Journal of Experimental Psychology:
Human Perception and Performance
1984, Vol. 10. No 1, 429-448

Evidence Against Late Selection: Stimulus Quality Effects in Previewed Displays

Harold Pashler
University of Pennsylvania

Strong late-selection theories of visual attention assert that when multiple stimuli belonging to familiar categories are presented, their identities are computed automatically and tagged for their locations. When selection by location is required, the identities are said to be retrieved without any need to repeat the perceptual processing. Five experiments designed to test this account are reported. All included a condition in which a display of eight characters was previewed for several hundred ms; a bar probe then designated one character the target for speeded classification. Stimulus factors that slow the character encoding process were manipulated. If selection is late, then such factors should have no effect in this condition because the probe occurs after automatic encoding is complete. There was no evidence of any such reduction in these factors' effects on reaction times or errors. The results were unchanged when catch trials with postdisplay masks were included, to discourage any optional delay of encoding. Several possible accounts are considered of how the strong late-selection model may be wrong, even if parallel encoding occurs in various situations.

Theoretical discussion of attention has often been organized around the question of what happens when a person selectively responds to one of many simultaneously available stimuli. On the one hand, all of the stimuli might immediately be identified without intention or interference; selection might fetch the *results* of this parallel process. On the other hand, selection might precede the perceptual analysis. These two views are generally referred to as *late selection* and *early selection.* This issue has understandably been confounded in many discussions with the question of whether simultaneous identification of stimuli is possible under any circumstances. Despite the enormous amount of work devoted to the late-versus early-selection issue, it has generally been addressed with relatively indirect measures, and a very wide divergence of opinion still exists on which type of model best represents the organization of human information processing (cf., for instance, Broadbent, 1982, and Kahneman & Treisman, in press, on the one hand; Posner, 1982, on the other).

Models of various aspects of divided attention characteristically make claims about limitations on human information processes that implicitly or explicitly refer to particular *stages* of information processing—for example, perceptual encoding (Johnston & Dark, 1982), decision making (Duncan, 1980) or response initiation (Keele & Neill, 1978). It is noteworthy, then, that experimental work in divided attention has not generally involved manipulation of stimulus factors in reaction time tasks targeted to affect particular stages of processing. (Some exceptions are the dual-task studies of Briggs, Peters, & Fisher, 1972; Egeth, Pomerantz, & Shwartz, 1977, November; and Logan, 1978). The present work involves an attempt to derive from the late-selection theory some fairly straightforward predictions for the behavior of stimulus factors in tasks involving selective classification. A related approach was recently applied to testing bottleneck models of the "psychological refractory period" (Pashler, 1984).

The author is supported by a National Science Foundation Graduate Fellowship, and subject funds for this work were provided by the Department of Psychology, University of Pennsylvania.

The author is grateful to Peter Badgio, Jonathan Baron, and James C. Johnston for many useful discussions of this work. In addition, John Duncan, Jeff Miller, Jacob Nachmias, and Anne Treisman provided helpful comments and criticisms.

Requests for reprints should be sent to Harold Pashler, Department of Psychology, University of Pennsylvania, Philadelphia, Pennsylvania 19104.

The present experiments use the so-called *bar-probe task.* In this kind of experiment, subjects are presented with an array of characters, typically from 6 to 18, coupled with a probe (e.g., an arrow or bar) indicating which character the subject should respond to. The bar-probe task was introduced by Averbach and Coriell (1961) and has been widely used to study visual ("iconic") persistence. For these purposes, the subject's task is generally to name the probed character, and performance is studied by looking at response accuracy when the bar probe follows the offset of the display at varying intervals. The basic observation made by Averbach and Coriell (paralleling Sperling's 1960 observations in his very similar partial report paradigm) is now quite familiar: Subjects can report the identity of probed items quite accurately even when the cue follows the array offset. The level of performance decreases rapidly as the array offset-probe onset interval is lengthened to several hundred milliseconds.

Much of the evidence used to support early-or late-selection models has come from experiments concerning visual search or Stroop effects. However, the late-selection view described earlier makes a number of claims that apply to an enormous range of laboratory and real-world situations, including the partial report paradigms. Basically, proponents of the late-selection view propose that identification of stimuli that belong to well-learned and frequently encountered categories occurs regardless of whether the subject "pays attention" to the stimuli—that is, whether he or she tries to become aware of them for the purpose of selecting a response. Furthermore, identification is involuntary: It cannot be suppressed even when it would be advantageous to do so, a fact that is supposed to account for the various Stroop effects (e.g., Eriksen & Hoffman, 1972; Shaffer & LaBerge, 1979; Stroop, 1935). Together, these alleged characteristics of perceptual processing—involuntariness and unlimited parallel processing—constitute the common definition of *automatic processes* (e.g., Posner & Snyder, 1975).

If this view is correct, a particular temporal sequence of processes should occur in the bar-probe task. When the array is presented, the preattentive identification process automatically determines the identities of all of the characters in parallel. The process of selecting by location a particular item for report follows this identification process. Thus, the location serves as a retrieval cue to access the already computed identity corresponding to that location.

This model has in fact been specifically suggested by a number of proponents of the late-selection view, although the evidence they offer comes primarily from other paradigms. Shiffrin (1976), for instance, wrote that

> each character in Sperling's experiment is analyzed to a high degree, including for example the character's visual name, verbal code, and classification (letter or number). . . . The limited report is due either to the limited speed with which the subject can report these fully analyzed characters before the decay occurs, or to interference caused by the report process itself. Note that controlled processing may indeed occur in this model, but subsequent to the perceptual processing stage, while forgetting is occurring, (p. 180)

Similarly, Coltheart (1980) suggested that selection in the bar-probe task may involve a process of "lexical stabilization," which preserves in a more durable format the already computed identities of the selected subset of the activated entries in long-term memory. Duncan (1980, 1981) and van der Heijden (1982) also presented detailed proposals to this effect.

This kind of late-selection model for selective visual report follows very naturally from the general views of late-selection theorists. According to this view, bottlenecks in human information processing are located subsequent to perceptual analysis. The limits might occur in transfer to a more limited storage system that is necessary to support response selection (Duncan, 1980). Alternatively, the bottleneck might occur even later in the initiation of distinct responses (Keele & Neill, 1978). Actually, it is unclear whether the latter writers regard response production as the only bottleneck in tasks where there are many stimuli; their discussion centers on refractory period paradigms with only two stimulus-response (S-R) processes. In any case, *identification* of multiple items is regarded as both cost-free and involuntary when the subject has sufficient practice in dealing with the categories in question.

On the other hand, an early-selection view of performance in partial report tasks has also been expounded. This view is often summarized in the claim that iconic memory is precategorical. This statement occurs in a number of elementary textbooks (e.g., Howard, 1983), as well as in some more specialized texts (e.g., Spoehr & Lehmkuhle, 1982). On this account, presentation of the display automatically generates only a "raw" or "literal" representation of its contents. When a location is probed, the corresponding item is *then* identified. In the texts cited, this view is treated under the heading of sensory storage, separately from the discussion of attentional issues; a point sometimes overlooked is that the "precategorical" model of the icon is consistent with early-selection but not late-selection theory.

A serious problem with many treatments is the weakness of the evidence commonly cited in support of the precategorical icon. What is usually mentioned as compelling support is the finding that a partial-report superiority effect can be obtained for location and color cues, but not for category (digit/letter) cues (von Wright, 1968; Sperling, 1960; but see Duncan, 1983 and Merikle, 1980). That is, when subjects are cued (after display offset) to report only the letters from among a mixed letter/digit display, they cannot do much better than they would if they were asked to report all the characters they could, and then were marked correct on only the letters reported. Accounts such as those cited earlier have jumped from these data to the conclusion that the categorical information is *not present* in the iconic representation, and hence that it cannot serve as the basis for selection.

As Duncan (1981) and Coltheart (1980) have pointed out, the conclusion does not follow. It might be, as the late-selection model suggests, that a rapid automatic identification process produces a representation of the array complete with identities, tagged for their locations. However, it may be easier to utilize this representation in one way than in another. For instance, it might be possible for a "central processor" to ascertain directly what identity was found in a particular location, but not what items were present that belonged to some particular category. As Duncan (1981) puts it, the efficiency of different selection procedures is a "purely empirical matter" (p. 92). When the variety of plausible selection models that might be proposed is considered carefully, it becomes clear that accuracy data for different sorts of selection in partial-report tasks cannot provide strong evidence for any particular view of the basic attentional organization of the task.

