Two considerations may weaken the conclusions that can be drawn from this experiment. First, the D scale technique was designed for use with unidimensional stimuli. The squares used in this experiment can be considered to be unidimensional stimuli varying in area, or to be two dimensional stimuli in which length and width provide completely redundant information. If the judgment process is based upon use of two dimensions rather than one, the applicability of the test is open to question. However, the predicted D% values are the same whether calculated from the areas or from the edge dimensions of the squares.

Second, the stimuli were introduced to the subjects in a random order, rather than in increasing or decreasing order, as is usual in absolute judgment work. This may have weakened the end effect.

The stimulus set used in this study has a spacing seldom seen in absolute judgment work. Thus the data reported may be useful in the validation of other techniques for predicting the discriminability of stimuli from their physical dimensions.

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Selective attention: Noise suppression or signal enhancement?*

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RTs were obtained to single letter displays when an indicator, designating in which of four possible positions the letter would appear, preceded the display by intervals of 0-150 msec. Prior information, even by as little as 50 msec as to the letter's position, resulted in reduction in RT. Controls ruled out the possibility that the effect was attributable to changes in fixation, masking, or facilitating effects of a first signal. Instead, the effect appears to reflect characteristics of a central selective attentional mechanism.

The present experiment is a follow-up of an unexpected but incidental finding in a previous experiment (Eriksen & Hoffman, 1973). We have been investigating characteristics of selective attention in the visual field. The basic procedure has employed a circular display of letters with a target letter defined by a black bar indicator. The S's task has been to name or to respond to the target letter as quickly as possible. In addition to manipulating the display variables, a primary manipulation has been to have the indicator precede the letter display by several hundred milliseconds. Reaction time (RT) to the target letter decreases as the indicator precedes the display out to approximately 300 msec.

In this previous experiment a single letter display (only the target letter was presented) was used to assess baseline performance when no noise elements were present in the display. As part of the balanced design, a single letter display was preceded by an indicator at stimulus onset asynchronies (SOAs) varying from 0-350 msec. In this instance, the indicator designated in which of 12 positions in the visual field (all foveal) the target letter would appear. The unanticipated result was the finding that RT to the single letter display decreased as the indicator preceded the display, an effect comparable to that of 12-letter displays.

Now it is not particularly surprising that with multiletter displays, an S can respond more rapidly to the target letter if he is given information as to where its location will be several hundred milliseconds before the multiletter display appears. But, with a single letter display, no search or location would appear to be necessary since it is the only stimulus present in the visual field. So we are faced with the question of how this reduction in RT is mediated. Prior research has shown that the facilitation in RT in multiletter displays is not mediated via a change in eye fixation nor to a "priming" effect of a first stimulus upon RT to a second stimulus (Bertelson, 1967; Posner & Boies, 1971).

An effect of attention upon the input side of perceptual processing has been difficult to demonstrate experimentally (Deutsch & Deutsch, 1967; Reynolds, 1964; and Egeth, 1967). It has been very difficult to rule out, of any selective effects obtained, interpretations

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based upon response selection, response completion, and limitations and order effects in short-term memory. However, an interpretation of the effect of an indicator in single letter displays in terms of these variables is not readily apparent. Since only a single letter appears, order effects in short-term memory are not involved nor is response competition. Since the number of response alternatives is constant and fixed, the problem of response selection remains constant over all the SOAs by which the indicator precedes the display.

While response processes seem inadequate to the task of explaining our phenomenon, the hypothesized processes by which selective attention can operate on the input side of processing do not seem to fare much better. Treisman (1969) has provided some of the most detailed speculation upon mechanisms by which selective attention could operate on the input side of perceptual processing. The three loci she considers are selection of inputs, selection of analyzers, and selection of tests and targets. Selection of inputs which acts by selecting which set of sensory data to analyze does not seem appropriate to our present phenomenon since the target letter is the only letter in the visual field. Similarly, selection of analyzers or selection of test and targets are inadequate since the dimensions of the stimuli and the particular targets are constant over the SOAs by which the indicator precedes the display in the phenomenon under consideration.

