On the nonautomaticity of "automatic" activation: Evidence of selective seeing

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Early perceptual selection refers to a sequence of perceptual processing in which attentional selection of stimuli occurs before perceptual processing is complete. By contrast, late perceptual selection refers to a sequence in which all stimuli receive complete perceptual processing before selection takes place. An attempt was made to determine if early selection is possible. Three experiments were conducted in which subjects were presented with arrays containing a variable number of red items and a variable number of black items; all array items were randomly positioned around the circumference of an imaginary circle. The subject's task was to report the number of red items. Response time increased with the number of red items, but was essentially independent of the number of black items. The nature of the red and black items was also varied. When the to-be-attended red items were given "Stroop-like" quality (the symbols that were used were directly inconsistent with the correct response for that trial), mean reaction time was increased compared to a baseline condition; when the to-be-ignored black items were given "Stroop-like" quality, mean reaction time was unaffected. These results imply that the relevant (red) and irrelevant (black) items were processed differentially. We conclude that early selection is possible; late-selection models are not supported.

The visual system, as part of the limited-capacity human organism, is selective in its processing of information. Much research has been conducted to determine where along the continuum of visual information processing this selection occurs. The issue to be discussed in this paper concerns whether it is possible for selection of to-be-attended items to occur during perceptual processing (early selection) or whether selection cannot occur until perceptual processing is complete (late selection).

Some well-known studies (e.g., Cherry, 1953) have strongly suggested that early selection is possible. In dichotic listening studies, for example, it was usually found that it was easy for subjects to attend to information presented to one ear (channel) and to ignore information presented to the opposite ear. Such findings lead to models of perceptual processing like that of Broadbent (1958). His model proposed a large-capacity sensory storage mechanism that maintained stimuli in a relatively unprocessed state for a short period of time. From this temporary storage, a selective filter (or device for allocating attention) designated certain stimuli for further processing or elaboration.¹ Broadbent reasoned that a selection device was necessary to prevent the limited-capacity central processing system from being overloaded. Unattended stimuli decay quickly in the short-term store, and for this reason information on

an unattended channel quickly becomes unavailable if not designated for further processing.

Several later studies, however, have supported the notion that stimuli on "unattended" channels are also processed (Lewis, 1970; Moray, 1959). For example, Moray (1959) demonstrated that a message presented to the unattended ear in a dichotic listening task may be heard if it is preceded by the subject's name. This result is consistent with a model in which stimuli on all channels receive processing to the point of recognition, with attention being allocated to the stimuli after perceptual processing has occurred (e.g., Deutsch & Deutsch, 1963). In a similar vein, some recent theorists (LaBerge & Samuels, 1974; Posner & Snyder, 1975) have proposed a type of information processing that they call automatic activation. In this mode of processing, all highly practiced, well-learned stimuli are processed regardless of where attention is directed at the time. Furthermore, automatic processing occurs without drawing from a limited-capacity central mechanism. A prime example of this type of processing is the act of reading (e.g., words, symbols such as numerals, etc.). Evidence demonstrating that well-learned stimuli were not processed automatically would tend to refute such models of automatic activation as discussed above.

In a recent paper, Francolini and Egeth (1979) have claimed that early perceptual selectivity is possible and is partially determined by task demands. In one experiment, subjects searched for a specific letter among arrays containing an assortment of red and black letters randomly positioned around the cir-

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cumference of an imaginary circle. Color has been shown to be a very salient aspect of stimuli, both as a partial report cue (e.g., von Wright, 1968) and as a stimulus dimension that cannot be ignored even in a task in which subjects attempt to ignore the "irrelevant" color dimensions (Egeth, 1966). The colors red and black were intentionally chosen because we wanted an obvious color distinction to enable segregation of the to-be-attended items from the to-be-ignored items. Subjects were told that if a target letter was present in an array, it would only be a red letter—never a black one. Thus, if subjects were able to restrict their attention to the red letters, then mean reaction time (RT) for this task should be affected only by the number of red letters and not by the number of black letters. Failure of perceptual selectivity in that experiment was indicated by the fact that mean RT was found to increase not only with the number of red letters but also with the number of black letters in the arrays.

In another experiment, Francolini and Egeth asked subjects to report the *number* of red letters present in arrays again containing both red and black letters. The arrays used in that experiment were essentially the same as those used in their first experiment, but now the results indicated essentially perfect selectivity for red items. Here, mean RT to count red letters increased with the number of red letters, but did not increase as the number of black letters in the arrays increased. Since the stimuli were similar in both the counting and search experiments, it was concluded that perceptual selectivity was task dependent.

What conclusions can be drawn from the Francolini and Egeth experiments? On the one hand, in the search task (e.g., is a red A present in the array?), the black distractor items influenced mean RT. Thus, these items probably were not "filtered out" at an early level. On the other hand, in the counting task, the black distractor items had no effect on mean RT. It is tempting to conclude that in the latter case the red items were selected at an early level (i.e., prior to the complete perceptual processing of the black items). Several influential automatic activation theories, however, allow only for late selection and not early selection. Thus, the alleged demonstration of perfect filtering assumes considerable theoretical significance. In view of this, it is important to point out a potential problem with the interpretation of the counting data in that paper. It was assumed that if the black distractor letters had been processed to the point of recognition, this would have been manifested as an increase in RT. However, it is not necessarily the case that merely recognizing the identities of black letters should slow down the counting of red letters. In other words, the two processes might well proceed concurrently and independently.