Supporters of late-selection theory have pointed out another result from the bar-probe task that might lend support to the idea that selection follows identification of the array. In the bar-probe task, the accuracy of report declines rapidly as the onset of the probe is delayed beyond the offset of the array. Townsend (1973) appears to be the first to have systematically examined the nature of the errors that occur as this interval is lengthened. Mewhort, Campbell, Marchetti, and Campbell (1981) more recently analyzed these error patterns with exceptional thoroughness. Their data show that the increase in errors takes the form mostly *of substitutions* of other items from the array, rather than *intrusions* of items not present in the array. Coltheart (1980) points out that this would not make sense if the delay of the probe leaves the subject with nothing except a decayed but unprocessed image of the display. If this were the case, the subject should confuse the target with whatever letters are intrinsically most confusable with it, including other items from the array with a likelihood no greater than chance. The alternative Coltheart suggests is that the probe delay lessens the subject's ability to *localize* the target from among the set of already computed identities. On account of this, errors tend to be items that were in the array but were present at unprobed locations.

It is not clear that this particular evidence should be seen as compelling. It is plausible, as Sperling (1960) emphasized in his original report, that subjects generally begin strategically encoding items and storing their identities in a more durable form while awaiting the probe. This process might not be automatic in any sense. If they have lost the precategorical image when the probe arrives, they may simply make the best guess they can based upon the durable memory. Because this memory might also contain at least some rough location information, the substitution errors might tend somewhat to be neighbors of the target in the array, as Mewhort et al. observe. So as with von Wright's selection criteria data, these results do not compel one to accept either a late-or an early-selection model of partial visual report.

It appears, then, that the data generally cited to favor one or the other view of the role of attention in partial report paradigms are not conclusive. Basically, this seems to be because the dependent measure (reporting accuracy) cannot specify the nature of the representation from which selection takes place. The fundamental question of interest concerns what happens when a probe follows an array after some interval of time has elapsed: Does that probe trigger a process that consults low-level visual information and computes an identity, or does it trigger a process that fetches an already computed identity? The experiments reported here are based on a very simple idea: If this late probe triggers a process of fetching the *result* of a perceptual analysis, then stimulus factors that slowed the determination of that identity should no longer have any effect upon the RT. The reasoning is simple: If the encoding process has been completed before the probe arrives, then the speed of that encoding process can affect only the amount of time elapsed since encoding was complete, which can make no difference for the response time. This type of experiment requires the use of stimulus factors that delay the process leading from a retinal image to an identity code; they are henceforth referred to as *encoding factors.* The study of classification and search in reaction time (RT) paradigms has yielded a number of such encoding factors (Sanders, 1980; Sternberg, 1969.)

The experiments described here use a bar probe to designate the particular character that the subject must classify. In different blocks of trials, the probe appears 200 ms before the array onset, simultaneous with it, or 300 ms after the array (400 ms in the fifth experiment). In each experiment a factor believed to slow down the identification process is manipulated. Stimulus contrast and a manipulation involving both discriminability and size (letter case of the letters *A* and *E*) were chosen as the factors; the basis for their selection is discussed in the introduction to the experiments below.

The question of primary interest concerns the late-probe (300 ms) condition: Do the encoding factors still retard the RTs in that condition? Retardation would indicate that the visual processing of the target was not completed during the preview of this display. The early-probe conditions are included to provide some indication of the effects of the particular factors under different selection conditions. Different S-R mappings are used, but the basic idea is to require the subject to identify the probed character before making a response. In order to insure reasonably accurate performance, in the simultaneous- and late-probe conditions, the array remains visible until a short time (150 ms) after probe onset. Thus, the present experiments deal with a bar-probe task that is not necessarily iconic; that is, logically, the subject might consult the array of characters to perform the classification of the probed item. However, because selection in similar paradigms has been argued to take over 100 ms (Eriksen & Collins, 1969), this might, in fact, be an iconic memory task. Because the early selection theories described earlier explicitly make the same claim whether or not the stimulus is present, this is not a problem for the present purposes. (Of course, it might be difficult to apply the present reasoning to standard iconic perceptual situations, because the interpretability of RT measures might be jeopardized with very high error rates).

The overall RTs as a function of probe-onset condition will not be much discussed here. It might seem that late-selection theories predict an overall advantage for display preview. However, any such main effect predictions depend upon assumptions about the relative durations of encoding and of the probe-guided selection process. One consequence of this is that even if late selection were to be assumed, the status of the simultaneous probe condition cannot be known a priori. If the late-selection account were correct, but the encoding took less time than the selection process, then this condition would effectively involve a display preview, for present purposes. For that reason, late-selection models could account for identical overall RTs in the simultaneous and late-probe conditions, with quality effects washed out in both. On the other hand, if encoding took longer than selection, then the late-selection model would predict an intact quality effect in the simultaneous condition, with reduction in both quality effects and overall RTs only in the late-probe condition. Thus the critical test must involve quality effects, not merely overall RTs, because the relative durations of encoding and selection are unknown.

The present method makes no assumptions about such durations, other than that any capacity-free automatic encoding process should be completed in 300 ms (400 ms in Experiment 5), plus the time required for probe-guided selection, on virtually all trials. Because the entire choice RT for classifying single-letter stimuli is often under 300 ms, this would seem to be fairly certain. Substantially longer previews were not used because of concern that they would encourage the subject to develop strategies that could confound the design. For instance, if the display-probe interval were too leisurely, the subject might identify sections of the display all mapping onto the same response and prepare to execute that response contingent only on detecting a probe in that region. (In pilot work with 1-s previews, such strategies were reported.) Finally, the probe-display onsets were blocked in order to give the late-selection view a fair chance: Perhaps subjects have a complete register of identities but must prepare in advance if they are to make use of it.

It should also be pointed out that the method described here is best regarded as a paradigm capable of falsifying strong late-selection theories; it is not clear that the results could provide more than very weak support for the theory. For instance, if the effect of encoding factors *were* abolished with the late probe, it would not follow that the encoding process was automatic or preattentive in anything like the sense suggested by late-selection theory. As was pointed out in connection with the results of Townsend (1973) and Mewhort et al. (1981), evidence supporting the encoding of unreported items does *not* necessarily show that all items are encoded involuntarily and in parallel. In contrast, showing that available letters are *not* computed before selection *would* falsify the view that selection is applied to the results of an automatic parallel encoding of the entire array.

General Method

This section describes aspects of the method that are common to most of the experiments. Departures from this method will be noted specifically in the *Method* section of the experiment involved.

Subjects

The subjects for each experiment were students at the University of Pennsylvania paid for their voluntary participation.

Apparatus and Stimuli

In all experiments, the presentation of stimuli and collection of responses were controlled by a Commodore microcomputer. Arrays consisted of eight characters displayed in two rows of four characters. The display occupied two text lines vertically (approximately 2.4° visual angle) and seven horizontal character spaces (3.6° visual angle). The probe that marked off the single character requiring response consisted of a white square occupying a space the size of a single character. It was displayed two text lines above or below a target character on the top or bottom row, respectively (separated by about 0.8° visual angle). This was sufficient to avoid any obvious perceptual interactions between probe and target. In Experiments 1-4, the accuracy of stimulus presentation times was limited by the uncertain phase of the screen refresh cycle, operating at 60/s. In Experiment 5, precise synchrony was obtained using machine language procedures adapted from those detailed by Merikle, Cheesman, and Bray (1982).

Design

Each session consisted of a practice block followed by 12 blocks of trials. Each block consisted of 80 trials. The array-probe asynchrony was constant throughout a block. This made for four blocks at each of the three asynchrony levels. Thus, the experiment cycled four times through the three conditions. Within each block, all levels of the factor(s) of interest were equally represented, and subject to this limitation, the order of trials was individually randomized for each subject. Bar-probe positions were selected randomly with replacement; therefore, the number of occurrences of the different probe positions was only approximately equal.

Procedure

In all experiments, the sequence of events proceeded as follows. Each trial began with a fixation point displayed in the position of the middle of the array to follow. It lasted 0.5 s, followed by 0.5 s of blank screen. The events specific to the condition then followed.

The temporal sequence of events for the three array-probe asynchrony conditions is presented in Figure 1. Basically, a period of 150 ms during which both probe and array were simultaneously present was preceded by (a) 200 ms of probe exposure, (b) nothing, or (c) 300 ms of array preview, in the early, simultaneous, and late probe conditions, respectively. As the figure indicates, all reaction times are measured from the first point at which both stimuli are present.

The motivation for selecting this particular set of temporal sequences was as follows. It seemed important to prevent eye movements toward the target in the late and simultaneous probe conditions. Therefore, the interval between probe onset and array offset in these conditions was held to 150 ms. By necessity, the early-probe condition could not provide a totally comparable control condition in which to obtain a baseline estimate of the encoding factor effects, because of the likelihood of eye movements in the early condition. The occurrence of eye movements toward the target (in this condition only) was regarded as inevitable, because a probe preview short enough to prevent eye movements would probably not allow the selection process to be completed by the time of array onset. Eriksen and Collins (1969) have provided evidence that bar-probe selection generally takes about 150 ms. The 200-ms onset asynchrony, therefore, seemed like a reasonable choice to permit selection to precede stimulus onset. Aspects of the data discussed below suggest that this was successful.