The novelty and potential importance of our finding seems evident. Thus, it is particularly important that it be carefully explored to determine that it really reflects an aspect of the selectivity process in attention and is not attributable to some other variable. As mentioned above, we have previously determined that the selectivity occurring in multiletter displays is not mediated by changes in eye fixation or the facilitory effect of a preparatory or first signal upon RT to a second signal. There is the possibility though, that the effect may be attributable to a form of visual masking. It has been found that visual masking effects are detectable with RT procedures (Eriksen & Eriksen, 1972), and it may be that the indicator occurring 1/2 deg of visual angle from the target letter exerts a masking influence. If this were the case, target recognition would be maximally impaired (slowed) when indicator and target occur simultaneously and the effect of the mask would decrease as the indicator was moved forward in time (forward masking function). The present experiment was undertaken primarily to determine to what extent a forward visual masking effect might be involved in producing the leading indicator effect for single letter displays.

METHOD

Subjects

Three males (including the junior author) and one female, all students at the University of Illinois served as paid volunteers. All Ss had normal or corrected to normal vision.

Apparatus and Stimuli

Stimuli were displayed in a Scientific Prototype Model GB three-field tachistoscope. All three fields were equated at 6 fL as measured with a Spectra spot photometer. A black fixation cross subtending .6 deg of visual angle was mounted on a white vinyl card placed in the adaptation field. This field remained on except when the stimulus fields were activated. The Ss initiated a trial by closing a hand held microswitch which triggered the tachistoscope and a Hunter Model 1052H digital clock. A microphone located below the S's viewer triggered a Scientific Prototype Model 761G audio visual detection relay which stopped the clock. Voice RTs were recorded in milliseconds.

The stimuli were the black capital letters "A", "H", "M", and "O" obtained from Paratipe 11316 and placed on a white vinyl card. Each letter subtended .2 deg of visual angle in height. Sixteen cards were constructed to permit each of the four letters to occur in the three, six, nine, or twelve o'clock position of an imaginary clock with a radius of 1 deg of visual angle. This display was centered on the fixation cross. The indicator was a black bar .5 x .1 deg of angle whose near end was .5 deg of visual angle from the indicated letter. It was positioned so that it would constitute an imaginary radius from the center of the display through the indicated position. The black dot used in the dot control condition consisted of a black disk .22 deg of visual angle appearing over the fixation dot. During the experimental trials, the indicator or the dot and the target letter were each presented for a duration of 25 msec.

Procedure

There were two experiemental conditions, one involving the use of the indicator and the other the dot control. In the indicator condition, the indicator appeared either simultaneously with the target letter or at an interstimulus interval (ISI) before the target letter of 50, 100, and 150 msec. The indicator pointed to whichever of the four possible positions the target letter would occur in on that trial. In the dot control condition, the black dot was presented in the center of the imaginary circular display either simultaneously with the occurrence of the target letter or at one of the three ISIs before the target letter appeared. All Ss served in two practice sessions followed by four experimental sessions. Each session consisted of eight blocks of 16 trials, one block for each of the eight experimental treatments (2 conditions by 4 ISIs). These eight blocks were further divided into four sets, each set consisting of one of the indicator or dot conditions at one of the ISI values. The order of sets within a session was counterbalanced across sessions as was the order of the indicator and dot conditions within each set. Within each condition, the four target letters occurred in each of the four positions equally often. Error rates averaged over Ss ranged from 3.2% to 4.7% for the various treatments and showed no systematic trend. Error trials were randomly rerun during later blocks so each S's mean latency is based on 64 correct trials. Standard deviations for each S were computed by averaging the standard deviations for each block.

RESULTS

Mean RT for each S as a function of indicator or dot conditions and ISI is shown in Table 1. The data were submitted to a three-way analysis of variance (indicator-dot, ISI, and Ss). The effects for conditions and ISI were both significant [$F(1,3) = 154$, $p < .01$ and $F(3,9) = 4.64$, $p < .05$, respectively] as was the

Table 1
Reaction Time as a Function of the ISI by Which the Indicator or Dot Preceded the Letter Display

