08773-64-T

HUMAN PERFORMANCE CENTER
DEPARTMENT OF PSYCHOLOGY
The University of Michigan, Ann Arbor

Spatial Processing Characteristics in the Perception of Brief Visual Arrays

GERALD T. GARDNER

1. This document has been approved for public release and sale; its distribution is unlimited.

Technical Report No. 23
August 1970

89

T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF LITERATURE, SCIENCE AND THE ARTS

DEPARTMENT OF PSYCHOLOGY

SPATIAL PROCESSING CHARACTERISTICS IN THE PERCEPTION OF BRIEF VISUAL ARRAYS

Gerald T. Gardner

HUMAN PERFORMANCE CENTER--TECHNICAL REPORT NO. 23

This research was supported by the Advanced Research Projects Agency, Department of Defense, and monitored by the Air Force Office of Scienfitic Research, under Contract No. AF 49(638)-1736 with the Human Performance Center, Department of Psychology, University of Michigan.

THE HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The Human Performance Center is a federation of research programs whose emphasis is on man as a processor of information. Topics under study include perception, attention, verbal learning and behavior, short- and long-term memory, choice and decision processes, and learning and performance in simple and complex skills. The integrating concept is the quantitative description, and theory, of man's performance capabilities and limitations and the ways in which these may be modified by learning, by instruction, and by task design.

The Center issues two series of reports. A Technical Report series includes original reports of experimental or theoretical studies, and integrative reviews of the scientific literature. A Memorandum Report series includes printed versions of papers presented orally at scientific or professional meetings or symposia, methodological notes and documentary materials, apparatus notes, and exploratory studies.

PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human information processing and retrieval, supported by the Advanced Research Projects Agency, Behavioral Sciences, Command and Control Research under Order No. 461, Amendments 3 and 5, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract No. AF 49(638)-1736.

This report was also a dissertaion submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1970. The doctoral dissertation committee was: Drs. R. W. Pew, Chairman, R. A. Bjork, W. M. Kincaid, and D. J. Weintraub.

BLANK PAGE

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

ABSTRACT

A central issue in perceptual research concerns the spatial processing characteristics of mechanisms that extract information from briefly presented alpha-numeric arrays. Recent work on this issue by Estes and Taylor (1964, 1966) incorporated a methodology that avoided the short-term memory confoundings of prior designs. In the Estes and Taylor experiments, each trial consisted of the brief presentation of an array containing random "noise" letters plus one of two critical letters, the S attempting to determine which critical letter appeared. As the number of noise letters was increased, the proportion of trials on which Ss selected the correct letter was found to decrease. This result was interpreted by Estes and Taylor, and by Rumelhart (1970) as demonstrating some limitation of perceptual capacity - either a serial scan from a fading trace, or a parallel attentional mechanism of limited capacity. However, these experiments involved potentially critical methodological confoundings: stimulus arrays containing more letters were either larger in size (visual angle) or were more "crowded" - with adjacent letters closer together; both of these factors have been shown to decrease letter perceptibility independent of the factors manipulated in the Estes and Taylor studies.

Experiment I in the present study was patterned after the Estes and Taylor paradigms, but controlled both angular size and crowding factors by means of a stimulus array incorporating the lack of interaction found for items separated by 1° or more of visual angle (cf., Eriksen, Munsinger, & Grenspon, 1966). The results indicated that, notwithstanding these controls, Ss' performance decreased with increases from 4 to 16 in the number of letters in the array. Experiment II was similar to Experiment I, except that stimulus arrays were sub-span, containing from 1 to 4 letters; the results showed the same performance decline as in Experiment I.

