transient-sustained dichotomy is preserved at many different levels of visual information processing. This is not an unreasonable assumption if we consider the fact that transient and sustained properties of visual stimulation impose radically different processing constraints on a perceptual system. Transient information by its very nature must be processed quickly or not at all, whereas sustained information will still be available if it is temporarily neglected. To maximize processing speed, the transient system has apparently limited its information load by sacrificing its sensitivity to fine details in the spatial patterning of visual stimulation. It is interesting to note, however, that there is a growing amount of evidence that the transient system has not sacrificed the complexity of its analytic capabilities. A number of investigators have reported that objects can be correctly identified solely on the basis of dynamic properties of visual stimulation

presumably analyzed by the transient system (Bassili, 1978; Cutting et al., 1978; Johansson, 1973, 1975; Kozlowski & Cutting, 1977). Other evidence suggests that the transient system can adequately perform these analyses even when the sustained system has been severely damaged. This is suggested by clinical reports of patients who are blind to stationary objects but can easily identify the same objects under dynamic transformation (Botez, 1975).

All of this has obvious implications for the continued widespread use of onset presentation procedures in experimental psychology. If the abrupt onset of a target stimulus invariably activates a transient component of the visual system that is capable of affecting many aspects of human information processing, then the results obtained using onset presentation procedures may not always be generalizable to other situations outside the laboratory. The actual extent of this problem can only be revealed by attempting to replicate the more classical research paradigms using alternative presentation procedures that do not involve abrupt onsets.

## Discussion

The five experiments described earlier provide conclusive evidence that human performance can be dramatically affected by the dynamic properties of a visual display. Several distinct phenomena are reported. First, responses to no-onset stimuli have longer latencies than identical responses to onset stimuli. Second, responses to no-onset stimuli are more greatly affected by target displacement (retinal locus) than are responses to onset stimuli. Third, the offset of the distractor elements in a no-onset presentation procedure has a facilitative effect on performance. Fourth, responses to no-onset stimuli are more greatly affected by a displacement cue than are responses to onset stimuli. Fifth, the differences in reaction time between responses to onset and no-onset stimuli increase dramatically with task complexity. And sixth, the relative differences in the effect of target displacement for onset

and no-onset stimuli are unaffected by increases in task complexity.

The model we propose to account for these data is similar to the one outlined by Breitmeyer and Ganz (1976) in their general explanation of visual masking phenomena. We assume that the visual system has two complementary components: a sustained system of high spatial acuity whose range of sensitivity is confined to a relatively small area in the center of the visual field; and a transient system of low spatial acuity that is globally sensitive in all portions of the visual field, but can only respond to rapid changes over time, such as onset, offset, or movement. We do not assume that the activities of either system are necessarily restricted to a particular stage of analysis.

The functional interactions between the transient and sustained systems are assumed to be dependent on the method of stimulus presentation. With an onset presentation procedure the transient system is automatically activated by the abrupt onset of the target stimulus. It must then initiate whatever analyses are required, recruiting other resources (e.g. the sustained system) when necessary. Since the transient system is globally sensitive in all portions of the visual field, performance is unaffected by the angular displacement of the target stimulus unless the nature of the task necessitates an analysis of the high spatial frequency components of the display. Moreover, since the target stimulus is detected automatically regardless of retinal locus, advance information about its probable location is unlikely to improve performance.

With a no-onset presentation procedure, the transient system is activated by the abrupt offset of the distraction elements. In this case, however, the abrupt changes in the display may not be directly relevant to the required task. The transient system might still affect performance by increasing the state of arousal, but it cannot direct other resources to the location of the target stimulus or participate in the resulting analyses. Thus, almost all of the required processing must be performed by the sustained system in isolation. A task of this kind may be quite

difficult, since the sustained system is poorly suited for analyzing information that is not presented within the foveal regions of the visual field. Because of this lack of sensitivity, performance deteriorates as a function of target displacement, and, since the sustained system must focus its attention on a relatively small area, the initial detection of the target stimulus is more likely to be facilitated by advanced knowledge of its probable location.

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Received September 18, 1978 ■