VISUAL PROCESSING OF MULTIELEMENT ARRAYS AND THE SELECTIVE MASKING FUNCTION

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by

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ABSTRACT

If a visually presented array of alphanumeric material is followed by a patterned masking stimulus the perception of the items at the ends of the display will be unaffected, while those in the centre of the array will be masked substantially. Termed selective masking, this phenomenon has been extensively investigated, largely as a technique to make inferences about the nature of visual information processing.

The results of numerous studies on the selective masking phenomenon indicate that the items at the ends of a row are processed first and thus escape the effect of a temporally following mask. There has been some uncertainty about the order of processing after the end items have been processed. Experiment I investigated this processing order by systematically varying the interval between the offset of the letter arrays and the onset of the masking stimulus. The results indicated that the ends of the row are indeed processed first and that subsequent serial processing is in general from both ends towards the middle.

It has also been shown that this ends-middle processing order can be altered if the observer is given sufficient information to direct his attention to a single item in the display. When a spatial cue is presented for one of the items at stimulus onset or when the subject is

instructed to report an item which differs in category from the background items, the subject attends to a single item and therefore does not process the array with an ends-first approach. The second experiment investigated the extent and nature of the processing strategy which observers use when presented with an array containing six letters and one digit. In addition, the effect of a categorically incongruous item on the processing of background items was studied. The results show that observers do not selectively process the incongruous item when digit report is required on only a small portion of the trials. The data also indicate that the processing of the odd item and the background items occurs at the same time, i.e. in parallel, but that the overriding serial, ends-first processing strategy common to encoding a multielement array is still employed.

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INTRODUCTION

Much of our visual perception involves the processing of sequential inputs. Reading this page of type or viewing a movie or television program requires the rapid processing of successive visual inputs. It is not surprising, then, that a great deal of research has been devoted to the investigation of how we process two rapidly presented visual stimuli (see, for example, Coltheart, 1972).

The phenomenon termed visual masking, first studied extensively by Werner (1935), has yielded a large amount of evidence concerning the nature of such visual information processing. When two stimuli are visually presented in close temporal contiguity the resulting perception may not always be of two distinct events. The detection or the recognition of the target stimulus may be impaired by the presentation of a preceding or succeeding masking stimulus. If the target stimulus is interfered with by a mask which precedes it in time, then forward masking is said to have occurred, whereas a target which is inhibited in its perception by a subsequent masking stimulus is said to have been subjected to backward masking.

This perceptual interference effect has been observed under a variety of stimulus conditions. Flashes of light have proved to be effective masking stimuli in some cases (Eriksen, 1966; Eriksen & Collins, 1964) as have annular ring masks which spatially surround the target

Averbach & Coriell, 1961) and random dot patterns (Kinsbourne & Warrington, 1962a, 1962b; Uttal, 1971). The latter type of mask is generally referred to as visual noise.

It has been established that masking by patterned stimuli is more effective in disrupting the perception of the target than is masking by flashes of light, presumably reflecting the higher information content present in the heterogeneous mask. It seems that masking by light fields reflects the operation of peripheral mechanisms while patterned masking involves a more central processing capacity (Schiller, 1965; Turvey, 1973). Moreover, it is clear that different patterned masks also vary in their effectiveness: the mask is substantially more effective if the pattern is a random one (Coltheart & Arthur, 1972), if it comprises elements subtending the same visual angle as the target stimulus elements (Turvey, 1973) and if it differs in its figure/ground relationship from the target stimulus (Keating & Sherrick, 1973).

While the investigation of visual masking has done much to enhance our understanding of the underlying mechanisms of visual information processing, a clear explanation of the masking phenomenon itself still eludes us (see Kahneman, 1968). However, two major explanations have emerged which describe this perceptual interference effect. The interruption or erasure theories maintain that the mask stops the processing of the target stimulus either because it interrupts the initial consolidation of the target (Lindsley,

1961) or because the target image, although completely formed, is erased from iconic memory before it can be placed into more permanent storage (Averbach & Coriell, 1961). The second theoretical position, that of integration, proposes that making results from a lack of fine temporal resolution in the visual system. The impairment of the perception of the target stimulus is simply due to the fact that both the target and the mask are effectively simultaneous in the visual system, i.e. the features of the target are degraded by being perceptually embedded in the masking stimulus (see Coltheart & Arthur, 1972). Both theories are supported by substantial experimental evidence but it is clear that they are not mutually exclusive or exhaustive in their predictions (Henderson, 1973).

Most of the research on visual information processing within the backward masking paradigm has employed single element targets; e.g. a single letter, digit or geometric shape usually presented to the fovea. Some researchers, however, have concerned themselves with the way we process multielement arrays, generally a row of seven or eight randomly chosen letters. It has been consistently reported that the items at the ends of such a display, when followed by a patterned mask, are relatively unaffected while those items in the centre of the display are masked to a much greater extent (Butler, 1974; Butler & Merikle, 1973; Coltheart & Merikle, 1970; Henderson & Park, 1973; Merikle, Coltheart & Lowe, 1971). This differential efficacy of the mask for different serial positions has been termed <u>selective masking</u> (SM). A typical SM function is illustrated by Figure 1.

The selective masking effect is relatively unexpected for various reasons. First, Stewart & Purcell (1970) presented single letter targets at various retinal positions and discovered that the letters were more susceptible to a masking stimulus the farther they were from the point of fixation. Second, selective masking is contrary to the data relating target detection to retinal location. Coltheart & Merikle (1970) and Haber & Standing (1969) have demonstrated that when no mask is presented the items at the centre of the row of letters are identified with greater accuracy than those at the ends of the row. These results prompt the argument that the identification of target items depends on the retinal loci which they stimulate, with superior performance being observed at foveal and parafoveal regions. The results of the selective masking experiments, however, argue against such a parsimonious interpretation. If the items of a multi-element array are identifiable with varying degrees of accuracy, a subsequent patterned masking stimulus should have a greater effect on the items which are the most difficult to identify. It is not to be expected that the centre items, which are generally easier to identify under no-mask conditions, should be masked to a greater degree than the end items.