In order to support the claim that the distractor items are not being processed to the point of recognition, it is necessary to use a more sensitive technique. To this end, we devised a task for which it seemed quite reasonable to conclude that recognition of distractors would impair performance on the target items. The task again required counting of red letters. What is different is that on some trials the black distractors were given Stroop-like quality in that the verbal content of the black symbols that were present was directly inconsistent with the correct response for the number of red items on that trial. For example, suppose that two red As and four black 3s were presented. The subject's response for the number of red items should be "two," but if the black 3s are processed, an implicit "three" response should be elicited. In other words, response conflict should result and this response conflict should be manifested as a slowing of RT as compared to a condition in which no response conflict was engendered. If the black items are ignored, however, RT to count red items should be independent of the number and nature of black items.²

Our decision to try to look for interference effects in the counting paradigm is based upon the fact that the existence of Stroop-like interference effects is one of the cornerstones of the automatic activation models. The Stroop effect in itself provides a telling argument in support of the notion of automatic activation. Stroop (1935) had subjects name the ink colors of printed symbols. In a control condition, the symbols formed a meaningless ensemble (e.g., a row of red Xs). In a conflict condition, the symbols formed words that named colors different from the ink colors in which they were printed (e.g., the word *red* printed in blue ink). Subjects took much longer to name the colors in the conflict condition than in the neutral condition. The point is that subjects could not attend selectively to color information; if they had, performance would have been the same in the two conditions. Under such circumstances, subjects cannot avoid "reading" the words no matter how hard they try. The word meanings appear to be activated automatically. Moreover, not only are the meanings activated, but this activation has a specific effect at the output stage since response conflict is engendered. (See Posner & Snyder, 1975, for a further discussion of the role of the Stroop effect in the development of a model of automatic activation.) Since Stroop's original paper, there have been numerous demonstrations of interference effects in domains other than color naming. Studies by Hock and Petrusek (1973), Flowers, Warner, and Polansky (1979), Morton (1969), and Windes (1968) have shown that a response such as counting can be affected by incompatible numerical information (e.g., it takes longer to count the number of symbols

in the array 444 than in the array XXX). This conclusion suggests to us that under appropriate circumstances numerals as well as words may automatically activate their representations in memory.

Of particular relevance to the present experiments are some earlier experiments, similar in logic, conducted by Kahneman and Henik (in press). In their experiments, subjects were asked to name the ink color of printed symbols. The spatial location of incompatible color words in relation to the to-be-reported ink color was varied. Their results demonstrated that the effect (on RT) due to incompatible color words was greatly diminished if the incompatible information was in a location different from the location of the to-be-reported ink color. Kahneman and Henik argued that the concept of automatic activation entails the prediction that the location of an interfering stimulus should have no effect on the magnitude of the interference. Consequently, their data are inconsistent with the concept of automatic activation. In the present experiments, we use this logic to examine the nature of processing in the counting paradigm.

EXPERIMENT 1

In this experiment, subjects were presented with arrays containing 0, 1, 2, or 3 red letters and from 1 to 6 black items. The black items were either letters or digits, depending on the condition. The number of red letters and the number of black items varied independently from trial to trial except for the constraint that the maximum array size (red plus black items) was 6 items total. Thus, arrays with 0 red letters could have from 1 to 6 black items, arrays with 1 red letter could have from 1 to 5 black items, arrays with 2 red letters could have from 1 to 4 black items, and arrays with 3 red letters from 1 to 3 black items.

The subjects' task was to report vocally the number of red items. It was emphasized to the subjects that they would never be asked which particular red or black items were present and that their task was only to report the number of red items. The subjects were told that the black distractors could be interfering and that it would be to their advantage to ignore them. If the black items in the arrays are not processed to the point of recognition, then making the black items inconsistent with the response for the task should not result in increased RTs for the inconsistent condition as compared to the baseline condition of black letters. To the extent that interference is observed, we may conclude that attentional selectivity is imperfect.

To maximize the likelihood of interference, the black items in one condition were repeated examples of a digit inconsistent with the numerical response required on that trial. For example, if two red letters

were presented, each of the black items in the array would be the digit 1 (or 3) for the inconsistent distractor condition. The repeated 1s are inconsistent with the "two" response. Repeated items (e.g., 111) were used instead of unique items (e.g., 136) because the conflicting information ought to be more salient due to the redundancy. In addition to the two conditions already described (i.e., letters or inconsistent digits as black distractors), a third condition was used in which black distractors were digits consistent with the response (e.g., three red Fs were presented and the black items present were all 3s).

If subjects do not process the black distractors, then RT should be independent of the number of black items and also there should be no difference in results for the three types of black distractors: letters, response-inconsistent digits, and response-consistent digits.

Method

Subjects. Nine students at The Johns Hopkins University served as subjects in the experiment and received either \$2 or partial fulfillment of an undergraduate course requirement. The subjects were tested individually for approximately 50 min.

Stimulus materials and Apparatus. The stimulus elements were drawn in either red or black ink (Pilot razor point) on white cardboard cards using a Pickett No. 13 lettering guide. The stimulus cards were displayed in a conventional mirror tachistoscope at a viewing distance of 91 cm. Luminances in both the stimulus and fixation channels were 78.1 cd/m². To maintain a constant overall visual angle, as the number of stimulus elements on a card varied each element was located at one of eight equally spaced locations on the circumference of an imaginary circle. The center-to-center distance between the two diametrically opposed stimulus elements subtended a visual angle of approximately 3.2 deg; the mean visual angle between the edges of two adjacent elements was approximately .9 deg. For more detailed information about the construction of stimuli, the reader is referred to Francolini and Egeth (1979).

A constraint on the composition of the stimulus arrays was that two red items never occupied adjacent array positions. The interleaving of red and black elements should, if anything, increase the likelihood that subjects would process the black items.

The red items on each trial were randomly selected letters (except I, O, Q, S), and were always the same letter repeated when more than one was present in an array (e.g., three red items in an array might be three red As). The black items were either randomly selected letters (except I, O, Q, or S) or the digits 1, 2, or 3. Whenever more than one black item was present in an array, the same item was repeated. The same letter never occurred in one array both as a red and black item. All letters (except I, O, Q, and S) were used approximately equally often for red and black letters. The digits 1, 2, and 3 were used equally often as black digit distractors, and all array locations were used approximately equally often for all kinds of items.

Design. Red letters were the items to be counted and black items were the items to be ignored. Three types of black items were used: Letters (baseline distractor condition), digits that were inconsistent with the correct numerical response required for that trial (inconsistent distractor condition), and digits that were consistent with the numerical response (consistent distractor condition).