Subjects were instructed to respond as rapidly and accurately as possible. At the end of each block, the subjects received feedback regarding both speed and accuracy and terminated the rest period whenever they wished.

Results

Reaction times below 150 ms, or greater than 1.5 s, were discarded. For each subject, the mean in each level of the stimulus factor in each block was computed; then, all the blocks in a given condition were averaged to yield the subject's average for each Condition x Stimulus-Factor cell. The analysis of variance was performed on these data. In Experiments 2-4, a separate analysis of the data, broken down by probe position, is also reported. Probe positions were selected randomly with replacement in order to keep positional expectancies from developing toward the end of each block; therefore, each position did not occur equally often in each Block X Condition cell. For this analysis, all trials in a particular condition at a particular probe position were averaged, aggregating over blocks. Therefore, the

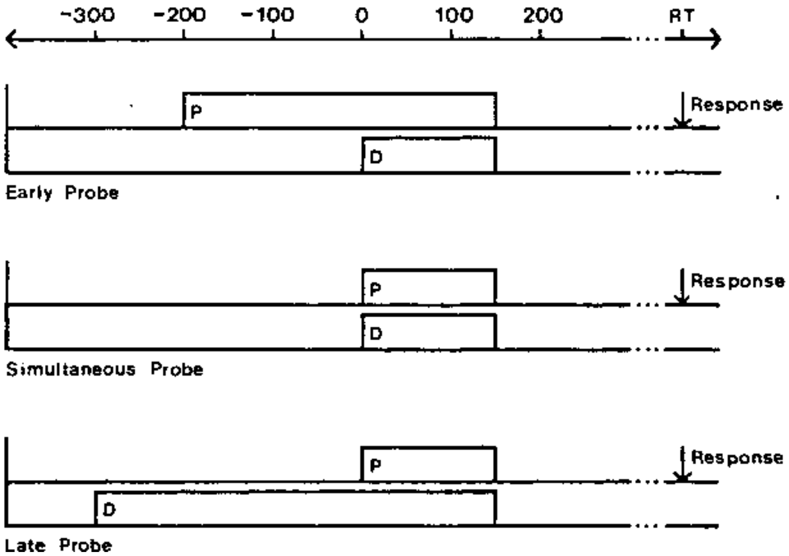

Figure 1. Sequence of stimuli and timing for Experiments 1-4. (P = probe, D = display of characters. RTs are measured from first time when P & D are both present.)

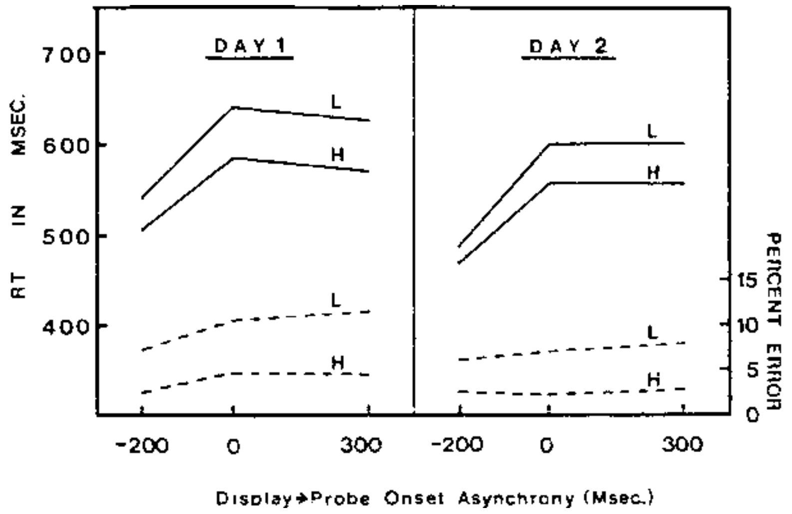

Figure 2. RTs and error rates for high-discriminability (H) and low-discriminability (L) characters. (Experiment 1: *A, a* vs. *E, e:* heterogeneous-case displays.)

probe-position results do not have precisely the same average as the primary analysis. The results of the two ANOVAS agree in each case, however.

Experiment 1

This experiment concerned the effect of stimulus discriminability and size in a bar-probe RT task, at varying array-probe onset asynchronies. In this experiment, subjects decided if the letter in the array that was adjacent to the probe was an *A* or an *E*. Upper- and lowercase letters were used. In the character set used, the uppercase letters have obvious featural differences, whereas the lowercase letters appear featurally more similar and are smaller; pilot work confirmed that this produced a modest but reliable difference in performance measured in both speed and accuracy. No attempt was made to distinguish the contribution of letter size and featural similarity to the increased difficulty of distinguishing the lowercase letters; so long as both contributions have their locus prior to resolution of the character's identity, that issue does not matter for present purposes. As a first discriminability manipulation, this particular stimulus configuration was favored because it permitted a sensitive within-block manipulation of discriminability while keeping the task demands uniform and simple.

A variety of discriminability manipulations have been employed in classification experiments (e.g., Miller & Bauer, 1981). The present design was adopted with a view to insuring that postperceptual processing differences would be unlikely, because the S-R mapping rule remains the same for stimuli at both levels of discriminability. Because the response rule is the same, it seems very unlikely that RT effects would originate in processes that follow stimulus identification.

Method

Subjects. Seven subjects each participated in two sessions, lasting about $1^1/4$ hr each.

Apparatus and stimuli. The stimuli consisted of eight characters, in which each possible target (upper- and lowercase *A* and *E)* was represented twice.

Procedure. Subjects made their responses with their index and second fingers of their right hands. If the probed character was an *A,* the subject pressed the (.) key; if it was an *E*, the subject pressed the (/) key.

Results

The mean reaction times and error rates, broken down by session, array-probe asynchrony condition, and discriminability, are shown in Figure 2. Each data point in the figure represents observations from 1,120 trials. The average discriminability effects for the early, simultaneous, and late probes were

35 ms, 56 ms, and 55 ms, respectively, in Session One; 18 ms, 42 ms, and 43 ms in Session Two.

The effect of discriminability was significant, $F(1, 6) = 31.63$, $p < .005$. The effect of probe condition was also significant, $F(2, 12) = 73.77$, $p < .0001$. It is apparent in Figure 2 that the discriminability effect is smaller with the early probe; the interaction of discriminability with probe condition was marginally significant, $F(2, 12) = 4.35$, $p < .05$. The effect of sessions was not significant, but the interaction of sessions and conditions was marginally so, $F(2, 12) = 3.92$, $p < .05$. No other effects were significant.

The error rates were analyzed in the same way. The effect of sessions was not significant $F(1, 6) = 2.53$, $p > .15$. The effect of condition also failed significance, $F(2, 12) = 2.98$. $p > .05$. Discriminability, however, had a significant effect, $F(1, 6) = 34.66$, $p < .002$. The interaction of Discriminability X Condition was not significant, $F(2, 12) = 0.95$, $p > .40$; neither were any other interactions.

Discussion

The basic finding of this study can be very simply stated: A manipulation believed to affect the rate of perceptual identification of letters had a greater effect when the probe indicating which letter was to be selected occurred simultaneously with or 300 ms after the onset of the display. This is in clear conflict with the predictions of the late-selection accounts discussed in the introduction, which predict that display preview would reduce or eliminate the visual quality effects.

One slightly puzzling aspect of the data is why the effect of discriminability is smaller with the early probe. One natural account points to the perceptual differences between the onset conditions, remarked on in the General Method section. The subjects presumably can often make an eye fixation on the target in the early probe condition, something they cannot do in the simultaneous and late conditions. Distance from fixation has been found to interact overadditively with factors increasing the difficulty of encoding (Eriksen & Schultz, 1977), presumably because of sensory factors. There are also other possible accounts of why the discriminability effect might have increased with display preview. For instance, the selective encoding process that follows the determination of the probed position may be made more difficult when the distractors have already been available. Similar observations have been made in the Stroop-like paradigms, where effects of unattended material are exacerbated by prior presentation (Eriksen & Schultz, 1979). This may indicate some involuntary processing of distractors, a fact well known since the work of Eriksen & Hoffman (1972). However, the present results suggest that this involuntary processing does not generate a representation storing the identities, ready to be fetched by location (see Kahneman & Treisman, in press, for discussion of whether involuntary processing can be reconciled with early-selection models).