What inferences can be made about the way we process individual items in a multi-letter row given a selective

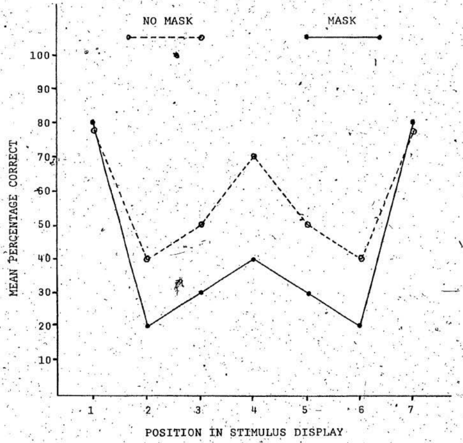

Figure 1: Graphic representation of a typical selective masking function

masking effect like that shown in Figure 1? If we accept the premise that the flow of processing is a serial recoding of the items from a rapidly decaying visual trace into a more permanent auditory-verbal-linguistic (a-v-l) store (Atkinson & Shiffrin, 1968), one possible interpretation is that the items at the ends of the array are processed first. This is the explanation which has been proposed by several investigators of the phenomenon (Butler, 1974; Coltheart, 1972; Merikle et al., 1971). When the masking stimulus is presented following the stimulus display the items at the ends of the row have already been transferred to the a-v-l store and are thus no longer maskable while those at the centre of the array are still in a sensory, and therefore maskable form. A strong piece of converging evidence for this explanation has been reported using a forward masking technique. When a multielement array is preceded by a patterned mask the recall for the end items is depressed relative to a no-mask control group while the recall for the centre items of the display is relatively unaffected (Merikle & Coltheart, 1972). The interpretation of these results is the same as the explanation of the selective masking curves obtained using the backward masking paradigm; i.e. that the observer tends to process the array ends-first. When the patterned mask precedes the letter array the mask is presumably still exerting an effect when the array is presented and since the end items are the ones which are being processed first, they are maximally affected by the mask.

While the selective masking effect can reasonably be attributed to an ends-first processing strategy adopted by the observer, and while such an explanation clearly accounts for the observed function, there remain two possible artifacts which could produce the same pattern of results. The exaggeration of an ends-first strategy under the stress of the masking situation may be a control process (one which the observer controls - see Atkinson & Shiffrin, 1968). If this is the case then it is possible that experimentally blocking mask and no-mask trials or treating masking as a between-subjects variable (as in Butler & Merikle, 1973; Merikle & Coltheart, 1972) could artifactually generate different recall curves under the mask and no-mask conditions. Similarly, it may be that the selective masking function has nothing to do with processing order. The higher recall for the end items may not reflect an ends-first processing order but merely an ends-better recall score. The latter possibility is a reasonable argument since it is likely that lateral masking by adjacent contours is operating on the centre items in the display more than on the items at the ends of the row (Matthews, 1973).

Merikle (1973, 1974) conducted two experiments designed to investigate these possible interpretations of selective masking. Two relevant control procedures were used. A within-subjects design was employed wherein subjects were unable to anticipate whether or not any given letter row would or would not be followed by a mask. In a second experiment a series of "O"s was placed at both ends of the array with the same amount of spacing as between adjacent target letters of the display. The selective masking effect was again observed: the items at the ends of the row were not masked while those in the centre were. The results of these experiments indicate that the selective masking function is not being influenced artifactually by either the observer's strategy during trial blocking or by lateral masking by adjacent contours.

The logical question which arises from this sort of evidence is that if the items are processed ends-first, then which items are subsequently processed? Surprisingly, little of the research to date has been directed toward this question, although Merikle et al. (1971) have indirectly addressed the point. In their experiment an eight-item row of letters was presented for either 30, 50 or 90 milliseconds followed by a visual noise mask presented for two seconds. A close inspection of their data yields some interesting information. At an exposure duration of 30 milliseconds only the right-end item escaped the effect of the mask (or had been encoded into an unmaskable memory store). When the letter array was exposed for 50 milliseconds the items at both ends and the item second from the right were unaffected by the mask, while with an exposure duration of 90 milliseconds both end items and the letters second and third from the right were not masked. An obvious inference to be drawn from these results is that the letter row is processed ends-first and thence from right to left. Such a processing order appears anomalous since the recall scores for the items to the right of fixation is the inverse of the apparent processing order; the recall for the item at serial position five exceeding that of position six which in turn exceeds that of position seven. This latter interpretation, however, is confounded by the fact that output interference occurs. It seems that regardless of the order in which the letters are encoded, subjects usually report them in a left to right sequence (see Bryden, 1960).

Let us now return to the assumption that the individual items of the stimulus display are sequentially processed into an unmaskable short-term auditory (STAM) or short-term visual (STVM) store. If this is a valid premise then any increase in the time in which items are available for processing (i.e. presented without a masking stimulus) should lead to an increasing number of items being unmaskable when the mask is finally presented. Statistically speaking, the selective masking effect is measured by the masking x serial position interaction. An increase, then, in the exposure duration of the stimulus display (as Merikle <u>et al.</u>, 1971 have done) should lead to a change in the masking x serial position interaction as the exposure duration is increased; i.e. a masking x exposure duration x serial position interaction would be predicted. In the experiment described above, however, this interaction did not reach statistical significance.

Merikle & Glick (1976) also attempted to determine the processing order of an observer presented with a multi-element array. Again, it was the exposure duration of the target letters that was manipulated. It was found that as the exposure duration of the target letters was increased performance at the various serial positions improved differentially. Specifically, items to the right of fixation improved more rapidly than the report of items to the left of fixation, although only marginally and not significantly. Additionally, measuring the improvement in performance does not provide a clean test of processing order but merely a vehicle for possible inference.

The salient temporal variable in backward masking involving central processing capacity has been demonstrated to be the onset-onset interval (Turvey, 1973). The experimental manipulation of this stimulus onset asynchrony (SOA) in the Merikle _et al._ (1971) study and by Merikle & Glick (1976) is confounded by an increasing exposure duration of the letter array. A cleaner test of the order of processing of the individual items in the display can be made by delaying the onset of the mask while keeping the exposure duration constant, i.e. by varying the interstimulus interval or ISI.

Lowe (1975) presented seven letter arrays for 100 msec. followed at 50, 550 or 1050 msec. by a patterned masking stimulus. The usual selective masking curve was obtained at an ISI of 50 milliseconds with the centre items being masked and the items at the ends of the rows escaping the effect of the mask. With a delay of 550 msec., however, no masking at all is evident, suggesting that all items have been transformed to an unmaskable form. Lowe argues that the processing of the end items is virtually complete at the 50 msec. delay but the processing of the centre items continues and "by 200 msec delay, the effects of masking have largely dissipated". If the rationale of the Merikle et al. (1971) and the Coltheart (1972) investigations is accepted, i.e. that the end items have been transferred to some unmaskable store by the time the mask arrives, then increasing the time interval between the display offset and the mask onset should lead to an increasing number of items being processed. The temporal manipulations of Lowe (1972), however, are not fine enough to allow information about processing order to be obtained or short enough to be within the bounds of iconic memory. The first experiment performed here, then, was designed to provide data relevant to these considerations.