All conditions (including the distractor conditions) in the experiment were presented in mixed decks. Zero, 1, 2, or 3 red letters were present on every trial. Since the maximum total array size was 6 items, the number of black-distractor conditions was different

Table 1
Black Item Conditions Used With Each Number of Red
Items Condition in Experiment 1

Number of Red Letters	Number of Black Items					
	1	2	3	4	5	6
3	X	X	X			
2	X	X	X	X		
1	X	X	X	X	X	
0	X	X	X	X	X	X

Note—X indicates the specified condition was used in the experiment.

for each of the red-letter conditions. Thus, there were 6 black-item conditions (1 to 6) for the 0-red-letter condition, 5 black-item conditions (1 to 5) for the 1-red-letter condition, 4 black-item conditions (1 to 4) for the 2-red-letter condition, and 3 black-item conditions (1 to 3) for the 3-red-letter condition, making a total of 18 conditions (see Table 1). For each of the 18 conditions, one-half of all the stimulus cards were made such that the black distractor items were letters and the other half such that the black distractors were digits. (For the cards with digit distractors, on two-thirds of the cards in a given condition the digits were inconsistent with the response for that particular array and on one-third the digits were consistent. See below for further explanation.)

The particular letter used as a black distractor on any given array was selected randomly from the permissible letters (i.e., I, O, Q, and S were not used and the same letter could not occur as both a red and black item in the same array). The particular digits used as black distractors were chosen such that the set of inconsistent digits was the same as the set of possible numerical responses (except for "zero," of course). This overlap should maximize the degree of interference (Hock & Petrusek, 1973; Klein, 1964; Morton, 1969). Thus, only the digits 1, 2, and 3 were used for the digit-distractor conditions (0, 1, 2, or 3 red items were present on each trial). Of the stimulus cards with digits as distractors (for each of the 18 conditions), one-third had 1 as the distractor, one-third had 2 as the distractor, and one-third had 3 as the distractor. For example, for the 2-red-letter/4-black-item combination, on one-third of the cards the four black distractors were 1, on one-third of the cards the distractors were 2, and on one-third of the cards the distractors were 3. In this case, the black 2s as distractors were consistent with the response for the number of red letters, while the digits 1 and 3 as distractors were inconsistent. Of course, for the 0-red-letter conditions, since the distractors were 1, 2, or 3 and the correct response was zero, all three distractor digits were inconsistent.

The stimulus cards were divided into nine decks of 36 trials each. All 18 conditions were represented twice within a deck, once using black digits as the distractors and once using black letters as distractors. Within a deck, then, on the average, two-thirds of the cards with digits as distractors were the inconsistent distractor condition while the other one-third were the consistent distractor condition (excluding the stimuli for the 0-red-letter condition). All cards within a deck were randomized, and therefore all conditions were mixed. The subjects made their responses vocally. To measure RT, a clock was started at the onset of each stimulus array and was stopped by a voice key.

Each subject received all nine decks, and the order of the decks was counterbalanced according to a Latin square. The subjects were given the option of taking a 5-min break after the fifth deck. Twenty-four stimulus arrays were prepared to present to the subjects for an initial practice session. Data were not collected on the practice trials.

Procedure. The subjects were read the instructions for the experiment by the experimenter. The procedure for each trial was as follows. Each trial began with the subject fixating a dot at the center of the imaginary circle. The center of the imaginary circle

coincided with the center of the viewing field. A .5-sec warning buzzer was sounded, and at the offset of the buzzer the stimulus array was presented for 1 sec. The fixation point reappeared at the offset of the stimulus array. Subjects vocally reported the number of red letters present. Their instructions emphasized both speed and accuracy. The subjects were warned that the distractors could be interfering and that it would be to their advantage to try to ignore the black items and to just attend to the red items. Three and one-half seconds elapsed from the onset of one trial to the onset of the next trial. The first five trials at the beginning of each deck were practice trials selected from the cards used in the initial practice session; data were not collected on these trials.

Results and Discussion

The results for the 0-, 1-, 2-, and 3-red-letter conditions are shown in Figure 1. In the figure, mean RT to report the number of red letters is plotted as a function of the number of black items. The four sections of the figure going from bottom to top correspond to the 0-, 1-, 2-, and 3-red-letter conditions. Within each section, mean RT for the three distractor conditions (letters, consistent digits, and inconsistent digits) is plotted as a function of the number of distracting black items.

An analysis of variance was performed on the data. The factors in the ANOVA were number of red

Figure 1. Mean reaction to count red letters as a function of the number of black items within each type of black distractor condition for the 0-, 1-, 2-, and 3-red-letter conditions. Experiment 1. (Since the only digits used as black distractors were 1, 2, and 3, for the 0-red condition, there are only inconsistent digits and letters as the type of distractors.)

letters,³ number of black letters,⁴ and type of black distractor (letter, inconsistent digits, and consistent digits). The main effect of number of black items did not reach significance [$F(2,16) = 2.271$, $p > .10$], indicating that mean RT did not increase as the number of black items in the arrays increased. Separate trend analyses were conducted for each of the three distractor conditions within the 1-, 2-, and 3-red-letter conditions (nine analyses in all). No linear or quadratic components were significant ($p > .05$), except for the linear component of the 3-red-letter/consistent-distractor condition [$F(1,8) = 7.36$, $p < .05$]. We have no interpretation to offer for this particular pattern of results.

The effect of number of red letters was highly significant [$F(2,16) = 50.601$, $p < .001$], indicating that mean RT increased as the number of red letters in the arrays increased. Mean RTs for the 1-, 2-, and 3-red-letter conditions (collapsed over all other factors) are 591, 655, and 680 msec, respectively. These significant effects replicate the Francolini and Egeth (1979) results demonstrating that RT for counting red letters is independent of the number of black items, but is affected by the number of red items.

The main effect of distractor type failed to reach significance [$F(2,16) = 1.10$, $p > .20$]. Digit distractors that were inconsistent with the response for a given array did not result in an increase in RT as compared to letters or even consistent digit distractors. The means for the letter, inconsistent, and consistent distractor conditions were 641, 646, and 636 msec, respectively. One should note that the black items on the white background produced greater brightness contrast than the red items on the white background. Thus, even though the black items are salient, they are essentially ignored.⁵

No other effects reached significance ($p > .10$ in all cases), except for the Number of Black Items by Distractor Type interaction [$F(4,32) = 2.908$, $p < .05$]. We have no interpretation to offer for this effect. The overall error rate averaged across subjects in this counting task was .6%, with no subject obtaining an error rate of higher than 1.5%. Because of these low error rates and an absence of consistent trends in the errors, the error data were not submitted to an ANOVA.