Experiment 2

In the previous experiment, each display included both high-discriminable and low-discriminable characters. This has some advantages but also a possible disadvantage. Suppose that subjects encode all the letters in parallel, as the late-selection theory states. Conceivably, during the preview period they might optionally attend selectively to the more discriminable characters. As a result, subjects would be more ready to fetch the identity of a high-discriminable character than a low-discriminable one, yielding a discriminability effect on RTs (and possibly error rates, as well). This account has the odd feature that it suggests that the discriminability effect in the late-probe condition has an entirely different source than the discriminability effect in the early-probe condition. However, it cannot be ruled out on the basis of Experiment 1. Experiment 2 therefore replicated Experiment 1, manipulating discriminability between trials (although still with trials of both levels in each block). In addition, another small change was made. In other experiments reported in this paper, the probe was a light square presented at a 0.8° visual angle separation from the character probed. This separation was designed to minimize perceptual interactions, but it seemed possible that a more immediately adjacent probe might make some difference. Therefore, in this experiment a horizontal white rectangle, half as tall as the square probe

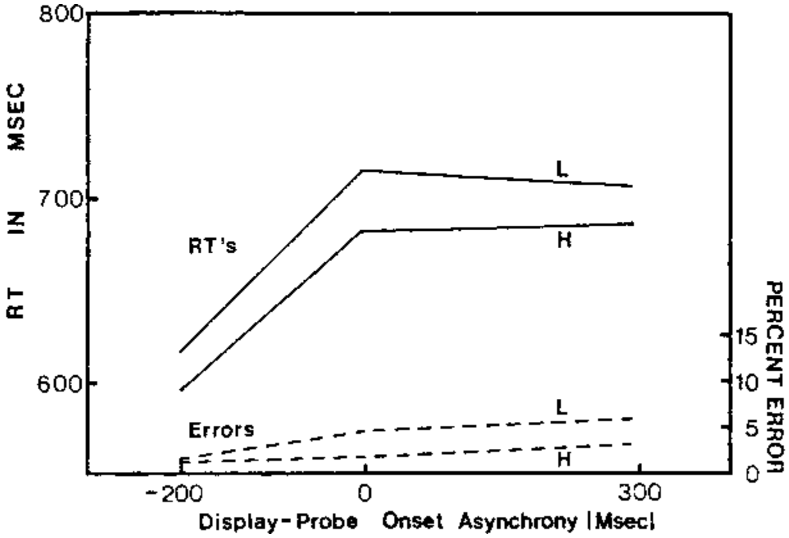

Figure 3. RTs and error rates for high-discriminability (H) and low-discriminable (L) characters. (Experiment 2: *A,a* vs. *E,e:* homogeneous-case displays.)

but the same width, was presented about 0.4° away from the probed character. Informally speaking, this seemed to designate the character more obviously, while still avoiding any obvious perceptual interactions.

Method

Subjects. Ten subjects participated in one session, lasting about 40 min.

Apparatus and stimuli. The stimuli for each trial consisted of two rows, each containing two *A*s and two *E*s. On each trial, all the characters were either uppercase (high discriminable) or lowercase (low discriminable).

Design. The design followed that of the General Method section, except that each of the 12 experimental blocks consisted of 40 trials rather than 80.

Results

The results are shown in Figure 3. The discriminability effects were 22 ms, 33 ms, and 22 ms for the early, simultaneous, and late probes, respectively.

In the reaction times, the effect of onset condition was significant, *F*(2, 18) = 44.4, $p <$ .0001, as was the effect of discriminability, *F*(1, 9) = 15.4, $p < .005$. The interaction of condition and discriminability was not significant, however, *F*(2, 18) = 1.55, $p > .20$. The error rates were analyzed likewise. The effect of condition was significant, *F*(2, 18) = 12.3, $p < .0005$. The effect of discriminability narrowly missed significance, *F*(1, 9) = 4.7, $.05 < p < .10$. The interaction was not significant, *F*(2, 18) = 1.53, $p > .20$.

In a separate analysis, each subject's reaction times for each horizontal probe position (1 -4) were averaged (see General Method section). These averages are presented in Table 1.

In this analysis, the effect of discriminability was significant. *F*(1, 9) = 12.7, $p < .01$, as was the effect of condition, *F*(2, 18) = 39.0, $p <$ .0001. A Condition X Discriminability interaction did not appear, *F*(2, 18) = .62, $p > .50$.

Table 1
Reaction Times (in ms) for Each Probe Position: Experiment 2

	Probe position			
Discriminability	1	2	3	4
SOA = -200 ms				
Low	600	618	627	611
High	578	598	602	604
SOA = 0 ms				
Low	702	705	696	750
High	681	680	671	691
SOA = +300 ms				
Low	707	708	691	733
High	692	682	688	696

Note. SOA = stimulus onset asynchrony.

Probe position had a significant effect, $F(3, 27) = 3.1$, $p < .05$, but it did not interact with discriminability, $F(3, 27) = .65$, $p > .50$, or with condition, $F(6, 54) = 1.2$, $p > .30$. The Discriminability X Condition X Probe Position interaction was not significant, $F(6, 54) = .95$, $p > .40$.

Discussion

This experiment replicates the basic finding of Experiment 1—no reduction in the size/discriminability manipulation occurs with array preview. The difference between Experiments 1 and 2 in method is that displays were of homogeneous discriminability, and the bar probes were smaller and closer to their targets in this experiment. The significant difference in the discriminability effect between early probe and the other two conditions observed in Experiment 1 did not occur in the present experiment. The absence of Probe Position X Discriminability interaction here suggests that the foveality of the target is not the major source of this increase, a possibility suggested in the Discussion of Experiment 1. Other possibilities, mentioned there, remain viable. The tendency is for the discriminability effect with simultaneous and late probes to be smaller in this experiment than in the last. One possible account is that encoding is somehow facilitated if subjects have detected the (homogeneous) case of the display and in some way prepare selectively to encode an upper- or lowercase letter. If such preknowledge were useful, subjects would surely have the opportunity to avail themselves of it in the simultaneous and late-probe conditions, with homogeneous-case displays, as in the present experiment.

Experiment 3

The previous experiments dealt with character size and discriminability as a factor slowing down the process of deriving the identities of characters. The next two experiments deal with stimulus contrast. Hardzinski and Pachella (1980) observed that contrast is additive with the effects of memory set size in the Sternberg paradigm, using both physical and name matches. Schwartz, Pomerantz, and Egeth (1977) found contrast additive with manipulations of both decision and response selection difficulty. Miller (1979) observed that contrast interacts with stimulus probability manipulations under fewer circumstances than does visual noise degradation. Hardzinski and Pachella, and also Miller, interpreted their results as providing evidence that contrast may have earlier effects in the encoding process. McClelland (1979) makes a similar suggestion. There appears to be wide consensus that the effects of contrast manipulations can be primarily localized prior to the point of stimulus identification in a wide range of tasks. For the purposes of the present work, then, contrast serves as an interesting converging operation.

Method

Subjects. Eight subjects were paid for their participation in this experiment.

Apparatus and stimuli. The stimuli consisted of eight characters: uppercase *A*s and uppercase *E*s. There were four of each in the display, although the order was randomized. Contrast reduction was accomplished by presenting a character in the microcomputer's standard dark gray color, rather than white. The luminance of homogeneous fields presented in the colors of the bright letters, dim letters, and background field was measured to be 45.0, 0.9, and 0.4 footlamberts, respectively (or 154.4 cd/m^2, 3.1 cd/m^2, and 1.4 cd/m^2, respectively). Reducing the brightness of the dots composing a letter in this fashion may not have precisely the same effects as reducing contrast by interposing a neutral density filter. However, it has the advantage of keeping the subject ignorant of what stimulus quality to expect. Furthermore, the effects on speed and accuracy are certainly modest by the standards of the previously reported degradation effects.

Procedure. Subjects made their responses with their index and second fingers of their right hands. If the probed character was an *A*, the subject pressed the (.) key; if it was an *E*, the subject pressed the (/) key.

Results

The mean reaction times and error rates, broken down by array-probe asynchrony condition and discriminability, are shown in Figure 4. The effect of contrast averaged 36 ms, 41 ms, and 36 ms, for early, simultaneous, and late probes, respectively.

The effect of probe condition was significant, $F(2, 14) = 101.89$, $p < .0001$, as was the contrast effect, $F(1, 7) = 63.32$, $p < .0001$. The interaction was not significant, $F(2, 14) = .58$, $p > .50$. The errors were analyzed likewise. The effect of condition was significant, $F(2, 14) = 5.3$, $p < .02$, as was the contrast effect, $F(1, 7) = 17.9$, $p < .005$. The interaction was not significant, $F(2, 14) = .88$, $p > .40$.