As has been mentioned previously, the most important use of our knowledge of the selective masking function has been as a technique to allow investigation of how we process more complex visual information. The ends-first processing order, it appears, may be a strategy of the observer employed under the stress of the masking situation; i.e. when a subject is required to process the entire row of letters, as he is with full report or delayed cue partial report (Butler & Merikle, 1973), he uses an ends-first strategy in order to maximize the amount of information abstracted from the array (see Butler, 1974, 1975). If this is an accepted premise, then there are several worthwhile manipulations of stimulus information which, using the selective masking effect as a basis, could provide data relevant to how we encode certain types of visual information.

Butler & Merikle (1973) presented a row of letters tachistoscopically with an ensuing patterned mask and cued for report of a single item by presenting bar-marker cues above and below the target letter position. The cue was presented either at the onset of the letter array (simultaneous cue) or with the presentation of the masking stimulus (delayed cue). When the partial report cue was delayed the usual selective masking curve was obtained (see Figure 1 - page 5); however, when the cue was presented simultaneously with the letters no selective masking was evident. All items were masked equally at all serial positions, i.e. a distributed masking (DM) function was observed. An example of a distributed masking curve is graphically represented in Figure 2. It was argued that when an observer is able to attend selectively to a single item in the array, an ends-first processing strategy is not demonstrated since it is not necessary. Subjects are apparently able to select the indicated item within some finite period of time (in the order of 200 milliseconds according to Eriksen & Collins, 1969) and subsequently process that item exclusively. When the partial report cue is delayed, then the limited processing

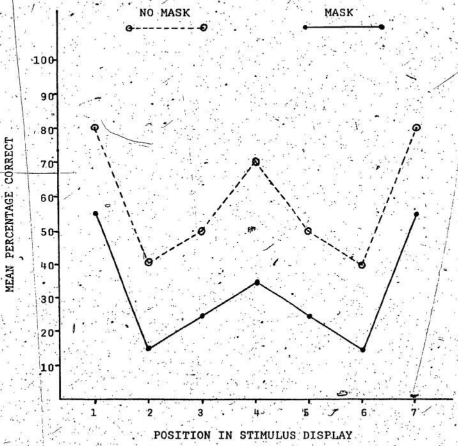

Figure 2: Graphic representation of a typical distributed masking function

capacity which the observer possesses leads to a strategy yielding no masking at the ends of the array. However, when the cue for report is simultaneous with the onset of the letter array the observer directs his attention to that particular item and an ends-first selection of the items to be recoded into short-term memory is unnecessary.

It items can be selectively processed on the basis of cuing by location, then what about other types of cuing? Butler (1975) had subjects report a digit embedded in a row of letters, or alternatively to search for a letter in a row of digits. Under both of these conditions a distributed masking effect was obtained. The explanation proposed in this case was that the identification of tachistoscopically presented multielement arrays proceeds in two distinct stages: an initial *parallel* stage and a subsequent *serial* one. The distributed masking effect is evidenced because the subject is able to direct his attention to one individual item, making ~~an~~ ends-first processing strategy unnecessary. Butler claims that during the parallel operation some information is abstracted from all of the items in the array *at the same time*. The subsequent serial processing of the items, it is argued, must be directed by the information obtained during the initial parallel stage of processing. If this information is not salient, i.e. if the observer cannot isolate one item for processing then the subsequent serial operation will proceed ends-first and a selective masking function will be obtained. A related study provides more information on this point. Butler (1974) in a very well designed and controlled experiment manipulated the semantic content of non-cued material (material which need not be recalled) and measured its effect on the recall of the cued material. The results clearly demonstrate that sufficient information is abstracted from the background, or non-cued, items to determine the category of the items but not enough to determine the identity of any individual item. Butler (1975) argued, of course, that this is exactly what happens during the parallel stage of processing and the actual identification of the items is left for the subsequent serial stage of processing. Estes' (1972) model for the processing of visually presented material is congruent with this proposition. The actual selective attention, according to Estes, occurs at the interface of the two stages of processing.

The selective masking effect, then, was not observed under two experimental conditions in Butler's research: when the stimulus array and the cue to report an individual item appeared simultaneously and when the subject was instructed to report an item which differed in category from the rest of the items in the row. The explanation proposed for these similar sets of data, however, differs greatly. When a bar-marker probe is provided at stimulus onset the observer is said to process only that item, the only delay being the time it takes to locate that item (Butler & Merikle, 1973). However, when the observer is required to report an item which differs in category from the other items in the display he is said to process the entire array in parallel to a level sufficient to determine the category of the odd item (Butler, 1974, 1975). Such an explanation is curious since in all previous experiments in which subjects were forced to process the entire array (as in full report - Merikle et al., 1971, or in delayed cue partial report — Butler & Merikle, 1973) a selective masking function was obtained. A more consistent argument would be to say that in both experimental conditions the subjects are able to attend selectively to one single item in the display. Since in both cases a distributed masking function was found, it is logical to assume that similar mechanisms are responsible for selection on the basis of category as for selection on the basis of spatial location. It may be that subjects can process selectively a digit embedded in a row of letters just as they can attend selectively to an item presented with bar-markers around it. To say that the observers are able to abstract category information in parallel is at least one step above the level of interpretation justified by the experimental procedure used. That is to say, Butler (1975) instructed his subjects to "report the digit in the following displays" - in other words the subjects were given the category information - they had no need to extract that information at all. It is conceivable, indeed highly probable, that knowing the category of the odd item beforehand enables the subjects to activate some specified subset of feature analyzers and the name of the item is accessed more quickly than if the category is unspecified, i.e. knowing the category facilitates recognition (see Jonides & Gleitman, 1972; Busche & Lazar, 1973 for similar discussions).

A much cleaner test of Butler's notion of parallel-sequential processing and categorical selection would be to present arrays of six letters and one digit tachistoscopically and probe for the digit and other times for the letter rather than providing the subjects with category information beforehand. Since a simultaneous cue also appears to produce a distributed masking function (Butler & Merikle, 1973) a manipulation of cue delay with a visual probe should assist in assessing the type of processing occurring under both conditions. Accordingly, a second experiment was designed to determine whether or not, as Butler (1974) suggests, parallel processing of the arrays to the level of category determination occurs automatically, or whether it is a direct effect of a strategy employed by the subjects elicited by (a) knowing the category of the odd item beforehand and (b) digit report being required all of the time. The experimental procedure (after Butler & Merikle, 1973) is illustrated in Figure 3. Arrays containing all letters (as shown) were used as well as displays of six letters and one digit. When subjects are presented with one of the mixed-category arrays, the visual bar-marker cue does not always designate report of the digit. In this way the subjects are