The results of Experiment 1 replicate the results of Francolini and Egeth (1979) in that RT to count red items is independent of the number of black items. Furthermore, the previous conclusion that the black items are essentially ignored was strengthened by the lack of a main effect of distractor type. It is important to point out a logical problem with this conclusion. As indicated earlier, our argument was as follows: If black items are ignored, mean RT to count red items should be independent of the number and nature of the black items. Our data do, indeed, indicate independence. However, to reason backwards

that this establishes the validity of the premise is not strictly correct, as it is possible to argue that the observed data can be explained in some other way. For example, even though inconsistent digits have been shown to yield Stroop-like interference in previous experiments (e.g., Morton, 1969; Windes, 1968), one might wish to argue that the conditions of our experiment conspired to reduce the readability of the digits. Such a situation might arise, for example, if subjects attempted to minimize interference by defocusing their eyes or fixating away from the center of the display. It might also arise if stimulus elements were printed in an unusual typeface and were not easily recognizable, but their color was readily apparent. In such a case, one could hardly expect the nature of the to-be-ignored material to affect processing time. Experiment 2 was conducted to find out whether interference would be demonstrated if subjects were instructed to attend to the inconsistent information. Thus, in Experiment 2, both the to-be-counted red items and the to-be-ignored black items consisted of either elements that were inconsistent with the required response or not inconsistent with it. Thus the degree of Stroop-like interference could be assessed separately for the red and black items. More specifically, the to-be-counted red items were either red letters (as in Experiment 1) or red digits that were inconsistent with the correct response for that trial. It should be noted that if evidence of interference is obtained when subjects are asked to attend to inconsistent digits, visibility cannot be used as an alternative explanation for the lack of interference from inconsistent digits when occurring as black distractors (as in Experiment 1), since both red and black items were made using the same template and thus are equally visible (if anything, the black items are easier to see due to greater contrast). The only difference in these two situations is that subjects are asked to attend to the digits (because they are red items) in one case and to ignore them in the other case (because they are black items). The results of Experiment 2 indicate that interference effects occurred when inconsistent information was a property of the red items but not when a property of the black items.

EXPERIMENT 2

In this experiment, we presented two types of red target items (to-be-attended items): either identical letters as in Experiment 1 (baseline target condition) or identical digits that were inconsistent with the correct response for the number of red items on that trial (inconsistent target condition). This inconsistent-red-digit condition presents the same inconsistent information as the "Stroop" condition for the black items in the previous experiment, but here it occurs as a property of the to-be-attended items. The sub-

Table 2
Black Item Conditions Used With Each Number of Red
Items Condition in Experiment 2

Number of Red Letters	Number of Black Items				
	1	2	3	4	5
3	X		X		
2	X			X	
1	X				X
0	X	X	X	X	X

Note—X indicates the specified condition was used in the experiment.

ject's task is to report the number of red items. The red-letter-condition provides a baseline from which to compare the effect of attending to the potentially interfering information from the inconsistent red digits. If our Stroop condition is a sensitive test of whether complete perceptual processing is occurring, then mean RT to count inconsistent red digits should be longer than for counting red letters. If there is no effect of the type of red target, then the Stroop distractor condition is not an appropriate test for the processing of the black items.

As in the preceding experiment, there were three kinds of black distractors (letters, inconsistent digits, and consistent digits). These were combined factorially with the two kinds of red targets. Since it has been shown twice (Francolini & Egeth, 1979; Experiment 1 of the present paper) that mean RT to count red items is independent of the number of black items, we felt that it was no longer necessary to use all the levels of the number of black distractors condition previously used with each red-letter condition. When red items were present only the extreme values for the levels of the black distractor conditions were used. That is, for the 1-, 2-, and 3-red-item conditions, we used only the 1-black-distractor-item condition and the black-distractor condition for each number of red items condition that made the total array size (red plus black) six items (see Table 2). In addition, there was a condition (0 red items) in which no red items were present; the rationale for including this condition is given in the Design section.

Method

Subjects. Twelve students at The Johns Hopkins University served as subjects in the experiment and received either \$2 or partial fulfillment of an undergraduate course requirement. The subjects were tested individually for approximately 45 min.

Stimulus material. Except for the fact that the red items in this experiment were either identical red letters or identical inconsistent red digits, the arrays were constructed in essentially the same way as in Experiment 1. All arrays containing red letters as targets were exactly the same as arrays containing inconsistent red digits, except for the fact that red letters were used in the arrays instead of the red digits. Thus, red letters in a particular array occurred in the same array locations as the red digits in a corresponding red-digit array, and the same black distractors were used in the same locations in the two arrays.

All letters (except I, O, Q, and S) were used approximately equally often as elements for the red-letter conditions. The digits 1, 2, and 3 were used approximately equally often as elements for the inconsistent-red-digit conditions. For the inconsistent-red-digit conditions, if 1 red item was present it would be either a 2 or a 3, if 2 red items were present they would be either 1s or 3s, and if 3 red items were present they would all be either 1s or 2s.

All letters (except I, O, Q and S) were used approximately equally often for the black-letter distractors, with the constraint that the same letter not be used both as a target and distractor in the same array. The digits 1, 2, and 3 were used approximately equally often for the black-digit distractors. In this experiment, both targets and distractors in the same array could be digits, but the same digit could not occur as a target and distractor in the same array.

Design. As in Experiment 1, subjects again counted the number of red items. Zero, 1, 2, or 3 red items were present on each trial. For both kinds of red targets (i.e., red letters and inconsistent red digits), three kinds of black distractors were used: black letters (baseline distractor condition), black digits that were inconsistent with the numerical response for that trial (inconsistent distractor condition),⁶ and black digits that were consistent with the numerical response for that trial (consistent distractor condition). On each trial (except for the 0 red condition), either 1 black item or that number of black items such that the total array size was equal to 6 was presented; the number of red items and the number of black items varied independently from trial to trial. Disregarding the 0-number-of-red-items condition for a moment, all conditions were factorially combined for a total of 36 conditions: kinds of red items (2) by number of red items (3) by number of black items (2) by kinds of black distractors (3).