The data from Experiments I and II supported models involving a limitation of perceptual capacity. However, there was evidence that Ss in detection experiments often confused noise letters with the critical alternatives; a mathematical model incorporating such confusions was developed and was found to predict the obtained decline in performance with increasing number of letters due to the decisional structure of the detection paradigm, even though the perceptual stage embodied no limitation of capacity, i.e., the model conceptualized an independent, parallel perceptual channel for each stimulus letter. Experiment III attempted a critical test between previous limited-capacity models and the unlimited-capacity "confusions" (UCC) model; it was similar to an experiment by Eriksen and Lappin (1967), and employed 1 - 4 letter arrays and a specially designed whole-report procedure. The results failed to duplicate the invariance of per-item identification accuracy found by Eriksen and Lappin. Such a performance invariance, along with the decrease in detection accuracy found in Experiment II for 1 - 4 letter arrays, would have been required to support the UCC model. Experiment IV attempted to resolve the discrepancy between the results of Eriksen and Lappin (1967) and Experiment III by means of an exact replication of the Eriksen and Lappin paradigm; the replication, however, failed to yield the invariance of per-item identification accuracy required by the UCC model.

It was concluded that, notwithstanding the methodological and theoretical considerations of Experiments I - IV, limited-capacity conceptions such as Rumelhart's remain viable models for alpha-numeric character recognition under tachistoscopic conditions. Further considerations suggest, however, that a truly decisive rejection of unlimited-capacity conceptions may not be possible within current methodologies.

CHAPTER I

INTRODUCTION

In real-life situations, we integrate information from successive eye fixations when perceiving a complex stimulus. This paper is concerned with the nature of the perceptual processes that occur within a single fixation. More specifically, it is concerned with the spatial characteristics of the visual recognition processes that extract information from a briefly presented stimulus array. Researchers in this area have asked such questions as: How many items (e.g., geometric forms or alpha-numeric characters) are perceived in an array of such items? How many items are being processed at at any given instant of time? How is the processing efficiency for one item affected by the number and nature of other items to be processed? A popular debate related to these questions concerns whether stimulus items are perceived serially or in parallel. Researchers have recently come to appreciate, however, the theoretical subtleties and complications involved in the serial-parallel issue.

Before reviewing the relevant literature, a taxonomy devised by Neisser (1967) will be defined; it is a useful scheme in conceptualizing the logical structure of recognition processes. In this taxonomy, an array is processed in a spatially parallel manner if the same recognition operations are carried out simultaneously on all individual stimulus items in the array. The processing is spatially serial if recognition operations are carried out on only a subset of the items at the same time. Limited-capacity and unlimited-capacity (or pure) spatially parallel processing may also be distinguished.

The limited-capacity conception is exemplified by Rumelhart's (1970) multicomponent model in which processing is parallel, in the sense that all stimulus items are operated on at essentially the same time, but the processing efficiency for any given item varies inversely with the number of other items to be processed. In a pure spatially parallel conception, all items are processed simultaneously, and the efficiency of processing for any given item is invariant with the number of other items to be processed.

As will be discussed below in more detail, researchers have run into difficulties in experimentally distinguishing between serial and parallel conceptions. Those difficulties are due to the similarity of the data predicted by serial models and limited-capacity parallel models for brief stimulus conditions. Experimental distinction between limited-capacity conceptions (i.e., serial models and limited-capacity parallel models) versus unlimited-capacity conceptions (i.e., pure parallel models) may, however, be less difficult. The viability of unlimited-capacity conceptions has been suggested in a small number of (human behavioral) experiments, and indirectly in the physiological work of Hubel and Wiesel (cf., 1965) which found spatially parallel "feature analyzers" at lower cortical levels in animals. Certainly, information is processed in a pure parallel manner at the human retina. An important basic question is whether the convergence to the essentially serial stream of verbal response begins before or after character recognition. Note also that the limited vs. unlimited capacity issue is central to other contemporary human performance research, pervading the literature on a variety of topics - e.g., dichotic listening, time sharing, the psycholcgical refractory period - and appearing as a basic dimension of most general models of information processing - e.g., Broadbent (1958), Neisser (1967), and Atkinson and Shiffrin (1968).