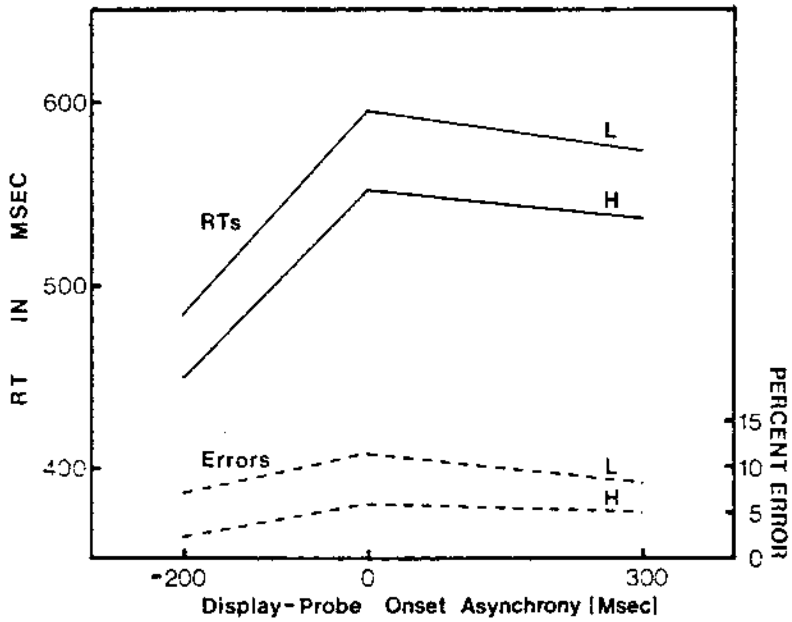

Figure 4. RTs and error rates for high-contrast (H) and low-contrast (L) characters. (Experiment 3: *A* vs. *E;* heterogeneous contrast displays.)

The horizontal probe positions were separately analyzed, as outlined in the General Method section. The averages of each subject's reaction times are presented in Table 2. In this analysis, the effect of contrast was significant, $F(1, 7) = 61.8$, $p < .0001$, as was the effect of condition, $F(2, 14) = 100.8$, $p < .0001$. They did not interact, $F(2, 14) = .39$, $p > .6$. Probe position had a significant effect, $F(3, 21) = 27.6$, $p < .0001$. Probe position interacted with condition, $F(6, 42) = 13.0$, $p < .0001$, but not with contrast, $F(3, 21) = 1.3$, $p > .25$. Further, the Contrast X Condition X Probe Position interaction was not significant, $F(6, 42) = 1.4$, $p > .20$. Thus, the persistence of the contrast effect appears to be uniform with respect to probe position.

Table 2
Reaction Times (in ms) for Each Probe Position: Experiment 3

Contrast	Probe position 1	2	3	4
SOA = -200 ms				
Low	477	494	492	485
High	445	456	456	447
SOA = 0 ms				
Low	611	577	570	639
High	563	546	540	577
SOA = +300 ms				
Low	607	546	546	616
High	557	515	512	578

Note. SOA = stimulus onset asynchrony.

Discussion

The basic finding of this study, then, is that stimulus contrast effects do not appear to be reduced when the probe indicating which letter should be selected appears 300 ms after the onset of the display. This provides further evidence that selection in this paradigm is early, in the sense described in the introduction.

It is possible that some of the effects of contrast may be *so* early in the stimulus registration process that they must be eliminated by preview, for example, effects on the time taken by the information to reach the visual cortex. Such small underlying interactions might not be detectable in this paradigm. The stimulus registration processes affected are presumably more rapid than probe-based selection, so this minor underadditivity should appear already in the simultaneous-probe condition, not just in the preview condition. However, for reasons discussed in the General Method section, the comparison between quality effects in the early probe condition and the other conditions is not perfect, given the necessary differences in foveality and response competition. This limitation of the method does not undermine the basic finding that the contrast variable still has substantial effects after preview, effects that seem highly likely to stem from retardation of pattern-recognition processes.

Experiment 4

The previous experiment finds no significant reduction in the effect of contrast, when a multielement display is previewed. It was felt important to replicate the result in a slightly different paradigm. One interesting possibility is that the failure to find automatic processing eliminating the quality effect in prior experiments might have to do with the choice of stimuli. The arrays in the previous experiments have been composed entirely out of *A*s and *E*s. It seems conceivable that any preattentive extraction of identities cannot proceed when the different channels contain a number of items with the same identity. Several conceptions of the pattern recognition system might suggest such a possibility. For instance, perhaps each identity is represented by a different "specialist," copies of which are in short supply. Or perhaps disruptive cross-talk between channels occurs under these circumstances, possibly akin to feature-specific inhibition. In any case, it is clearly important to be able to generalize any conclusions to displays without such repetitions. The present experiment, therefore, involved displays with no repeated items.

In this experiment, subjects were presented with an array consisting of mixed letters and digits and required to decide if the probed character was a letter or a digit. This task has another possible virtue. The distinction between letters and digits has a special status in attention studies because it has been observed that search for a letter among digits is relatively unaffected by the number of distractors in the display (Egeth, Jonides, & Wall, 1972). It has been suggested that this distinction is especially salient preattentively (e.g., Schneider & Shiffrin, 1977), providing a favorable opportunity for manifestation of late selection.

Method

Stimuli. The digits 1, 2, 3, and 4 and the letters *A, B, C* and *D* were used in forming the arrays. Contrast was reduced the same way as in Experiment 3. However, the effective contrast reduction may not have been identical because of possible small differences in ambient lighting in the experimental rooms used, so the magnitude of the effects cannot be compared across experiments.

Design. The design followed the General Method section. Forty trials were included in each block.

Subjects. Ten subjects participated in a single session.

Procedure. Subjects responded with their right hand. They pressed the (/) key for letters and the (.) key for digits.

Results

The mean RTs and error rates for both levels of discriminability and all three probe conditions are presented in Figure 5.

Each subject's mean RTs in each cell, averaged across blocks, were subjected to an analysis of variance. The contrast effect was significant, $F(1, 9) = 12.6$, $p < .01$, as was the effect of probe condition, $F(2, 18) = 42.9$, $p < .0001$. No interaction among these factors appeared, $F(2, 18) = .23$, $p > .70$.

The errors were analyzed in the same fashion. The effect of condition was significant, $F(2, 18) = 4.8$, $p < .05$. The contrast effect, however, was not significant, $F(1, 9) = 3.5$, $.05 < p < .10$, while their interaction was marginally significant, $F(2, 18) = 4.6$, $p < .05$.

Finally, the RTs were broken down by horizontal probe position (1-4), and each subject's average over the entire session was computed; these means are presented in Table 3. One subject's data were not included in this analysis; he had a high enough error rate that some probe position cells had only a few trials in them and thus an enormous standard error. (His inclusion or exclusion in the earlier analysis was found to have no effect upon those results, however). The effect of contrast was significant, $F(1, 8) = 15.9$, $p < .005$, as was the effect of condition, $F(2, 16) = 46.2$, $p < .0001$. These factors did not interact, $F(2, 16) = .31$, $p > .70$. The probe position effect was significant, $F(3, 24) = 4.5$, $p < .05$, and it interacted marginally with contrast, $F(3, 24) = 3.1$, $p < .05$, and with condition, $F(6,$

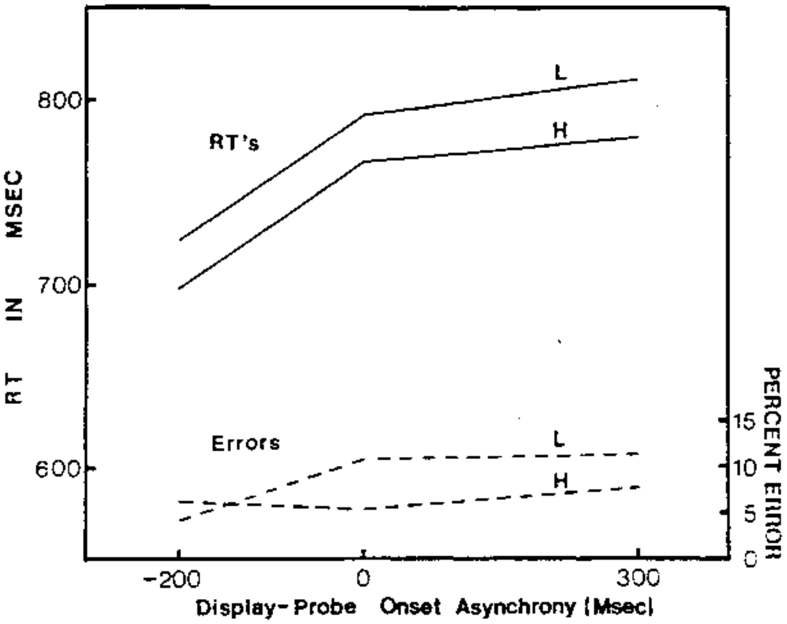

Figure 5. RTs and error rates for high-contrast (H) and low-contrast (L) characters, (Experiment 4: letter or digit, repetitionless displays.)