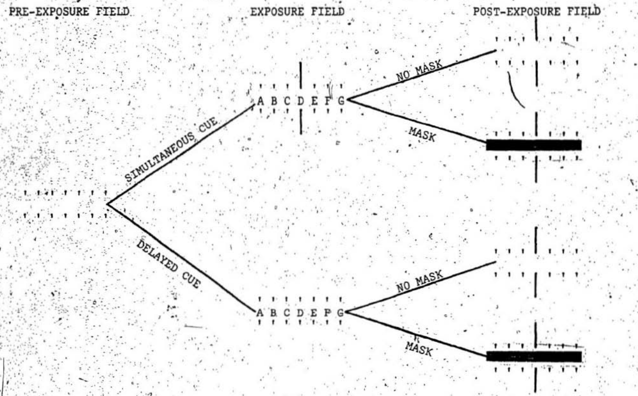

Figure 3: A schematic representation of the major experimental conditions of Experiment II (Arrays containing six letters and one digit were used as well as arrays of seven letters, as shown).

not given the category information beforehand. If Butler (1974) wished to make conclusions concerning the processing strategy involved in encoding an array of six letters and one digit then the subjects should have been given a choice of the item to which to attend. The subjects in his study were told to report the digit from the mixed arrays. In other words, the fact that they were able to do this equally well from all serial positions does not provide information about the abstraction of category information or about individual processing strategies. The present experiment, since it only requires report of the incongruous item on some of the trials, should provide data on whether or not subjects choose to attend to the incongruous item. The manipulation of these stimulus conditions should provide relevant evidence concerning the nature of processing taking place.

If category information is obtained from the arrays and the subject chooses to process the incongruous item, then how will the processing of that item affect the encoding of the background items? The odd item may be processed at the expense of the others even though a background item is cued for report, or alternatively the odd item may be dismissed as a possible response and thus facilitate the identification of one of the background items. Such possibilities have important consequences for any theoretical interpretations of how we process semantic material as well as having implications for models of selective attention.

The second experiment was designed then to determine the nature and extent of processing involved when a categorically incongruous item is present in the display.

In summary, both experiments propose to use the well established effect and technique of selective masking to examine further the nature of visual information processing of alphanumeric material and the strategies that subjects use when processing information presented visually. The first experiment was designed to investigate the order of processing of such information by manipulating the critical temporal variable of stimulus onset asnchrony (Turvey, 1973). The exposure duration of the target arrays was held constant and the interval between the offset of the letters and the onset of the mask was systematically varied to allow the SOA to be changed without increasing the exposure duration of the letter arrays. The second experiment was designed to examine the nature of the processing involved and the strategies employed by observers when presented with an array of six letters and one digit. The item to be reported from the mixed arrays was probed randomly using bar-marker cues either simultaneous with the presentation of the displays or after a short delay. The examination of the masking effects under these conditions should provide data concerning individual processing strategies and selective attention.

EXPERIMENT I

The major purpose of this experiment was to provide data relevant to the order of visual processing of multi-element arrays. Accordingly, displays of seven-letter rows were presented tachistoscopically followed at various interstimulus intervals by a mask or no-mask. The letter to be reported was cued using a visual bar-marker probe.

Method

Subjects. All subjects were undergraduate students of Memorial University and were paid at the rate of $2.00/hour for their participation in the experiment. All had normal or corrected to normal vision and all received 56 practice trials before beginning the experiment. A total of nine subjects was used.

Apparatus and Stimuli. A set of 56 sequences of seven randomly chosen letters was constructed so that the letters B, C, D, F, H, K, L, N, P, S, T, V, X and Z were used in each serial position four times. No letter was repeated within a single sequence. The arrays were first typewritten on white index cards using an IBM electric typewriter with a black film ribbon and were uppercase using element Courier 72. The index cards were subsequently photographed using Kodak direct positive high speed duplicating film #2575.

The film was then mounted into 2 mm. x 2 mm. slides for presentation in a Scientific Prototype Model GB 3 - channel tachistoscope. The fixation field and bar-marker probes were typed and photographed in a similar manner. The visual angle subtended by the letter rows was 12°45' horizontally and 1°10' vertically when viewed in the tachistoscope. The probe set subtended a visual angle of 12°25' horizontally and 3°27' vertically (the latter angle being that of the long pair of bar-markers. The masking stimulus was a strip from a photograph of random white dots on a black background (Keating & Sherrick, 1973) which subtended a visual angle of 1°40' vertically and extended horizontally across the entire visual field. The luminance of the white background of all fields was set at approximately 20 millilamberts.

Design and Procedure. Prior to each trial the subject viewed a fixation field consisting of seven pairs of small bars which occupied the positions above and below where the letters were to appear. A similar set of bars appeared concurrently with the mask/no-mask with one longer pair of bars designating the item to be reported. This probe type is analogous to one developed by Lowe (1972). The probe set was presented either alone (no-mask condition) or surrounding the strip of visual noise (masking condition). Mask and no-mask trials were blocked into groups of 56 trials. The delay between the offset of the letter array and the onset of the masking stimulus was systematically varied yielding intervals of 0, 25, 50, 75, 100 and 200 milliseconds. The factorial combination of the mask/no-mask conditions with the six interstimulus intervals produced the twelve experimental conditions. The stimulus arrays were presented for 100 milliseconds followed by the mask/no-mask for a duration of one second. The interstimulus intervals between the target and the mask were each blocked into groups of 56 trials, a different array being presented on each trial. The order of presentation of the arrays and the experimental conditions were randomized within and between subjects with the restriction that half of the subjects received a no-mask condition first and the other half a masking condition.

Each subject received 56 trials in each of the 12 experimental conditions over 4 daily one hour sessions with eight trials being presented for each of the seven serial positions. The order in which the serial positions were probed was randomly determined with the restriction that each serial position was probed an equal number of times. The experiment was conducted in a darkened room and subjects were dark-adapted for approximately 10 minutes prior to the experiment. Following a verbal ready signal from the experimenter the subject initiated a trial sequence: letter array (100 msec.) followed at one of the six delays (these ISI's were dark) by the bar-marker set (1 sec.) surrounding a mask or no-mask. The subjects' task was to report the item indicated by the vertical bars. The experimenter recorded the response and the fixation field returned automatically after each trial sequence.

Results and Discussion

The number of letters correctly recalled for each subject at each serial position in each experimental condition was calculated and the data submitted to a 2 x 6 x 7 analysis of variance to assess the main and interactive effects of masking, interstimulus interval and serial position. The results of the analysis are shown in Table 1 of Appendix A. The mean probability of a correct response across subjects for each interstimulus interval and serial position for both masking and no-mask conditions is illustrated in Figure 4. Since there were eight items tested at each serial position for each subject in each experimental condition, 72 responses are represented by each point on the graph.