		Interstimulus Interval in Msec							
		0		50		100		150	
Conditions		RT	σ	RT	σ	RT	σ	RT	σ
Indicator	JH	359.5	16.1	336.7	17.7	341.7	18.8	326.0	20.2
	RC	404.8	19.4	368.0	19.2	345.4	22.6	333.1	21.2
	DM	402.1	26.9	386.2	26.0	361.9	29.4	361.3	29.9
	AW	385.8	31.1	368.5	24.5	374.2	28.5	371.8	27.3
	Average	388.1	23.4	364.9	21.9	355.8	24.8	348.1	24.6
Dot	JH	367.0	18.3	349.3	17.5	354.8	20.5	362.5	19.8
	RC	402.9	22.6	388.0	22.8	365.2	21.6	359.5	20.2
	DM	392.6	26.0	388.2	27.5	392.1	26.4	385.5	31.9
	AW	392.6	32.3	382.8	25.9	391.1	25.3	396.5	32.6
	Average	388.7	24.8	377.0	23.4	375.8	23.5	376.0	26.1

Conditions by ISI interaction [$F(3,9) = 8.76$, $p < .01$]. Separate analyses were conducted on the indicator and dot condition. For the indicator condition ISI was significant [$F(3,9)$ - 8.2, $p < .01$], but for the dot condition ISI failed to reach significance [$F(3,9) = 1.3$, $p < .10$].

DISCUSSION

The above results show quite clearly that a S's RT to a target letter is significantly shortened if he is informed by means of an indicator 50-150 msec before the letter appears as to the exact location of the letter in the visual field. The basis of this effect would not appear to be attributable to such obvious processes as a change of foveal fixation, a first signal facilitation or warning effect upon RT (Bertleson, 1967; Posner & Boies, 1971), or to masking effects of the indicator upon the target letter.

A change of foveal fixation can be ruled out on the following basis. Voluntary saccades required to change fixation to the position designated by the indicator require on the average approximately 220 msec (Colegate, Hoffman, & Eriksen, 1973). In the present experimental arrangement, the indicator, and the letter were tachistoscopicly presented for only 25 msec each. Even in the condition in which the indicator preceded the display by 150 msec, the total stimulation sequence of indicator, ISI, and letter comprised a total of 200 msec, still shorter than the average time required for a change in fixation. Further, over half the reduction in RT obtained with the preceding indicator occurs when the indicator leads the letter by only 50 msec, giving a total stimulation time of 100 msec–much too short even for the fastest saccade.

The condition in which the dot precedes the target letter provides a control for a first signal or warning facilitation effect. Like the indicator, the dot is a stimulus or change in the visual field that precedes the occurrence of the target letter. But unlike the indicator, the dot provides no information as to the target's location. As the results show, the effect of the informationless dot had no significant facilatory effect upon RT and differed significantly from the indicator condition.

The dot condition also serves as control for a possible masking of the letter by the indicator. In the present experiment, the indicator occurring .5 deg of angle from the letter might possibly exert a masking effect (Eriksen & Eriksen, 1972). On the other hand, the dot was separate from the target letter by .9 deg of visual angle. Even if some masking occurs with this greater separation, it should be appreciably less than that obtained for the indicator. However, in the condition where the indicator appeared simultaneously with the target letter, performance was essentially identical with that obtained when the dot appeared simultaneously with the indicator. This is the expected outcome if no masking was involved since in the simultaneous condition (zero ISI) the S receives no prior information as to the location of the target. Further, if the dot was also exerting some masking influence it would be expected that this effect would decrease as the ISI by which the dot preceded the target was increased. However, no significant effect for ISI in the dot condition was obtained.

Having ruled out alternative interpretations for our phenomenon, we are left with the strong possibility that the leading indicator effect with single letter displays reflects a characteristic of attentional selectivity in visual percetion. The evidence is certainly strong enough to justify speculation concerning the nature of the underlying mechanisms.

One clear implication is that attentional selectivity occurs, at least in part, by some form of a signal enhancement rather than solely by noise suppression or filtering. Since the effect occurs with single letter display, there is no noise or irrelevant visual signals to inhibit or attenuate. But–what kind of a process can provide this enhancement or "tuned-up gain" for the signal?

As we noted in the introduction, the mechanisms or processes proposed by Treisman (1969) by which selective attention could be localized on the input side of stimulus processing, do not appear adequate to account for the present phenomenon. Instead, the effect seems to require a conception in terms of multiple processing channels that differ in speed and/or the detail or level of information extraction and further are capable of being directed to specific loci in the visual field.

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