48) = 4.5, $p < .005$. However, the Contrast X Condition X Probe Position interaction was not significant, $F(6, 48) = 1.5, p > .15$.

Discussion

The basic finding of Experiment 3—persisting contrast effect with the display preview—is replicated here, with displays involving no item repetitions. Certain differences in the results appear, however. For one, the contrast effect interacts with probe position in this experiment, unlike Experiments 2 and 3. However, this interaction is only marginally significant. It might be that stimulus identification is more difficult in this experiment because of the larger stimulus set, and this might cause some difference in the sensitivity of the tasks to acuity, hence foveality (see Discussion of Experiment 1). In any case, the finding does not particularly bear on the general conclusions argued for here, and no particular account of it is proposed. The absence of a Probe Position X Contrast X Condition interaction, here as in the earlier experiments, suggests that there is no change in the relation of contrast to probe position across the different stimulus onset asynchrony (SOA) conditions.

Table 3
Reaction Times (in ms) for Each Probe Position: Experiment 4

	Probe position			
Contrast	1	2	3	4
SOA = -200 ms				
Low	672	702	688	710
High	646	674	673	650
SOA = 0 ms				
Low	775	757	741	803
High	782	736	699	758
SOA = +300 ms				
Low	796	744	746	837
High	760	736	753	761

Note. SOA = stimulus onset asynchrony.

Experiment 5

The previous four experiments seem to argue that when subjects select by location from a previewed display, the selection precedes the identification of that item. This conclusion is at odds with late-selection theories that assert that a map of identities and locations is constructured automatically and used in tasks such as these. However, the possibility remains that the probed item is optionally *reprocessed* by the subject, even though it is already represented in such a map. Such a strategy might be adopted for a variety of reasons. For instance, reprocessing might take less resources than the hypothetical late-selection option or better guard against response competition. Granting such a strategic option for the subject would represent a modification of the late-selection position typically proposed, but it would retain the fundamental claims of that view. What is needed to assess this possibility is a task in which subjects are given a strong incentive to make use of this preattentively computed map, if they have one.

The following experiment is based upon a suggestion made by Anne Treisman to the present author, which is gratefully acknowledged. One third of the trials in this experiment are "catch trials" in which, unpredictably to the subject, a mask appears in the position of the display at the moment of display offset. Presumably, this has the consequence that the subjects cannot be sure of having an iconic representation to work on for as long as they might wish. Clearly, this has adverse effects on their performance, evidenced by the error rates.

If the subjects have available a strategy that relies less upon maskable representations, such as a postcategorical map of the sort mentioned above, this experiment should incline them to use it, changing the pattern of stimulus quality effects. Of course, the experiment cannot rule out all models of this sort, for example, if both a precategorical fading image and a postcategorical identity-by-location map were available, but both were affected in the same way by the mask, then the catch trials might not induce a change of strategy. Nonetheless, if the earlier results represented a reprocessing strategy of the sort suggested, this experiment would seem to offer some hope of altering the strategies subjects choose to employ, at least frequently enough to change the results somewhat.

A further change was made in this experiment: The display preview condition was lengthened from 300 to 400 ms. In view of the length of overall RTs, it seemed conceivable (although quite unlikely) that the 300-ms preview was insufficient for a hypothetical automatic encoding to take place.

Method

Subjects. Eight undergraduate subjects participated in a session lasting about 1 hr.

Apparatus and stimuli. This experiment followed Experiment 1 in the selection of stimuli: The discriminability manipulation involved varying the case of *A*s and *E*s, with the lowercase letters found to be harder to discriminate. Displays contained both upper- and lowercase letters. The mask consisted of two rows of 15 immediately adjacent ampersands filling the two rows occupied by the display, including intervening spaces. Thus the mask occluded the positions formerly occupied by the characters, but not the position formerly occupied by the probe. The probe was like that of Experiment 2—that is, slightly closer to us target than in the other experiments; this was thought to be the easiest to interpret.

Design. Twelve experimental blocks consisted of 60 trials per block. THEre were 20 high-discriminability and 20 low-discriminability unmasked trials, and 20 masked catch trials per block: the catch trials were equally divided by discriminability.

Procedure. Subjects were advised of the nature of the catch trials and told that they should try to maintain a high level of accuracy on all trials as best they could despite inevitable difficulties on the catch trials. Timing was performed with machine routines adapted from Merikle et al. (1982), permitting response timing to operate in exact synchrony with the displays and eliminating the small errors referred to in the General Method section. Responses were made by pressing one of two external switches located on a wood panel resting on the subject's lap. The switches connected to the microprocessor through its parallel input port. In this experiment, subjects used index fingers of their left and right hand, rather than adjacent fingers of the right hand, to indicate *A* and *E*, respectively.

The timing on noncatch-trials was like that shown in Figure 1, except that the display preview was 400 ms, rather than 300 ms. On the catch trials, the offset of the probe and display coincided with onset of the mask. The mask remained on the screen until response.

Results

The results from the noncatch trials are presented in Figure 6. Table 4 presents the RTs and error rates on the catch trials.

For the noncatch trials shown in the figure, the discriminability effects in mean RT were 26 ms, 60 ms, and 54 ms, respectively. The effect of discriminability was significant, $F(1, 7) = 85.2$, $p < .0001$, as was the effect of probe condition, $F(2, 14) = 94.4$, $p < .0001$. The lesser discriminability effect evident with the early probe led to a significant interaction of discriminability and condition, $F(2, 14) = 4.36$, $p < .05$. The error rates for the noncatch trials were analyzed in the same fashion. The

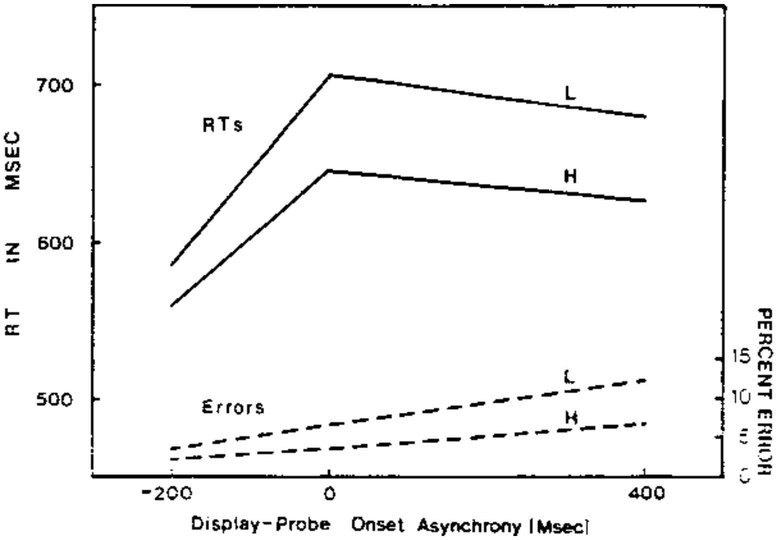

Figure 6. RTs and error rates for high-discriminable (H) and low-discriminable (L) characters—noncatch trials only. (Experiment 5: *A,a* vs. *E,e;* heterogeneous displays with masked catch trials.)

effect of discriminability was significant, $F(1, 7) = 35.0, p < .001$, as was the effect of condition, $F(2, 14) = 23.4, p < .0001$. The interaction missed significance, $F(2, 14) = 3.05$, $.05 < p < .10$.

The data from the catch trials (shown in Table 4) was analyzed similarly. In the RTs, there were significant effects of discriminability, $F(1, 7) = 72.6, p < .0001$, and condition, $F(2, 14) = 40.3, p < .0001$. The interaction of the two was not significant, $F(2, 14) = 1.34, p > .25$. Catch trial error rates were analyzed likewise; discriminability had a significant effect, $F(1, 7) = 35.8, p < .0005$, as did condition, $F(2, 14) = 14.6, p < .0005$. The interaction was also significant, $F(2, 14) = 7.6, p < .01$.

Discussion

The results on the noncatch trials are highly similar to the results of Experiment 1, on which the current experiment was largely patterned. A comparison of Figure 6 with the Day 1 data in Figure 2 suggests that the introduction of masks on one third of the trials had little effect on the remaining trials. As in Experiment 1, the discriminability effect with the early probe is significantly smaller than at the other two probe conditions. In the *Discussion* of the earlier experiment, several accounts of this were described. Both lessened response competition and fixations on the target in the early condition were mentioned as possibilities.