At every specified delay of the mask the percentage recall for the end items is approximately equal under mask and no-mask conditions, while the percentage correct recall for the items in the centre of the display is never as high with the mask as when there is no masking stimulus presented. This result is typical of all experiments demonstrating the selective masking phenomenon. The existence of the selective masking function in this experiment is supported statistically by the significant masking x serial position interaction ($F = 2.82$, $df = 6, 48$, $p < .05$). The masking

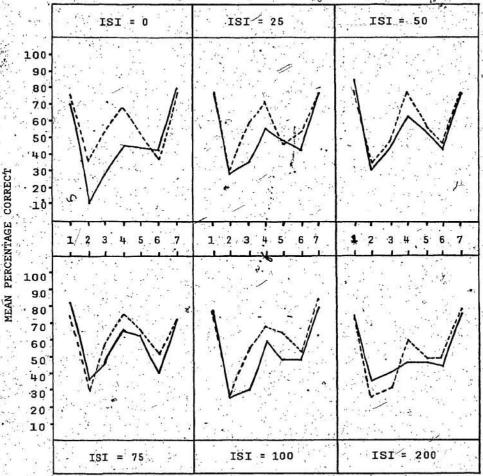

Figure 4: Percentage correct recall under mask (———) and no mask (-----) conditions for each interstimulus interval

main effect ($F = 10.86$, $df = 1, 8$, $p < .05$), serial position main effect ($F = 15.68$, $df = 6, 48$, $p < .01$) and the masking x serial position x interstimulus interval interaction ($F = 1.53$, $df = 30, 240$, $p < .05$) were also statistically significant. All other main and interactive effects were not significant.

The three-way interaction was the most interesting effect observed. It was this interaction which did not reach statistical significance in the Merikle et al. (1971) experiment. In that study the manipulation of stimulus onset asynchrony (the critical temporal variable according to Turvey, 1973) was confounded by an increasing exposure duration of the target letters. The present experiment was designed to test the effect of increasing the available processing time on the recall of items at the various serial positions in the display. The present manipulations of SOA by holding the exposure duration constant and varying the ISI produced the predicted effect. The relevant three-way interaction demonstrates statistically that the masking x serial position interaction changes as the interstimulus interval is increased.

How do the mask/no-mask curves change as the interstimulus interval is increased? An elementary analysis of the order of processing of the individual items in the display may be conducted by examining the actual serial positions which are not affected by the mask at the various interstimulus intervals. Table 1 illustrates the results

TABLE 1

Experiment I

Significant recall differences for mask vs no-mask conditions for the various serial positions at each interstimulus interval

	Serial Position						
ISI (msec)	1	2	3	4	5	6	7
0		*	*	*	*		
25			*	*		*	
50				*			
75			*	*		*	
100			*	*	*		
200				*		*	

*p < .01 - Scheffe test.

of comparisons with the Scheffé test of the relevant data points. The significant recall differences for the mask vs no-mask conditions at the various serial positions and interstimulus intervals are marked by an asterisk in the table. The results clearly illustrate the strength of the selective masking effect. The items at the ends of the array (serial positions 1 and 7) are never masked while the items in the centre of the display are always affected by the mask.

It is apparent that an ends-first selection of the items is occurring. The end items become available for report prior to the centre items and report of the centre items is always inferior to report of the end items. These results support Merikle & Glick (1976). Another observation from their experiment was that items to the right of fixation become available for report somewhat more rapidly than items to the left of fixation. An inspection of Figure 4 seems to indicate higher performance levels for the right visual field as well. What does the experiment tell us about the order of processing after the ends are processed? An inspection of Table 1 yields some very relevant considerations. At an ISI of 0 msec, the centre four items of the display are masked while those at the ends have already been transferred into an unmaskable post-sensory store. This supports the conclusion by Lowe (1975) that the items at the ends are processed first and quickly while those items in the centre are processed later. As the ISI is increased up to 50 msec. only the item at serial position 4 is still affected by the mask, i.e. six items have by this time been transferred into an unmaskable form. If the items were being processed in a unidirectional manner (either from right to left or left to right) then the item at serial position four would certainly be one of the six items unaffected by the mask. At longer interstimulus intervals there is some loss of information occurring. This is probably due to the fact that the bar-marker cues designating the item to be reported were presented with the masking stimulus and therefore also delayed. In other words, in this case the delay of 50 msec. may represent optimal performance levels for mask and no-mask conditions. Another possible explanation is that the loss of information after 50 msec. ISI is from short term memory rather than from sensory storage and may have nothing at all to do with processing order. If we accept the fact that an item is not masked because it has been processed beyond the level of sensory storage, then six of the items are at this stage after 50 msec. delay. Items appearing to be masked after this delay then may merely reflect a loss of information from a short-term memory store. Despite these inconsistencies the general direction of the encoding operation is serial and not unidirectional. The results suggest the inference that not only are items being processed ends-first but in general from both ends towards the middle, with the items to the right of fixation improving more rapidly than items to the left of fixation.

EXPERIMENT II

The main purpose of this experiment was to determine the processing strategies involved when subjects are presented tachistoscopically with an array of six letters and one digit. It has been demonstrated (Butler & Merikle, 1973) that a spatial cue presented simultaneously with a row of letters can direct the attention of the observer to one item in the display and result in a distributed masking function. It has been suggested also (Butler, 1975) that a category cue can lead to selective processing of the categorically incongruous item and yield a similar distributed masking function. The present study tested the generality of the Butler (1975) conclusions by not always requiring report of the incongruous item. The effect of a categorically incongruous item on the processing strategy of the observer was thereby investigated.

Method

Subjects. All subjects were students of Memorial University and were paid at the rate of $3.00/hour for their participation in the experiment. All had normal or corrected to normal vision and each subject received 30 to 50 practice trials before beginning the experiment. A total of 80 subjects was used.

Apparatus and Stimuli. A set of 42 sequences was constructed of seven randomly chosen letters so that the letters B, C, D, F, H, K, L, N, R, S, T, V, X and Z were used in each serial position three times. No letter was repeated within a single sequence. Similarly, a set of 252 sequences was constructed with six letters and one digit in each sequence. Since it was important not to have the subjects pre-cued to expect to report a digit on every trial, such report was only required some of the time. The letters listed above were used in each serial position eighteen times and the numbers 2, 4, 5, 6, 7 and 9 were used in each serial position six times. Again no item was repeated within a single sequence. The stimuli were prepared for presentation as described in Experiment I. The visual angles of all stimuli and the luminance of the stimulus fields were also the same as in the first experiment.

Design and Procedure. The design was a mixed design with all variables except serial position being between-subjects. Two types of stimulus arrays were presented in the ecperiment: seven-letter rows (Letters) and rows of six letters and one digit (Mixed). The cue for the item to be reported was a pair of vertical bar-markers as described in Experiment I. Since it was not desirable to have subjects report a digit every time a mixed array was presented, on only 42 occasions was a digit cued for report (Mixed/Digit) and on 210 trials a letter was cued for report (Mixed/Letter).