Because we chose not to include all intermediate levels of the black-distractor conditions, total array size is confounded with the number of red items for the 1-, 2-, and 3-red-item conditions with the 1 black distractor. That is, a total array size of 2 would occur only for the 1-red-/1-black-item conditions, a total array size of 3 would occur only for the 2-red-/1-black-item conditions, and a total array size of 4 would occur only for the 3-red-/1-black-item conditions. To avoid facilitation of responses in these conditions compared to the other conditions in which the total array size was equal to 6 (and so there was not this confounding), we included a 0-red-item condition. In this condition, there were arrays with 1, 2, 3, 4, or 5 black items. In this way, alternative responses were possible for the smaller array sizes, and it was less likely that RT in those conditions that had 1 black distractor would be facilitated due to redundancy from the confounding with total array size.

For each of the five levels of the number of black distractors (1, 2, 3, 4, or 5) in the 0-red-item condition, on one-half of the trials the distractors were identical digits and on the other half they were identical letters. For the 0-red condition, the digits 1, 2, and 3 were used equally often as distractors; letter distractors were randomly selected from the set of permissible letters. Thus, these 10 conditions (5 levels by 2 types of black items) for the 0-red-item conditions plus the 36 conditions discussed previously combined for a total of 46 conditions in this experiment. Three decks of 46 stimulus cards were constructed. Each deck had one stimulus card for each condition. All conditions within decks were randomized. Each subject viewed each of the three decks three times. All subjects viewed the trials within a deck in the same randomized order. The first five trials of each deck were randomly selected from a separate deck of practice cards, and these trials were not included in any analyses. The stimuli for the practice trials were selected randomly for each subject. The order of the decks was counterbalanced according to a Latin square. For each subject, the same counterbalanced order for the three decks was used for each replication. The subjects were given the option of taking a short break after five decks.

Procedure. The procedure for each trial was exactly as in Experiment 1. The subjects were asked to report the total number of red items as quickly as possible, but accuracy was also stressed. They

were not informed that the inconsistent digits could be distracting. This information was omitted to minimize the possibility that subjects would attempt to fulfill experimenter expectations.

Results and Discussion

The results for counting the 0-, 1-, 2-, and 3-red-item conditions are shown in Figure 2. In the figure, mean RT to report the number of red items for the two target conditions is plotted as a function of the number of black items. The four sections of the figure, going from bottom to top, correspond to the 0-, 1-, 2-, and 3-red-item conditions. Within each section, conditions containing the red-letter targets are designated by the solid lines and conditions containing inconsistent red-digit targets by the dashed lines. (Note that a differently coded line is used for the 0-red-item condition, since it contained neither red letters nor inconsistent red digits.) An analysis of variance was performed on the data. The factors in the ANOVA were kind of red item (inconsistent red digit vs. red letter), number of red items (1, 2, or

3),³ kind of black distractor (baseline, inconsistent, consistent), and number of black items (1 black item or that number of black items such that the total array size was six⁷).

The main effect of kind of red target was highly significant [$F(1,11)=60.43$, $p < .001$], indicating that mean RT to count inconsistent red digits was significantly slower than for counting red letters. Thus, the nature (semantic content) of the stimuli that the subjects are counting (attending) affects performance. Mean RT for counting inconsistent red digits was, on the average, 26 msec slower than for counting red letters. This result validates our use of inconsistent digits as a source of interference. The main effect of number of red items was also highly significant [$F(2,22)=50.3$, $p < .001$]. Mean RT to count red items increased as the number of red items in the arrays increased.

The effect of number of black items [$F(1,11)=3.386$] failed to reach significance ($p > .05$), indicating that mean RT to count red items is independent of the number of black items. The effect of kind of black distractor [$F(2,22)=1.38$, $p > .25$] also failed to reach significance. The nature (semantic content) of the black stimuli that were present in the arrays but not to be counted did not affect performance. Mean RTs for the consistent, inconsistent, and letter distractor conditions (collapsed over all other factors) were 683, 687, and 686 msec, respectively. Thus, subjects were again able to ignore the black items in this counting task, even though the black distractors were given Stroop-type quality.

Other significant effects were the Kind of Red Item by Kind of Black Distractor interaction [$F(2,22)=4.216$, $p < .05$], the Number of Red Items by Number of Black Items interaction [$F(2,22)=4.038$, $p < .05$], and the Kind of Red Item by Number of Red Items by Kind of Black Distractor interaction [$F(4,44)=5.16$, $p < .005$]. We have no particular interpretations to offer for these effects. The overall error rate averaged across subjects in this counting task was 1.4%. The error data were analyzed by an ANOVA. The significant effects obtained were consistent with the effects obtained from the RT data and therefore will not be discussed further.

When subjects counted inconsistent red digits, mean RT was on the average a significant 26 msec slower than when counting red letters. When the black items were inconsistent digits, mean RT was on the average only 1 msec slower than when the black items were letters. In this experiment, however, the red items were the to-be-attended items and the black were not. One must keep in mind that the red and black items were all equidistant from the fixation point, that they were all randomly located around the imaginary circle, and that they were made using the same template so that the legibility of the black items was the same as that of the red items. Since

Figure 2. Mean reaction time to count red items as a function of the number of black items within each type of black distractor condition for the 0-red-item condition (panel A) and the 1-, 2-, and 3-red-item conditions (panel B). In each section of panel B, the kind of red items is indicated by the type of line (---- inconsistent red digits, — red letters). Experiment 2. (In panel A, a third type of line (—) was used for the 0-red-item condition, since neither red letters nor inconsistent red digits were present in the arrays. Also, since the only digits used as black distractors were 1, 2, and 3, there are only inconsistent digits and letters for the type of distractors.)

the Stroop information affected mean RT only when it was a property of the to-be-attended red items, our previous claim that the black items remain relatively unprocessed when the subject's task is to count red items can be reemphasized. The major results obtained in Experiment 1 were replicated in this experiment, since mean RT was again not affected by either the kind of black distractor or the number of black items. Both Experiment 1 and Experiment 2 strengthen the previous conclusion that the black distractors were essentially ignored.