The Neisser (1967) taxonomy further distinguishes between operational processing properties and the spatial processing properties just discussed. Operational properties are orthogonal to spatial properties and refer to the recognition processes applied to any single stimulus item. Processing is operationally parallel if all recognition sub-processes applied to an individual stimulus item (e.g., tests for various "features" or dimensions) are carried out simultaneously. The processing is operationally serial if only a sub-set of recognition operations on an individual item are carried out at the same time. Note that the distinction between spatial and operational properties is somewhat arbitrary and depends upon the definitions of stimulus "items" and "features." Operationally parallel and serial properties are illustrated in memory search experiments by Neisser (1963) and Sternberg (1967b) respectively; Neisser's results suggest that one stimulus item (a letter or digit) may be compared with several items in memory simultaneously, whereas Sternberg's results in somewhat different experiments suggest that a stimulus item is compared with only one memory item at a time. Research on operational properties in the recognition of different dimensions of individual stimulus items has been reviewed by Egeth (1966). The present paper will be concerned with research on spatial processing characteristics, this research generally treating the number of items (characters or symbols) in an array as a main independent variable.

Whole-Report and Partial-Report Paradigms

The earliest relevant experiments were the classic "span of apprehension" studies of the late 1800's which attempted to determine the number of stimulus items that could be perceived in a single fixation. They involved either numerosity judgements - an array of dots was tachistoscopically exposed and the subject (*S*) judged their number - or whole-report tasks - an array of symbols or forms was exposed and *S* named as many of them as he could (see Woodworth and Schlosberg, 1954, for a review of this work). In numerosity experiments, *Ss*' estimation accuracy was nearly perfect for up to about 6 dots and then dropped rapidly for larger numbers; 8 dots could be estimated correctly on 50% of the trials - this defining the "span of apprehension." A similar pattern was found for whole-report tasks. Accuracy of report was nearly perfect for up to 4-5 random letters, but as more letters were added to the array, *Ss* still reported a maximum of 4-5 correctly (cf., Sperling, 1960).

Lappin and Ellis (1970) reviewed the two basic theoretical explanations for the limits of performance found in the span paradigms. On the one hand, Miller (1956), Sperling (1960), and Neisser (1967) concluded that the span of apprehension is primarily a reflection of the span of immediate memory; in other words, performance in a tachistoscopic task is limited by the fixed quantity of information that can be retained - for report or for counting - in short-term memory following its recognition. If this explanation is correct, then apprehension spans *per se* provide no information on the capacity limits and spatial characteristics of visual recognition processes.

On the other hand, Mackworth (1963) and Haber (1966) concluded that apprehension span primarily reflects a limited rate of information extraction - perceptual processing and/or encoding into short-term memory - from the brief and fading stimulus image. The results of the Lappin and Ellis (1970) experiments were consonant with a modified limited-memory-capacity conception but not the limited-extraction-rate conception. These researchers reasoned that the number of dimensions per stimulus item should affect processing time as is found in many choice reaction-time (RT) studies. Their Ss were presented with a tachistoscopic array of multidimensional stimulus forms and attempted to identify each one by means of a previously learned coding scheme. The number of dimensions per stimulus form, however, had little or no effect on the number of forms correctly reported, suggesting that processing rate was not the limiting factor.

Sperling (1960) developed his partial-report paradigm in an attempt to separate the perceptual and short-term retention factors operating in whole-report tasks, and interpreted the resulting data as supporting a limited-memory-capacity explanation for apprehension span. In this paradigm, a randomly chosen row of a multi-rowed letter array was cued for recall during or following its tachistoscopic exposure. The number of letters in each row, and thus the number of letters S retained for report, was always below the span of immediate memory. Sperling found that report accuracy was extremely high at short array-cue intervals, and he inferred that virtually all of the letters in the array were perceptually "available" to S but could not be remembered; (as will be discussed below, however, Rumelhart, 1970a, arrived at a different interpretation). Averbach and Coriell (1961) replicated Sperling's findings in a partial-report paradigm in which only a single letter was cued for report. They also confirmed his inference of the existence of a fading image or "icon" following stimulus offset on the basis of the declining report accuracy with increasing cue delay. In a later study, Sperling (1963) inferred the operation of a serial, letter-by-letter extraction process, but maintained a retention limit as the source of the span of apprehension.