The bar-markers appeared either together with the stimulus array (Simultaneous Cue), SOA = 0 milliseconds, or at the offset of the stimulus array (Delayed Cue), SOA = 100 milliseconds. The stimulus rows were followed by a mask or no-mask as in the preceding experiment. The arrays were again presented for 100 milliseconds and the mask/no-mask for one second. The probing of the seven serial positions was randomized with the restriction that each position was probed an equal number of times within a given experimental condition. The factorial combination of masking (Mask and No-Mask), cue delay (Simultaneous and Delayed) and reporting condition (Mixed/Digit and Letter) produced the eight between subjects conditions (10 subjects were run in each condition) with serial position as a within-subjects variable.

The experiment was again run in a darkened room with each subject dark-adapted for approximately 10 minutes prior to the experiment. Following a verbal ready signal from the experimenter the subject initiated a trial sequence: stimulus array (with or without a cue for report) followed immediately at its offset by the bar-marker set surrounding a patterned mask or blank white field. The experimental procedure is illustrated in Figure 3 - Page 18. The subjects' task was to report the item designated by the long pair of bars. The experimenter recorded the subjects' responses and the fixation field returned automatically following the trial sequence.

Results and Discussion

Scores were calculated for each subject by tabulating the number of correct responses at each serial position in each of the eight experimental conditions. Since the processing of a categorically incongruous item was of prime experimental interest, the recall of letters from a row of letters was compared to the recall of an embedded digit from a row of letters. Accordingly, performance on the trials which required report of a digit from a mixed array (Mixed/Digit) was compared with performance which required report of letters from a homogeneous array (Letters). These scores were submitted to a 2 x 2 x 2 x 7 analysis of variance to assess the main and interactive effects of masking, cue delay, reporting condition and serial position. The results of the analysis are shown in Table 2 of Appendix A. The percentage correctly reported under mask and no-mask conditions at each serial position as a function of cue delay and reporting condition is illustrated by Figure 5. Since there were a maximum number of six possible correct responses for each subject, each data point on the graph represents 60 observations.

It can be readily seen from the graph that the mask/no-mask functions are quite different from one another. Panels (a) and (b) illustrate a different relationship between masking and serial position than that shown in panels (c) and (d). The masking observed when the cue for report

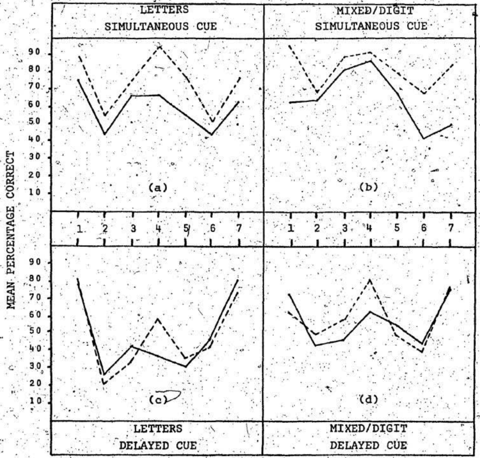

Figure 5: Percentage correct recall under mask (——) and no-mask (-----) conditions as a function of serial position, cue delay and reporting condition, (Mixed/digit vs Letters).

FIG 5

appears simultaneously with the display is not a selective function, i.e. the effect of the mask is distributed across all serial positions in the display. The lower two panels of the graph, however, clearly illustrate a selective masking function with the items at the ends of the row being unaffected by the mask.

It appears that when the cue for recall is given simultaneously with the onset of the display the effect of an aftercoming patterned masking stimulus is not a selective one; it affects all positions in the stimulus display. Under conditions when the cue for report is delayed the observer apparently processes the items in an ends-first manner and the selective masking function is obtained. Statistical support for this conclusion is demonstrated by the fact that the masking x serial position curves change with cue delay ($F = 2.65$, $df = 6, 432$, $p < .05$). Although this interaction did not reach statistical significance in the Butler & Merikle (1973) study, their basic findings were the same and the present results support their conclusions. Whether a masking curve across serial position is selective or not depends on whether or not the items at the ends of the row are masked. It can be readily seen that when the cue for recall is delayed the items at serial positions 1 and 7 are not affected by the mask while they are clearly affected when the cue is provided simultaneously with the stimulus display.

What processing strategies are involved in producing both distributed and selective masking functions? With a simultaneous visual cue the observer is not required to process the entire array since his attention is directed to a single item in the display at stimulus onset. Except for the time it takes to locate the probe the observer is presumably processing a single item. When the cue is delayed until stimulus offset, however, the subject is required to process the entire array and will thus have less available time to process each individual item. Consequently the report of items with simultaneous cues should be superior to report of items with delayed cues. This interpretation is supported by the cue delay main effect ($F = 50.07$, $df = 1, 72$, $p < .01$) and the cue delay x serial position interaction ($F = 14.93$, $df = 6, 432$, $p < .01$). The distributed masking function obtained when the cue for recall is given simultaneously is strong support for the fact that the selective masking effect is probably due to an observer employed strategy rather than an unmodifiable central process.

The higher recall for the digits in the centre of the display when the cue is simultaneous is probably due to the fact that two salient cues, the digit and the bar-markers, combine to make the digit very easy to perceive. This central digit superiority is also present when the cue is delayed but is not as pronounced. This would be expected since the bar-marker cue is not physically present with the digit but merely summated in the visual system.

The most interesting and important effect observed in the present experiment was the evidence of a selective masking function when the cue for recall is delayed and the subject is required to report a digit from a row of six letters and one digit (see Figure 5d). It has been demonstrated by Butler & Merikle (1973) and by the results of the present experiment that when the subject is cued to report an item simultaneously with the presentation of that item, a distributed masking function is obtained. Why does this happen? Butler & Merikle (1973) and Butler (1975) argue reasonably that under such conditions the subject is able to attend selectively to a single item in the display and therefore need not employ an ends-first processing strategy which would normally produce the selective masking function. This effect is clear in the present experiment and the argument for its occurrence is certainly a plausible one. The logical extension of this rationale is that any factors which can direct the attention of an observer to a single item in the display will produce a similar distributed masking function. Butler (1975) found that when subjects were presented with an array of seven letters and one digit and told to report the digit, the effect of an aftercoming patterned mask was distributed across the entire display. Butler argued that the observer processes the array in parallel to a level sufficient to determine the category of the odd item. The information thus obtained is sufficient to direct attention to that item which is then processed exclusively. This selective attention to a single item in the display results in a non-ends-first processing order and hence no selective masking. The common denominator of the explanations for the distributed masking functions both with simultaneous cuing and with reporting a digit from a letter array is the fact that the observer is attending to <u>one item</u> in the display in both cases. Whether or not the subjects can abstract category information in parallel or any other way is entirely another question, however. The subjects' task in Butler's (1975) study was to report the digit in the stimulus displays. Did the subjects selectively attend to the digit in the row of letters? Apparently so, since a distributed masking function was obtained. Did the subjects abstract category information is parallel? Probably not, since they were told the category of the odd item beforehand. There is no reason to conclude that they have abstracted category information from the display.