It might be argued that the significant 26-msec effect for counting inconsistent digits as compared to red letters might not be due to interference at all, but simply be due to some inherent difference that makes counting digits slower than counting letters (e.g., some physical difference in the stimuli such as in surface area, symmetry, etc., which may cause digits to be encoded more slowly than letters). To refute that point, we point first to the asymmetry in the difference between inconsistent digits vs. letters as red and as black items. If the 26-msec effect obtained for the red targets was due to an inherent difference between digits and letters and not to Stroop-like interference, then that same difference should be present for these stimuli when occurring as black items. On the contrary, the black-inconsistent-digit condition was only 1 msec slower than the black-letter condition (when collapsed over all other factors).

In addition, Windes (1968) had subjects perform a task very similar to that used in the present series of experiments. He had subjects count the number of digits presented. Two conditions were used in his experiment: in one condition, the digits displayed were consistent with the numerical response for the quantity of digits present (e.g., 1, 22, 333), and in the other condition, the digits displayed were inconsistent with the response for the quantity (numerosity) present (e.g., 2, 33, 111, 3, 222). Mean RT to count when the displayed digits were inconsistent with the numerosity was significantly slower than when the displayed digits and the numerosity were consistent. The same stimuli (digits) were used in both conditions, so the difference in RT obtained by Windes had to be due to interference from the inconsistent information (which is analogous to the Stroop-type interference used in our experiments). Thus, although some part of the difference found between the inconsistent-red-digit condition and the red-letter condition might possibly be due to stimulus differences, it seems clear that an important component of the difference is due to interference from the inconsistent information.

In these first two experiments, the arrays were presented for 1 sec, which is sufficient time to allow eye movements. If subjects had moved their eyes to fixate the red items, the black items would have fallen further from the fovea than the red items and

it would not be surprising if RT was unaffected by distractor type, since the black items would be less visible. Thus, Experiment 3 was conducted to rule out this alternative explanation to our alleged evidence of early selection. All stimuli and procedures from Experiment 2 were used in Experiment 3. The only difference was that the duration of the stimulus arrays was changed from 1 sec to 200 msec. Since the major results of Experiment 2 were completely replicated in Experiment 3, the eye-movement explanation was ruled out.⁸

EXPERIMENT 3

Method

In this experiment, the stimulus arrays from Experiment 2 were presented for 200 msec to eliminate the possibility of eye movements. Six subjects were run, and they received two full blocks of practice before the actual experiment to stabilize their performance. In all other respects, except for the array duration, this experiment was carried out in the same way as Experiment 2.

Results and Discussion

The results for this experiment are plotted in Figure 3 and are quite similar to the results of Experiment 2. The results from the ANOVA are as follows (discrepancies between this experiment and Experiment 2 will be pointed out): The main effect of kind of red target was highly significant [$F(1,5) = 23.42$, $p < .005$]. Mean RT to count inconsistent red digits was on the average 18 msec slower than for counting red letters. The main effect of number of red items was also highly significant [$F(2,10) = 33.44$, $p < .001$], indicating that mean RT to count red items increased as the number of red items in the arrays increased. The main effect of the number of black items [$F(1,5) = 5.42$] failed to reach significance ($p > .05$), indicating that mean RT to count red items is independent of the number of black items. The effect of the kind of black distractor [$F(2,10) < 1$], also failed to reach significance. Mean RTs for the consistent, inconsistent, and baseline (letter) distractor conditions (collapsed over all other factors) were 625, 629, and 628 msec, respectively. Thus, the Stroop information again affected mean RT only when occurring as a property of the to-be-attended red items and not when occurring as a property of the black items.

Other significant effects were the Kind of Red Item by Kind of Black Distractor interaction [$F(2,10) = 4.51$, $p < .05$] and the Number of Red Items by Kind of Black Distractor by Number of Black Items interaction [$F(4,20) = 3.72$, $p < .05$]. We have no particular interpretation for these effects. These two interactions were not significant in Experiment 2 (three different interactions reached significance in Experiment 2). Since no interaction was significant in both Experiment 2 and Experiment 3 (although all main effects significant in Experiment 2 were also significant in Experiment 3), we suggest that the interactions may safely be ignored.

Figure 3. Mean reaction time to count red items as a function of the number of black items within each type of black distractor condition for the 0-red-item condition (panel A) and the 1-, 2-, and 3-red-item conditions (panel B). In each section of panel B, the kind of red items is indicated by the type of line (--- inconsistent red digits, — red letters). Experiment 3. (In panel A, a third type of line (---) was used for the 0-red-item condition, since neither red letters nor inconsistent red digits were present in the arrays. Also, since the only digits used as black distractors were 1, 2, and 3, there are only inconsistent digits and letters for the type of distractors.)

The overall error rate averaged across subjects was 2.1%. The error data for each subject were also included in an ANOVA (the same factors as in the RT ANOVA). The kind of red target was the only significant effect, and this was due to the fact that more errors were made in the inconsistent-red-digit condition than in the red-letter condition. Since the major results from Experiment 2 were essentially replicated, and since we eliminated eye movements as an alternative explanation, the argument in favor of early selection is strengthened.

GENERAL DISCUSSION

A short summary of the results is as follows: Experiment 1 replicated the results of Francolini and Egeth (1979) in that, for the task of counting letters in a target color, mean RT increased as the number of items in the target color increased, but was independent of the number of items that were not of the

target color. More specifically, mean RT increased as the number of red items increased but not as the number of black items increased. In addition, mean RT for counting in Experiment 1 was unaffected by the nature of the distractor items. Counting red letters was essentially no different when black items were letters, consistent digits, or inconsistent digits (Stroop condition). Experiment 2 validated our use of the Stroop condition as a test of whether complete processing of to-be-ignored (black) items was occurring. In that experiment, "Stroop-like" inconsistent information lengthened mean RT when it was a property of the to-be-attended red items but had no influence when it was a property of the black items. Since the inconsistent digits affected mean RT only when they were red items, even though the visibility of the red and black items was essentially the same, the Stroop condition is a suitable test for examining the extent of processing of the to-be-ignored items. In Experiment 3, by changing the duration of the stimulus arrays from 1 sec to 200 msec, we ruled out the possibility that eye movements artifactually produced the effect of the inconsistent information for the red items but not for the black items by permitting the black items to fall further from the fovea than the red items.