Regardless of the source of the performance ceiling in span of apprehension experiments, there is evidence for the operation of a limited-capacity extraction process in these paradigms. One suggestive result is the distinctive serial-position function found in several whole-report experiments which employed a centrally-fixated horizontal row of stimulus characters (cf., Bryden, 1966 and Mathewson, Miller and Crovitz, 1968). Letters nearest the center and at the ends of the row were reported most accurately, these trends probably reflecting the maximal acuity at the center of the fovea and the relative freedom of end letters from the interaction of adjacent letters (discussed below). Superimposed upon the pattern, however, was a general fall-off of accuracy from left to right. This trend is consonant with a left-to-right serial scan of information from the stimulus and its fading trace. On the other hand, the trend was potentially confounded with the left-to-right order in which Ss characteristically reported the stimulus letters, and could thus have reflected the order of read-out from short-term memory. The results of experiments by Freeburne and Goldman (1969) and Harcum (1967), however, indicated an effect of left-to-right position independent of the effects of order of report. A left-to-right serial scan was also invoked in a leading hypothesis explaining certain laterality effects in tachistoscopic paradigms reviewed by White (1969). Lastly, Haber (1966) has used a limited-capacity encoding conception (of a partially non-spatial type) in explaining a body of data on the effects of pre-exposure set on tachistoscopic perception; this explanation involves the initial extraction of valued information from the fading trace of an array of multiple geometric forms.

The discussion above has reviewed evidence for the operation of spatial capacity limitations in whole-report tasks; evidence for such limitations will also be reviewed in the section below on masking paradigms. A dissonant - but important - finding, however, appeared in a whole-report experiment by Eriksen and Lappin (1967). Unlike most studies of this type, it involved highly impoverished stimuli, so that Ss made errors in reporting even 1-letter arrays. In addition, the arrays contained a maximum of 4 letters, an amount of information presumably within the spans of apprehension and immediate memory. Stimulus letters were drawn independently from a small set of vowels (A, O, and U) and appeared at the corners of an imaginary square centered on the fixation point. The experiment included a unique report technique that tended to equate the memory load for the 1, 2, 3, and 4-letter arrays: Ss always made 4 responses per trial, regardless of the number of letters exposed, indicating a "blank" for those corners perceived as not containing a letter. The resulting data were closely fit by a model that assumed an independent processing "channel" for each letter in an array.[1] This necessarily implied that the probability of S correctly reporting any given letter was not affected by the number of other letters exposed, i.e., that identification accuracy per letter was invariant with number of letters in the array (p.471). If a serial (letter-by-letter) scan or a limited-capacity parallel mechanism were extracting information from the brief stimulus and its fading trace, per-letter accuracy would be expected to decrease with increases in the number of array letters, in contrast to the invariance obtained. In the Eriksen and Lappin study, however, the corners in which letters appeared changed randomly from trial to trial for 1, 2, and 3-letter arrays. Rumelhart[2] has suggested that this positional uncertainty along with the unique report technique could result in a spurious performance invariance as the number of letters varied, even if perceptual capacity were truly limited; this would occur if the processing of a blank corner demanded as much processing capacity as the processing of a letter. Rumelhart's explanation, however, is put in some doubt by the failure of Garner and Flowers (1969) and Haber, Standing, and Boss (1970) to find effects of spatial uncertainty in tachistoscopic discrimination and repetition experiments respectively. Pending further investigation, the Eriksen and Lappin (1967) results remain uniquely inconsistent with limited-capacity conceptions.

Masking Paradigms

In contrast to the experiment above, the results of a number of studies employing visual "noise" masking suggest spatial capacity limitations in the processing of brief arrays. A visual noise mask is a dense field of random forms (e.g., an "alphabet soup" of letters) exposed before and/or after a stimulus array, and which characteristically interferes with the perception of the array. The nature of the interference effect is one of the currently debated topics in the literature (see Kahneman, 1968) and will only be reviewed here briefly. Kinsbourne and Warrington (1962a,b) and Eriksen (cf., Eriksen and Collins, 1967) concluded that, for array-mask intervals below 100 msec or so, the array and masking stimulus summate due to limitations in the temporal resolving power of the visual system; the net result is a composite image of the array and mask, and thus decreased perceptibility of the stimulus items. In contrast to this, Sperling (1963) concluded that the mask interrupts an ongoing process of extraction of information from a well-formed image of the array; Averbach and Coriell (1961) developed a similar concept they called "erasure" in explaining certain metacontrast effects at longer array-mask intervals.