The results of the masked trials are also very interesting. The mask produces many more errors in the simultaneous and late probe conditions. It also affects the less discriminable stimuli to a disproportionate degree. These effects make good sense on the assumptions that (a) selection is early—that is, encoding follows selection, (b) the less discriminable characters take longer to encode, and (c) the mask terminates the availability of a "precategorical" iconic image of the stimulus for further encoding. When selection precedes the 150-ms stimulus exposure (early-probe condition), the

Table 4
Reaction Times (in ms) and Error Rates for Catch Trials: Experiment 5

	High Discriminability		Low Discriminability	
SOA (ms)	Mean RT	Error %	Mean RT	Error %
-200	568	4	633	15
0	664	9	724	35
+400	642	9	683	30

Note. SOA = stimulus onset asynchrony.

need for the iconic image is not especially acute. The simultaneous- and late-probe conditions are effectively identical. By the time the probe-directed attention switching is complete, there is relatively little stimulus exposure time remaining for encoding the target, so the iconic representation is critical for good performance. The termination of this image by the mask prevents successful identification in many cases, especially with the low-discriminability items. The results follow naturally. In short, the pattern of results obtained in this experiment seems very much in line with a "classical," but recently somewhat maligned, conception of iconic memory and its role in the organization of visual information processing.

General Discussion

The results of five experiments involving speeded selective classification from multicharacter displays seem to strongly favor the view that selection in such situations is *early*—that is, that selection precedes rather than follows identification. In each case, when a display had been previewed for several hundred milliseconds, response times were still affected by the visual quality of the probed item at least as much as they were when location was pre-cued. If selection were a matter of retrieving precomputed identities, the preview would be expected to eliminate these quality effects.

Some Qualifications

The argument these data suggest against late selection would appear to be quite strong and considerably more direct than the sorts of evidence previously adduced in connection with this issue. Nonetheless, because the issue is basic for the organization of visual information processing, it is important to clearly acknowledge possible limitations and potential difficulties for the argument being put forward here. Therefore, prior to discussing the implications of the data for general theory, some potential pitfalls will be mentioned. First of all, the assumption has been made that visual quality effects are predominantly affecting the duration of stimulus identification (interpreted broadly). There seems to be formidable evidence for this assumption in a variety of paradigms: Quality manipulations have been found to combine in a robustly additive fashion with a range of manipulations thought to affect later stages (see, e.g., Hardzinski & Pachella, 1980; Logan, 1978; Sanders, 1980; Sternberg, 1969). Even views that reject the strict successiveness of stages postulated by Sternberg's additive-factors approach find it necessary to acknowledge some fundamental separation of this type (e.g., McClelland, 1979). However, we cannot be certain that this will always hold in new paradigms. For instance, the present method may involve severe response competition that could conceivably exacerbate any postperceptual effects of these factors.[1] So it seems reasonable, but by no means certain, to infer from the quality effects in the present data that target encoding is occurring after spatial selection is complete.

A second issue concerns the possibility that the early selection argued for here is merely strategic. Thus, one might grant that selection precedes identification in this paradigm but hold that subjects might still, under other conditions, use an automatically generated map of locations by identities. The fifth experiment was designed to test that view. The presence of catch trials in which the display was followed immediately by a mask did not change the pattern of results. This seems to argue against a strategic interpretation, but only on the assumption that the mask interferes more with the early selection strategy than with the hypothetical late selection strategy. In short, we cannot entirely rule out a strategic interpretation.

On the other hand, if the present results were merely to implicate a strategy, rather than a basic limit (which seems unlikely to this writer), then this strategy is surely much commoner than late-selection theorists have been supposing. The present paradigm seems to represent quite faithfully an extraordinarily common perceptual act—selecting by location from previewed visual scenes. If automatic processes generate representations capable of being used for such selection, it is unclear why this should not be evident in the present experiments.

---

[1] Jeff Miller pointed out this possible problem to the author.

General Implications

In the discussion thus far, care has been taken to emphasize that the late-selection view undermined by the present data is a "strong" one—strong in the sense of claiming that parallel perceptual processes generate a maplike representation containing identities appropriately tagged for locations, addressible by these locations. A much weaker view holds merely that it is possible to extract identities of a multielement display in parallel. The weaker and stronger claims have often been treated as if they were inseparable (e.g., Shiffrin, 1976). The present paradigm, however, highlights the need for careful distinctions here.

There are a number of types of information-processing operations, all of which could be said to involve perceptual processing of a multielement display, but each of which would have a distinct theoretical status. I will now try to enumerate some of these possibilities somewhat more systematically.

Type 1. The first kind of process would simultaneously generate a representation containing information about *what* objects were recognized and *where* each was located. The location and identity information would, of course, have to be appropriately connected; the metaphor of a labeled map seems apt here.

Type 2. Another possible process would produce in parallel a specification of just the identities present in a multielement display without preserving the locations of each item.

Type 3. A third and much weaker type of parallel process would simply determine whether a particular *prespecified* item was found *anywhere* in a multielement display and, if so, *where* in the display. The identities of the nontarget items would not be represented in the output of this type of process.

Type 4. A fourth type of process would simply determine whether a prespecified item was *anywhere* in a multielement display, without outputting location information about it nor any information about the nontarget items.

Type 5. A fifth type of process leaves the domain of parallel processing altogether; here, a location is prespecified and an identity is output—the identity of the object in that location.

These represent five logically different types of processes that might be available to deal with a multielement display; there may be other possibilities. They do *not* by any means represent hypothetical models of visual information processing. Rather, these process types represent possible *components* of a visual processing architecture, or alternatively, *strategies* that may or may not be available to the system.

Having specified some possible components, we can place the late-selection model discussed earlier in a larger framework of possibilities. The model attributed to Shiffrin (1976), Coltheart (1980), van der Heijden (1981), and Duncan (1980, 1981), to name a few, asserts that the system has the capability to perform a Type 1 analysis of a perceptual display for *all* levels of codes (i.e., features, letters, words, etc.); furthermore, they claim that it performs such an analysis involuntarily and without capacity limitations. The data of the present experiment argue against this.

Let us briefly consider the kind of evidence that seems to have led people to adopt this kind of strong late-selection theory and ask whether it in fact provides any support for a specifically Type 1 process.

The first kind of evidence generally cited concerns Stroop effects—broadly, effects of "unattended items," that is, items that the subject did not intend to pay attention to. In numerous paradigms (e.g., Eriksen & Hoffman, 1972; Shaffer & LaBerge, 1976; Stroop, 1935) these unattended items can be shown to have indirect effects dependent upon their identities. Clearly, this kind of result is equally compatible with a Type 2 analysis as with a Type 1 analysis; if the data indicate that unattended items were identified, it does not follow that they were represented together with their particular locations. Two considerations further weaken the Stroop effects as a source of evidence for strong late-selection models. First, these effects have been found to vary in their magnitude depending upon perceptual factors, which, on the late-selection account, ought not to have any effect (e.g. Egeth, 1977; Kahneman & Henik, 1981); they may even disappear under certain circumstances (Francolini & Egeth, 1979). The second problem is a logical one and even more serious: It is perfectly possible that these effects might merely represent imperfections in the focusing of a basically serial mechanism (see, e.g., Broadbent, 1982; Kahneman & Treisman, in press).

Thus, in principle they might result from a system employing only Type 5 processes. All of these considerations apply equally to priming effects that occur despite incentives to ignore (Neely, 1977; Posner & Snyder, 1975). The present results are therefore in no conflict with results from Strooplike paradigms, which, it seems only fair to say, have been widely overinterpreted.

The second kind of evidence often cited in support for strong late-selection models involves visual search. Under certain circumstances, subjects can search for a character in a display with RTs virtually unaffected by the number of distractors. This result has been observed after lengthy practice with fairly arbitrary targets (Schneider & Shiffrin, 1977); without special practice, search for letters among digits and vice versa also shows this pattern (Egeth, Jonides, & Wall, 1972). Taken at face value, this evidence still does not in any way argue for Type 1 processes as against Types 2 through 4. The task does not require that the target be localized, so it cannot be inferred that the targets have been located. (It should be acknowledged, however, that localization performance is often good enough to cast doubt on such a dissociation; see, for example, Sperling, Budiansky, Spivak, & Johnson, 1971). Furthermore, the distractors need only be processed in the sense of determining that they are *not* targets. A number of writers have suggested that visual search may involve a preliminary target localizer that does not depend upon "full" analysis of distractors; see, for instance, Rabbitt (1978) and Hoffman (1978). In conclusion, flat display size functions sometimes obtained in search tasks are quite inconclusive as to putative Type 1 processes, that is, parallel generation of a full identity by location map.