In our experiments, the edge-to-edge distance between adjacent array items was approximately .9 deg of visual angle. Red and black items were randomly positioned, except that two red items never occurred in adjacent array locations. Although the locations adjacent to red items were sometimes empty, black items often occupied those locations, especially when the number of black and red items was large. This circumstance provided ample opportunity for black distractors to be processed, and yet no evidence for processing them was obtained using the interference paradigm.

What do these results mean? In the first place, we should make it clear that we do not think that these results totally disconfirm the concept of automatic activation. On the contrary, these experiments clearly demonstrate that the meaning carried by the relevant red items was automatically activated. The activation of this meaning was unnecessary to the task at hand, and was, in fact, inimical to good performance. Nevertheless, such activation appeared to be mandatory, just as in other instances of Stroop-like interference effects.

What the results suggest is that the mandatory activation of the meaning of an item may, under certain circumstances, be restricted to just those items that are deemed relevant (in the present series of experiments, on the basis of the physical cue of color). Since activation depends on relevance, it is not totally automatic.

We believe our findings contradict theories that propose that well-learned stimuli will be processed

regardless of where attention is directed (e.g., Deutsch & Deutsch, 1963; LaBerge & Samuels, 1974; Norman, 1968; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). The difference between the present position and the automatic activation position may be seen clearly by contrasting the data of the present studies and how they support a model of early selection with one of the experiments reported by Shiffrin and Schneider (1977) and how it supports their model. In the comparable experiment in that paper (Experiment 4d), subjects were required to indicate whether or not a target letter appeared in a display. The display consisted of a rapidly presented sequence of frames, each frame containing four characters at the corners of an imaginary square. The subjects were told that the target letters could appear only in the upper-left or lower-right positions. Thus, one diagonal was relevant and the other diagonal was irrelevant. What is of chief interest to the present discussion is the nature of the items on the irrelevant diagonal. On some trials, a foil (a digit) was presented in either the lower-left or upper-right positions. The subjects had had some special previous experience with these foils. Specifically, in a previous experiment, the subjects had had thousands of trials in which digits were targets and letters were nontargets. This procedure, which Shiffrin and Schneider refer to as consistent-mapping, results in automatic-attention responses being attached to the digits, according to their theory.

The issue in their Experiment 4d, then, was whether previously consistently mapped foils would interfere with target detection even though the foils appeared in spatial locations that were known to be irrelevant. The results clearly indicated that the foils did interfere with target detection.

In many respects, the present experiments are analogous to the Shiffrin and Schneider experiment. In our case, instead of relevant and irrelevant diagonals, we have items defined as relevant and irrelevant on the basis of color. Also, instead of basing the experiment on automatic-attention responses learned in a previous experiment, we used a Stroop-like paradigm in which digits presumably engender automatic-attention responses as the result of extensive everyday experience. (As a check on the potency of those assumed implicit responses, note that there was a Stroop-like interference effect for the items appearing in the relevant color.) Despite the formal similarities of the experiments, their outcomes are quite different; we obtained essentially perfect attentional selectivity, and they did not. There are a formidable number of differences between the Shiffrin and Schneider experiment and our experiments, and so it is not clear how to explain the difference. We suspect the difference is due to the difference between the tasks. In the Shiffrin and Schneider experiment, the task was target detection. Francolini and Egeth (1979) have already shown that, with that kind of

task, subjects do not (or can not) ignore irrelevant items. In our present experiments, subjects simply counted the number of red items. In this circumstance, for as yet undetermined reasons, subjects give every evidence of being able to selectively process the relevant items. Of course, it is possible that some other factor is responsible for the difference between Shiffrin and Schneider's Experiment 4d and the present experiments. For example, color may permit more efficient attentional selectivity (even in the face of spatial uncertainty) than instructions to attend to one specific diagonal of a square display. Further research will be needed to resolve this issue.

To put our findings in historical perspective, note that ever since Broadbent proposed his early filter model, evidence in support of automatic activation models and against models proposing an early selection mechanism has been provided by demonstrating *some* processing of unattended items (e.g., Lewis, 1970; Moray, 1959). In other words, Broadbent's model had to support the null hypothesis that no processing occurred on unattended channels. Rejecting models favoring early selection only required rejecting that null hypothesis.

As Kahneman and Henik (in press) have pointed out, it is possible to turn the tables on the automatic activation theories by making those theories support the null hypothesis that selection is not at all possible. In other words, if there is no early selection, as suggested by automatic processing theories, then those theories must support the null hypothesis of no difference in the interfering "potency" of the red and black items. We claim that, for the counting task, we have obtained very strong evidence of early perceptual selection. In fact, if we had obtained *some* interference due to inconsistent information from the black-digit condition but significantly more interference due to inconsistent information from the red-digit condition, that would have been sufficient evidence of some degree of early selection. In other words, some interference for the black Stroop but significantly more for the red Stroop condition would have been sufficient to reject the null hypothesis of no difference in potency for the red and black items. However, in Experiments 2 and 3, there was virtually no Stroop effect for the black items (1 or 2 msec), while the effect for the red items was substantial (22 msec, on the average). These data thus provide very strong evidence of differential processing of attended and unattended stimuli. This conclusion is consistent with that of Kahneman and Henik, who also obtained data that are inconsistent with automatic activation theories. Using a related paradigm, they found that the magnitude of interference effects from inconsistent information depended upon whether the direction of attention was toward or away from the inconsistent items.