Kinsbourne and Warrington (1962a,b) and Kahneman (1968) have argued that the finding of effective forward masking (i.e., when the mask precedes the array) as well as backward masking causes some embarassment for the interruption theory, as the processing of the array could not possible be "interrupted" by a previously exposed mask. On the other hand, the results of some recent experiments pose problems for the summation theory and offer support for an interruption conception. Liss (1968) argued that if the summation theory is correct, the perceptual effects caused by the backward masking of a stimulus array should be similar to those due to degrading the array directly, such as by decreasing its exposure duration or by actually superimposing a masking pattern. The results indicated that this was not the case; at array-mask intervals of 30-40 msec or more, the subjective contrast of the array was markedly less under the degrading procedures than under backward masking. As Ss often report in these studies, the masked stimulus letters appeared sharp and contrasty even though the mask interfered with their recall; it was as if *S*s easily "saw" the array but "did not have time to read or remember" it. Haber and Standing (1968) found similar effects of noise masking on subjective stimulus clarity. Additional support for interruption theory appeared in experiments conducted by Spencer (1969).

Some of the most powerful evidence for the interruption conception appeared in results of Sperling (1963) and Liss (1968) that at the same time bear directly on the issue of spatial capacity limitations in information extraction - the main concern of this paper. Sperling (1963) presented his *S*s with a stimulus array of variable duration containing from 2 to 6 letters and followed immediately by an "alphabet soup" noise mask. As the exposure duration (processing time before mask onset) was increased, the number of letters correctly reported increased linearly, with about 10 msec exposure time needed for every letter read out. More importantly, however, the number of letters correctly reported for any given exposure duration was invariant over the number of letters in the stimulus array; 3 letter accuracy, for example, required 30 msec exposure for *all* array sizes. Sperling emphasized the consonance of these results with both a serial, letter-by-letter read-out conception and an interpretation of backward masking as stopping the read-out process. This line of reasoning was confirmed by Liss (1968). He replicated Sperling's finding that a constant *number* of letters was read out for a given delay of the mask, but also found that an approximately constant *proportion* was read out from an array bearing a (simultaneous) superimposed masking pattern, thus additionally supporting Sperling's interpretations.

Brief mention should be made of evidence for limited spatial capacity that has appeared in metacontrast paradigms. Metacontrast is a form of masking in which the perceptibility of a stimulus item is decreased when followed by a form (e.g., a ring) which surrounds, but does not cover, the item's locus (cf., Kahneman, 1968). In an experiment by Weisstein (1966), Ss attempted to report the single letter masked by a metacontrast ring in a multi-letter tachistoscopic array. The range of temporal delays over which the ring interfered with the perception of the letter increased with increases in the number of other letters in the array. This suggested that the perception process extended over a longer period of time for the larger arrays, thus tending to reject unlimited-capacity models. Similar interpretations have appeared in other experiments in the ongoing controversy over metacontrast mechanisms, cf., Eriksen and Rohrbaugh (1970).

Returning to noise masking paradigms, a number of recent experiments have suggested some additional properties of the limited-capacity process inferred in whole-report studies. Sperling (1967) followed a horizontal row of 5 letters with an "alphabet soup" mask, and plotted the accuracy of recall for each spatial position as a function of array-mask interval. He found a distinct left-to-right trend: for shorter delays, the left-most letters were reported accurately but performance on the right letters was poor; as the delay of the mask increased, performance on the right letters improved. Analogous results were obtained by Mewhort, Merikle, and Bryden (1969) in an experiment in which the left or right half of an 8-letter row was randomly masked. These data support the same left-to-right scanning bias inferred in the Harcum (1967) and White (1969) laterality-difference work previously cited. However, there is evidence that the left-to-right bias reflects a more complex process than a serial, letter-by-letter scan. Sperling (1967) found that accuracy on the right-most letters in the row was significantly greater than zero even for the shortest array-mask intervals. This finding is inconsistent with a model in which the processing of one item is completed before the next item is begun, and led him to reject his original (1963) serial scanning conception (note that to be rejected by these data, such a model would have to assume a left-right scanning order and a processing time per letter that were both perfectly invariant over trials). Sperling (1967) postulated a new and somewhat ambiguously described model possessing a parallel property - a simultaneous processing onset for all letters - but with a sumperimposed serial property - a left-to-right gradient of efficiency so that the processing of left-most letters tends to be completed first.