The same can be said about the additivity of visual quality with display size reported by Logan (1978) in a search task involving determining which of two targets was present. Johnsen and Briggs (1973) reported similar results in a presence/absence search task, although some hint of overadditivity appeared for the target-absent results. These results, which have been largely ignored in discussion of attentional issues, are provocative and worthy of further study. If encoding were fully serial or even capacity-limited in the search task (e.g., Harris, Shaw, and Bates, 1979), one would expect a substantial overadditivity reaching multiplicative proportions in the case of serial processing. The most natural way to account for the additivity would be to assume that encoding of the whole display occurs in parallel as specified by Shiffrin (1976). The display size slope might then originate in subsequent comparison processes, as Sternberg (1969) originally proposed. This view would make the present results quite paradoxical for the following reason: If memory comparison processes can use the results of this encoding, why cannot selective classification (also involving memory comparison) do likewise? However, as noted above, parallel encoding in search may occur as part of an operation with far more limited power than the Type 1 process that would be required to take advantage of the display preview in the paradigm reported in this article. Similar considerations apply to the results reported by Pashler (1984) on visual search performed as the second task in a refractory period paradigm. Contrast and display size effects were markedly underadditive, with the overall slowing produced by the preceding task. This was interpreted as providing evidence for parallel work on the encoding and comparison stages of the second task, during the period that more central mechanisms were still occupied with the first task. This sort of automaticity clearly does not entail that anything like Type 1 encoding of multi-element displays occurs automatically.

Several conclusions can be reached from the considerations discussed here. First, the evidence usually cited in support of strong late-selection models (Type 1 parallel identification of all familiar objects) is compatible with weaker kinds of analysis. That is, parallel perceptual processes that merely locate a specified target determine what is present without localizing anything, or search for a prespecified target seem viable at this time. The present experiments argue directly against Type 1 analysis of letter codes but leave Type 2, 3, or 4 analyses of these codes as live possibilities. Other more complex schemes are also possible.

This way of looking at the data suggests that despite the substantial amount of experimental work performed in this area, a range of possibilities remains. A number of theoretical accounts can be discarded with reasonable assurance, particularly the more extreme versions on both sides of the classic division. The progress with various paradigms provides encouragement that further experimental work with converging methodologies will continue to narrow down the range of possibilities and come to fully characterize the mechanisms and limitations underlying visual attention.

References

Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *Bell System Technical Journal, 40,* 309-328.

Briggs, G. E., Peters. G., & Fisher, R. P. (1972). On the iocus of the divided attention effects. *Perception & Psychophysics, 11,* 315-320.

Broadbent, D. (1982). Task combination and the selective intake of information. *Acta Psychologica, 50,* 253-290.

Coltheart, M. (1980). Iconic memory and visible persistence. *Perception & Psychophysics, 27,* 183-228.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87,* 272-300.

Duncan, J. (1981). Directing attention in the visual field. *Perception & Psychophysics, 30,* 90-93.

Duncan, J. (1983). Perceptual selection based on alphanumeric class: Evidence from partial reports. *Perception & Psychophysics, 33,* 533-547.

Egeth, H. (1977). Attention and preattention. In G. Bower, (Ed.), *The psychology of learning and motivation* (pp. 277-320). New York: Academic Press.

Egeth, H., Jonides, J., & Wall, S. (1972). Parallel processing of multielement displays. *Cognitive Psychology, 3,* 674-698.

Egeth, H., Pomerantz, J., and Shwartz, S. (1977, November). *Is encoding really effortless?* Paper presented at the 18th Annual Meeting of the Psychonomic Society, Washington, DC.

Eriksen, C. W., & Collins, A. (1969). Temporal course of selective attention. *Journal of Experimental Psychology, 80,* 254-261.

Eriksen, C. W., & Hoffman, J. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics, 12,* 201-204.

Eriksen, C. W., & Schultz, D. W. (1977). Retinal locus and acuity in visual information processing. *Bulletin of the Psychonomic Society, 9,* 81-84.

Eriksen, C W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow model and experimental results. *Perception & Psychophysics, 25,* 249-263.

Francolini, C. M., & Egeth, H. E. (1980). On the nonautomaticity of "automatic" activation: Evidence of selective seeing. *Perception & Psychophysics, 27,* 331-342.

Hardzinski, M., & Pachella, R. (1980). The manipulation of stimulus quality and the definition of stimulus encoding operations in memory scanning experiments. *Perception & Psychophysics, 27,* 232-240.

Harris, J., Shaw, M., & Bates, M. (1979). Visual search in multicharacter arrays with and without gaps. *Perception & Psychophysics, 26,* 69-84.

Hoffman, J. (1978). Search through a sequentially presented visual display. *Perception & Psychophysics, 23,* 1-11.

Howard, D. V. (1983). *Cognitive psychology: Memory, language and thought.* New York: MacMillan.

Johnsen, A. M., & Briggs, G. E. (1973). On the locus of display load effects in choice reactions. *Journal of Experimental Psychology, 99,* 266-271.

Johnston, W., & Dark, V. (1982). In defense of intraperceptual theories of attention. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 407-421.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy and J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181-209). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Treisman, A. (in press). Changing views of attention and automaticity. In R. Parasuraman, R. Davies, and J. Beatty (Eds.), *Varieties of attention.* New York: Academic Press.

Keele, S., & Neill, W. T. (1978). Mechanisms of attention. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception IX* (pp. 3-47). London: Academic Press.

Logan, G. D. (1978). Attention in character-classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General, 107,* 32-63.

McClelland J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86,* 287-330.

Merikle, P. (1980). Selection from visual persistence by perceptual grouping and category membership. *Journal of Experimental Psychology: General, 102,* 279-295.

Merikle, P., Cheesman, J., & Bray, J. (1982). PET flasher: A machine language subroutine for timing visual displays and response latencies. *Behavior Research Methods and Instrumentation, 14,* 26-28.

Mewhort, D., Campbell, A., Marchetti, F., & Campbell, J. (1981). Identification, localization, and "iconic memory": An evaluation of the bar-probe task. *Memory & Cognition, 9,* 50-67.

Miller, J. (1979). Cognitive influences on perceptual processing. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 546-556.

Miller, J., & Bauer, D. (1981). Visual similarity and discrimination demands. *Journal of Experimental Psychology: General, 110,* 39-55.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226-254.

Pashler, H. (1984). Processing stages in overlapping tasks: Evidence for a central bottleneck. *Journal of Experimental Psychology: Human Perception and Performance,10,* 358-377.

Posner, M. I. (1982). Cumulative development of attentional theory. *American Psychologist, 37,* 168-179.

Posner, M. I., & Snyder, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V* (pp. 669-682). London: Academic Press.

Rabbitt, P. M. A. (1978). Sorting, categorization and visual search. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception IX* (pp. 85-134). London: Academic Press.

Sanders, A. F. (1980). Stage analysis of reaction processes. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (*pp.* 331-354). Amsterdam: North-Holland.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review, 84,* 1-66.

Shwartz, S., Pomerantz, J., & Egeth, H. (1977). State and process limitations in information processing: An additive factors analysis. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 402-410.

Shaffer, W. O., & LaBerge, D. (1979). Automatic semantic processing of unattended words. *Journal of Verbal Learning and Verbal Behavior, 18,* 413-426.

Shiffrin, R. M. (1976). Capacity limitations in information processing, attention, and memory. In W. K. Estes (Ed.), *Handbook of learning and cognitive processes, Vol. 4: Attention and memory* (pp. 17~-236). Hillsdale, NJ: Erlbaum.

Sperling, G. (1960). The information available in brief visual presentation. P*sychological Monographs, 74,* 1-28.

Sperling, G., Budiansky, J., Spivak, J., & Johnson, M. (1971). Extremely rapid visual search: The maximum rate of scanning letters for the presence of a numeral. *Science, 174,* 307-311.

Spoehr, K., & Lehmkuhle, S. (1982). *Visual information processing.* San Francisco: W. H. Freeman.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), *Attention and performance II* (pp. 276-315). Amsterdam: North-Holland.

Stroop, J. (1935). Studies of interference in serial verbal reaction. *Journal of Experimental Psychology, 18,* 643-662.

Townsend, V. M. (1973). Loss of spatial and identity information following a tachistoscopic exposure. *Journal of Experimental Psychology, 98,* 113-118.

van der Heijden, A. H. C. (1981). *Short-term visual information forgetting.* London: Routledge and Kegan Paul.

Von Wright, J. M. (1968). Selection in immediate visual memory. *Quarterly Journal of Experimental Psychology, 20,* 62-68.

Received October 4, 1983
Revision received February 1, 1984 ■