It has already been argued that the distributed and selective masking curves reflect processing strategies adopted by the observers under various stimulus conditions. The results of the Butler (1975) experiment, then, were probably due to two factors. First, category information provided beforehand enabled the subjects to activate a set of feature analyzers which respond readily to digits. In other words the threshold for the digit analyzers is temporarily lowered and the digit is perceived more readily (see Treisman, 1969). The fact that a distributed masking curve was obtained indicating selective processing of the digit is not surprising. Apparently subjects choose to attend to the digit in order to maximize their reporting accuracy, since the digit is always the item to be reported.

According to this proposition if the subjects are not given category information beforehand and if the digit is not always the item to be reported then subjects should employ the strategy which is most efficient. That is to say, there should be no involvement with any sort of feature analysis and a normal ends-first processing of the array should take place and a selective masking function obtained. This is precisely what happens in the present experiment (see Figure 5, panel d). The fact that the masking by serial position curves change not only as the cue is delayed but also as a function of the reporting condition is demonstrated by the relevant four-way interaction ($F = 2.59$, $df = 6, 432$, $p < .05$).

An overall inspection of Figure 5 and of the results of the analysis of variance indicate that in general digits were reported better than letters ($F = 12.88$, $df = 1, 72$, $p < .01$). This result suggests that even though subjects are only required to report the digit on 42 of the 252 trials they appear to have a stronger perception of the digit than if it were just another letter. This comparison must be interpreted with some caution, however, since the superiority of digits may be due to the higher probability of a correct guess when a digit is cued for report. Although the digits seem to be processed with greater efficiency it is clear that they are not selectively processed since such a processing strategy would produce a distributed masking effect and not the selective function observed.

Although it was not of major experimental interest, the processing of the background letters in a mixed array was of some concern. Accordingly, the performance on the 210 trials for each subject when a letter was cued for report was examined and the scores tabulated. The total number correct at each serial position for each experimental condition was calculated as before. Since there were 30 correct responses possible at each serial position for each subject in the Mixed/Letter arrays, the total correct was divided by five to equate the data with those of the Letter conditions where there were only six possible correct. The scores for the Mixed/Letter conditions were substituted for those of the Mixed/Digit conditions and another 2 x 2 x 2 x 7 analysis of variance was performed. Although this procedure clearly violates the assumption of homogeneity of variance, there is considerable evidence that this does not invalidate the use of the analysis of variance (Keppel, 1973). The results of this analysis are tabulated in Table 3 of Appendix A and are illustrated in Figure 6. Again we find a distributed masking curve with a simultaneous report cue and the usual selective masking function when the cue for report is delayed.

What does this analysis tell us about the information processing involved when subjects encode an array containing six letters and one digit? Again there was an effect of the type of array from which subjects were reporting with

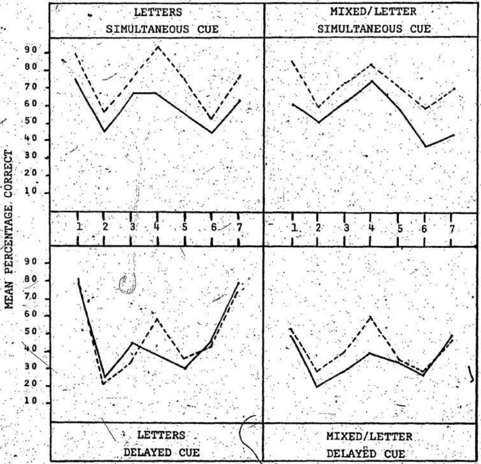

Figure 6: Percentage correct recall under mask (———) and no-mask (-----) conditions as a function of serial position, cue delay and reporting condition, (Mixed/letter vs Letters).

FIG.6

letters being recalled better from a row of letters than from an array with an embedded digit ($F = 7.65$, $df = 1, 72$, $p < .01$). What makes the letter 'B' in the array (ABCDEFG) followed by a cue to report 'B' different from the letter 'B' in (ABC6DEF) with a delayed cue to report 'B'? In both cases a selective masking function is obtained which suggests a similar ends-first processing order in both conditions. Clearly the only difference in the arrays is the presence or absence of the digit '6'. Again it seems that the digit is having an effect on processing but that it is not being <u>selectively</u> attended to. The effect that the digit has upon report of the background letters should be more pronounced when the cue is delayed than when the cue is provided simultaneously. This proposition is supported by the existence of a cue delay x reporting condition x serial position interaction ($F = 2.13$, $df = 6, 432$, $p < .01$). It appears that the digit is affecting the serial position curves but that the effect is greater when the cue for report is delayed. In other words the digit is a significant factor in impairing the report of the background letters especially when the cue is delayed. Again it seems that the digit, although not being selectively processed by the observer, is being processed to some extent and not treated as if it were just another letter.

The absence of a distributed masking effect when a digit is cued for report from a row of letters with a delayed cue certainly suggests an ends-first processing strategy, i.e. the digit is not being selectively processed. There is some evidence, however, that the digit is being processed to some level: (1) the superior recall for the digit over the letters (see Figure 5) and (2) the superior recall for the letters from homogeneous lists over letters from the mixed arrays, even when the cue for a letter is presented simultaneously (see Figure 6). It is also interesting to note that, although no formal analysis was performed, careful inspection of the data indicates that at every serial position with both cue delays report of the digit from the mixed arrays was always higher than report of the letters from the mixed arrays (compare Figures 5 and 6). It seems probable that the digit is not being processed to the level necessary for categorical selection, as Butler (1975) suggests, but that it is being processed in a parallel fashion with the letters.

It appears, then, for an incongruous item to exert control over processing strategy it must be the item to be reported on a large percentage of the trials. If it is not then subjects will maximize their reporting accuracy by employing the usual ends-first processing of the items in the array. In the Butler (1975) study the digit was to be reported on 100% of the trials while in the present experiment on only 17% of the trials. A manipulation of the probability of digit report may provide valuable information concerning whether or not processing strategy changes in a continuous or discrete fashion. Thus, although Butler (1975) may have been quite correct in proposing selection on the basis of category, his conclusions are limited to a description of individual strategies rather than a general model of information processing. It does seem clear, however, that his rationale for parallel processing of alphanumeric displays is not unreasonable.