A simple serial scan is also put into question by Mewhort, Merikle, and Bryden's (1969) finding that stimulus materials of higher-order approximation to English were reported more accurately than lower-order materials and also showed a greater left-to-right processing trend. In similar experiments by Reicher (1969) and Wheeler (1970), a given letter of a 4-letter word was detected more accurately than the same letter presented singly for a fixed delay of a noise mask. Assuming noise masking stops stimulus processing, these results could not be accounted for by Sperling's (1963) original letter-by-letter scan model as the expected probability of a given letter being extracted before mask onset would be lower when the letter is embedded in a multiletter stimulus. The failure to obtain poorer per-item accuracy on stimuli containing more items also runs counter to the Rumelhart model in its present form; even an independent-channels, unlimited-capacity conception would not predict the superior performance for 4- vs. 1-letter stimuli. As the models in question have not been formulated in sufficient depth to account for the complexities of meaningful stimulus materials, however, it is not possible to evaluate them on the basis of the obtained results (see Wheeler, 1970).

Detection and Other Single-Report Paradigms

In whole-report paradigms, the S must retain a variable amount of information in short-term memory before and during his overt response. The properties of short-term retention processes are thus likely to complicate inferences about the properties of perceptual processes. It is conceivable, for example, that all elements in a stimulus array are recognized by a pure parallel mechanism, and then loaded into a fixed-capacity memory store by means of a serial scan. The masking paradigm data suggesting a limited-capacity process with a left-to-right bias in operation would thus reflect the properties of this post-recognition scan; assuming the rate of scan were rapid relative to the duration of iconic persistence, the span of apprehension data would primarily reflect the capacity of the post-scan short-term memory and the efficiency of mnemonic codes. Sperling's (1960) partial-report technique attempted to separate perceptual and memorial factors by insuring that S's retention load was always below his short-term memory span. A number of items, though, were still retained for report on each trial and were conceivably subject to some form of non-perceptual interaction. Averbach and Coriell's (1961) technique circumvented this by cueing only a single letter for report. However, in both of these paradigms, S's performance is affected by the amount and nature of the information he has loaded into short-term memory before the onset of a delayed cue. A second problem involves the potential role of the cue in limiting the stimulus material that S processes perceptually - in addition to limiting the material he retains for report. In Rumelhart's (1970) model, a partial-report cue occurring at intervals before the stimulus icon has faded completely, causes the recognition process to focus exclusively on the subset of cued items; for zero or short delays between stimulus and cue, the total number of items in the array would have little or no effect on S's processing load as long as the number of items in the cued subset were invariant (as it must be to avoid confoundings with memory load). This complicates our use of the number of letters in the array as an independent variable in assessing capacity limitations.

There are two other paradigms which, like Averbach and Coriell's cueing technique, involve S's retention of only one item of information about the stimulus array for his report on each trial; these two paradigms - the "classification-RT" paradigm and the Estes detection paradigm - however, avoid the retention problems and interpretational complications of partial-report paradigms as discussed above. In a classification-RT experiment by Sternberg (1967a), Ss monitored a tachistoscopic array containing a variable number of digits for the presence or absence of one digit from a just previously specified set, and then made an appropriate "yes" or "no" key-press response. Error rates were very low, and RT was the main dependent variable. The paradigm was basically a Sternberg (1967b) memory search task with a variable number of items in the memory set. (Briggs and Blaha, 1969, and Burrows and Murdock, 1969, conducted analogous experiments, but these have not been included in this review due to their use of arrays subtending large visual angles and exposure durations permitting eyemovements; an analogous experiment by Nickerson, 1966, using angularly small, but response-terminated, arrays yielded data similar to Sternberg's, 1967a.)