We provide these data as evidence to reject the automatic activation theories that claim that all stim-

ulus inputs receive complete perceptual processing and that early selection is not possible. If the black items were processed fully to the point of recognition (and thus there was, in fact, no early selection in these experiments), something special about the counting task conspired to eliminate the usual Stroop interference from the black items (but not from the red). Indeed, we temper our conclusion of essentially perfect selection, since such a conspiracy is always a possibility, even if a remote one. We can provide a relevant example. It has been suggested (Lashley, 1942; Reynolds, 1961) that pigeons trained to peck to a particular multidimensional stimulus (e.g., a specific color-form configuration) but trained to refrain when another was present attended only to a particular single dimension of the multidimensional configurations. This conclusion was derived from experiments demonstrating that only a particular dimension of a multidimensional configuration, when presented individually, could elicit the previously trained behavior. Wilkie and Masson (1976) have now refuted that conclusion concerning selective attention. They demonstrated that pecking to a new multidimensional stimulus configuration was acquired faster if one of the dimensions of the new configuration was one of the allegedly "unattended" dimensions in the old configuration. Thus, a more appropriate test was necessary to demonstrate the fallacy of the plausible conclusion drawn from previous work.

We conclude, in retrospect, that when data like Moray's (or any other data demonstrating processing of information on the unattended channel) were taken as evidence that all stimulus inputs receive complete perceptual processing, that claim was probably too strong. Occasionally, hearing one's name on an unattended channel is not necessarily the same as the full processing that attended items receive. It will be interesting to see if future research, in turn, overturns our strong conclusion by developing a more appropriate test.

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NOTES

1. In discussions of early selection, other researchers have often used the word "filter." However, it is not our intention to imply a special mechanism that actively prevents the irrelevant information from being processed. It is equally plausible to consider selection to be a constructive process in which certain items are processed while others are just "left behind" (e.g., Hochberg, 1970; Neisser, 1967).
2. If RT to count the number of red items is independent of the nature and the number of the black items, we will make the claim that the black distractor items are not being fully processed. This claim makes the assumption that if a stimulus input receives complete perceptual processing, information about that stimulus item is automatically forwarded to an output stage where response

conflict could occur. We think that this assumption is not unreasonable. For example, Posner and Snyder (1975) cited Stroop interference as evidence for automatic activation, and thus implied that processing can proceed automatically to an output stage. This assumption may not even be necessary, however, since some researchers (Hock & Egeth, 1970) have argued that Stroop interference is not due to conflict at the response selection stage but rather to conflict during stimulus encoding.

3. The primary concern in this experiment is whether subjects can count the red items and ignore the black distractors. The 0-red-letter condition is obviously a special case in this experiment, since we are asking subjects to attend to something not present in the array. The uniqueness of this 0-red-item condition is further emphasized by the fact that some of the subjects chose to respond "none" (not normally considered one of the cardinal numbers) as opposed to "zero" to this condition. For this reason, the 0-red-letter condition was not included in the ANOVA, although all data from this condition are plotted.

4. Because the maximum array size was 6 items (including both red and black items) for the 1-, 2-, and 3-red-letter conditions, there were five levels of distractors for the 1-red-letter condition (1 to 5 black items), four levels of distractors for the 2-red-letter condition (1 to 4 black items), and three levels of distractors for the 3-red-letter condition (1 to 3 black items). The number-of-black-items factor in the three-factor ANOVA used only the 1-, 2-, and 3-black-item conditions (which were present in all the red-letter conditions), although all data are plotted. Subsequent trend analyses (reported later in the text) are based on all levels of distractors for each red-letter condition.

5. It might be argued that, even though black items contrast more with the background than the red items, the color red is, in some sense, more "alerting" than black. If this is the case, then one might further argue that the ability to ignore the black items is not surprising. However, there are grounds for rejecting the idea that the red items are more conspicuous or attention grabbing than the black items. First of all, Francolini and Egeth (1979) report two search experiments that were exactly the same (arrays contained red and black letters) except for the fact that in one experiment the possible targets were red letters and in the other the possible targets were black letters. The major results in the two experiments were identical. In addition, we have conducted a separate experiment ($N=6$) in which arrays composed of red and black letters were presented and the subjects' task was to report as many of the array items as possible independent of their color (whole report). There was no difference ($p > .10$) between

the number of red items and the number of black items correctly reported. Moreover, there was no difference between red and black items with respect to order of report. These results argue against any differential preference for the red compared to the black items.

6. For the case where the inconsistent black digits were combined with the inconsistent red digits, since the same digit could not occur both as a red target and black distractor in the same array, once the inconsistent red digit was chosen, the inconsistent black distractor was determined (since only the digits 1, 2, and 3 were used). For example, with two red items in the inconsistent-red-digit condition, either 1s or 3s could be used for the red items. If 1s had been used as the red items, 3s had to be used as the inconsistent-black-digit distractors. If 3s had been used as the red items, 1s had to be used as the inconsistent-black-digit distractors. The same logic follows for the 1- and 3-inconsistent-red-digit conditions.

7. Because the independence of RT and number of black items had been demonstrated twice previously (Francolini & Egeth, 1979; Experiment 1 of the present paper), we felt that we were not in violation of the assumption of the analysis of variance that levels of a factor should be the same for every level of the other factor(s). We assume that if the levels for the number of black items had been equal, the data used in the ANOVA would have been essentially the same as those used in this analysis.

8. Another criticism of Experiment 2 might be leveled at the discrepancy in the number of alternative red digits and red letters used in the experiment. Any letter (except I, O, Q, and S) could occur in the letter conditions, while only the digits 1, 2, and 3 were used in the inconsistent-red-digit conditions. It is not obvious just how this discrepancy could result in faster RTs in the letter condition than in the digit condition. Nevertheless, we thought it was necessary to rule out this possible artifact. In an experiment that will be reported elsewhere, we have collected some data that suggest that this criticism is not valid. Specifically, we performed an experiment in which we equated the number of alternative digits and number of letters. As in Experiments 2 and 3, subjects counted the two kinds of red items: letters and inconsistent digits. The significant main effect of kind of red target [$F(1,7)=10.66$, $p < .025$] indicated that counting inconsistent red digits was slower than counting red letters. Thus, the effect on performance due to the nature of the red items was replicated.

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