GENERAL DISCUSSION

The present experiments illustrate the strength and generality of an ends-first processing order in the scanning of tachistoscopically presented arrays of alphanumeric material. Experiment I investigated the possible variations in the order of processing as the masking stimulus was delayed. The ends-first approach was evidenced at every interstimulus interval. The second experiment showed that unless the attention of the observer can be directed to a single item in the display at stimulus onset the processing of the array will proceed in an ends-first manner. Moreover, the processing order was not modified by presenting an item categorically incongruous with the other items in the display.

If the visual processing of a briefly presented array is an ends-first selection then which items are subsequently processed? The first experiment addressed this question directly by systematically varying the delay of the mask and noting the changes in the resultant selective masking curves.

The items at the ends of the display were always unaffected by an aftercoming patterned mask while items in the centre of the display never escaped degradation by the visual noise mask. Even when six of the seven letters presented were not masked, the item at serial position four (the centre of the display) was still reported significantly less often when a mask followed than when no mask was presented. It is apparent, then, that the items in the array generally are not being processed left to right or right to left but from both ends towards the middle.

Experiment II attempted to investigate the mechanisms involved and the processing order used when an array of letters and digits was visually presented. The consistency and strength of the selective masking function and the ends-first processing order it reflects were used to determine (1) the possibility of an item being selected for exclusive processing by category and spatial cues and (2) whether or not the processing of the categorically different items proceeded at the same time or sequentially.

The presence of the usual selective masking function, representative of an ends-first processing order, when a digit was cued for report with a delayed visual cue suggests that the digit is not being selectively processed. The failure of the Butler (1975) experiment to show this effect with similar stimuli is probably due to the fact that in his study the subjects were instructed to report the digit beforehand. Why should pre-cuing so dramatically affect the results? It is clear that we are able to perceive such things as color and movement, depth and shape at the same time because they stimulate different neural pathways. Similarly, parallel processing and divided attention between digits and letters may also be possible but only if they reach different feature analyzers (see Kahneman, 1973). If such is the case then instructing the subjects that they are to search for a digit in a row of letters will allow them to activate their 'digit analyzers'. The threshold of these analyzers will be temporarily lowered relative to those for letters and the digit will be perceived more readily. Support for this interpretation of the results is given by the fact that (a) digits were reported consistently better than letters and (b) that letters from the homogeneous arrays were reported better than letters from arrays containing a digit. Both results indicate that the digit is being processed to some extent even when it is not being cued for report. The fact that the processing of the letters and the digit in a mixed array was occurring at the same time is supported by the observation that even when the cue to report a letter from an array containing an embedded digit was presented simultaneously with the array, the recall of that letter was lower than when a letter was to be reported from a row of letters.

It appears that the digit and the letters are indeed being processed in parallel to some degree but that the overriding mode of processing is still a serial one since a selective masking function still results when digits are cued for report from a row of letters with the cue being delayed. Breitmeyer & Ganz (1976) have argued that when the display size exceeds the limits of our functional fovea a "sequential scanning superimposed on a parallel readout" occurs. This explanation incorporates the results of the second experiment quite well. The digits do appear to be processed in parallel but the presence of the selective masking effect when the digit is cued for report with a delayed cue suggests a strong, overriding, serial, ends-first processing strategy.

In summary, then, it is apparent that the dominant mode of processing alphanumeric material is a serial one which begins at the ends of the display and in general goes towards the middle. It is also clear that this serial operation can be arrested if the attention of the observer can be directed to a single item in the display by the simultaneous presentation of a spatial cue. Whether or not an incongruous item can direct attention to an individual item appears to depend on whether or not it is to be reported all of the time. Thus, although Butler's (1975) hypothesis that items can be selected on the basis of category may not have been entirely correct, his parallel-sequential model of processing seems to be reasonable. Because the present results suggest that both operations occur and that these may be partially temporally superimposed (Breitmeyer & Ganz, 1976), the parallel-sequential model of visual processing appears to be a valid proposal.

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APPENDIX A – TABLE 1

EXPERIMENT I

Summary table for analysis of variance on number of correct responses for each subject at each serial position

Source	df	MS	F
Masking (M)	1	38.00	10.86*
M x Subjects	8	3.50	
Interstimulus Int. (I)	5	5.53	2.07
I x Subjects	40	2.67	
Serial Position (SP)	6	205.88	15.68**
SP x Subjects	48	13.13	
M x I	5	2.09	1.14
M x I x Subjects	40	1.84	
M x SP	6	7.19	2.82*
M x SP x Subjects	48	2.55	
I x SP	30	1.45	0.93
I x SP x Subjects	240	1.56	
M x I x SP	30	1.83	1.53*
M x I x SP x Subjects	240	1.20	
Subjects	8	46.82	

*p < .05
**p < .01

APPENDIX A - TABLE 2

EXPERIMENT II

Summary table for analysis of variance on mean number of correct responses for all experimental conditions (Letters vs Mixed/Digit)

Source	df	MS	F
Masking (M)	1	42.35	15.59**
Cue Delay (C)	1	136.03	50.07**
Reporting Condition (R)	1	35.00	12.88**
M x C	1	28.35	10.44**
M x R	1	1.21	0.45
C x R	1	0.25	0.09
M x C x R	1	0.07	0.02
Error	72	2.72	
Serial Position (SP)	6	46.31	45.72**
M x SP	6	2.04	2.02
C x SP	6	15.12	14.93**
M x C x SP	6	2.68	2.65*
R x SP	6	7.71	7.61**
M x R x SP	6	2.39	2.36*
C x R x SP	6	1.75	1.73
M x C x R x SP	6	2.63	2.59*
Error	432	1.01	

*p < .05
**p < .01

APPENDIX A - TABLE 3

EXPERIMENT II

Summary table for analysis of variance on mean number of correct responses for all experimental conditions (Letters vs Mixed/Letter)

Source	df	MS	F
Masking (M)	1	46.23	19.62**
Cue Delay (C)	1	221.64	94.07**
Reporting Condition (R)	1	17.97	7.65**
M x C	1	20.18	8.56**
M x R	1	1.93	0.82
C x R	1	7.38	3.13
M x C x R	1	1.18	0.50
Error	72	2.36	
Serial Position (SP)	6	44.34	58.19**
M x SP	6	1.96	2.57*
C x SP	6	11.93	15.65**
M x C x SP	6	1.72	2.25*
R x SP	6	6.83	8.95**
M x R x SP	6	1.96	2.58*
C x R x SP	6	1.62	2.13**
M x C x R x SP	6	1.16	1.52
Error	432	0.76	

*p < .05
**p < .01