Sternberg's (1967a) results showed an approximately linear increase in RT with increases in the number of items in the array, for any given memory set size; furthermore, the slope of the RT function was approximately twice as great for negative response trials than for positive response trials. Sternberg interpreted these data as supporting a serial, self-terminating scan of the items in the array. However, the involvement of multi-item memory sets on the great majority of trials raises the question of whether or not the resulting data primarily reflected the properties of recognition processes or the properties of post-recognition memory search processes. The results might thus be consonant with a conception in which visual information is recognized in an unlimited-capacity parallel manner and then - due to the nature of the paradigm - undergoes a serial comparison with an item (or items) in memory. Bjork and Estes (1970) offered a similar explanation to account for the portion of the RT data in an experiment by Bamber (1969) that suggested a serial, self-terminating scan. The Ss in the latter study indicated whether two successively presented horizontal rows of letters were identical or different, the first row presented on each trial being analogous to the memory set in the Sternberg (1967a) experiment.

A classification-RT study by Atkinson, Holmgren, and Juola (1969) used only single-item memory "sets" and thus may have circumvented the possible involvement of memory search mechanisms as discussed above. These researchers found a linear relation between RT and number of array items, but the slopes were the same for both positive and negative responses suggesting an exhaustive, rather than a self-terminating, serial process. There is, however, a serious problem of model identifiability that arises in attempting to infer properties of perceptual processes from these data. Atkinson _et al._, and Townsend (1970a) have pointed out that a serial exhaustive scanning process and an exhaustive limited-capacity parallel process _both_ predict the two linear same-sloped functions obtained. The kind of parallel conception making this prediction is one which assumes a limited quantity of processing capacity that initially is spread over all items in the array; as soon as the processing of an item is complete, its share of the capacity is re-allocated to other items not yet fully processed. Actually, equal-sloped linear functions may be predicted under some circumstances by an exhaustive _un_limited-capacity parallel conception in which each item is processed independently and the processing time per item has non-zero variance. As shown by Gumbel (1954, p. 20), this occurs when the underlying item-distributions have special forms. Sternberg (1966) cited a procedure for assessing an upper bound on negative response RT functions that may be used in rejecting such an independent-parallel conception.

To the extent that serial, limited-capacity parallel, and unlimited-capacity parallel models make identical predictions for the above classification-RT data, the task of inferring the spatial properties of perceptual processes becomes impossible within the paradigm as it stands. Townsend (1970a) has systematically reviewed the mathematics of this general problem of model "mimickry." The problem is encountered in other paradigms discussed in this paper, but it - and other methodological problems as well - have been more successfully dealt with in the detection paradigm devised by Estes (Estes and Taylor, 1964). Each detection trial consists of the tachistoscopic presentation of an array containing random "noise" letters plus one of two pre-specified "critical" letters ("B" and "F" for example), the same pair being used consistently throughout the experiment; the S attempts to determine which of the critical letters appeared. Because the location of the critical letter varies randomly from trial to trial, S presumably must process all of the stimulus items or process items until he detects the critical one. The array is presented briefly enough so that the error rate is non-zero, and response accuracy and latency may both be treated as dependent variables. Using this paradigm, Estes and Taylor (1964, 1966) and Estes and Wessel (1966) found a monotonic decrease in Ss' detection accuracy with increases in the number of letters in the array. If stimuli were being processed by a pure parallel mechanism, the critical item on each trial would always have its own "channel," and detection efficiency should not drop with increases in the number of noise letters; the results of these experiments therefore support a limited-capacity conception. Estes and his colleagues successfully fit the data with the following serial self-terminating scanning model: the S processes one letter of the array at a time until he extracts the critical item, in which case he responds correctly, or until the icon has faded below some threshold level, in which case he guesses; as the number of letters in the array is increased, predicted detection accuracy decreases due to the decrease in probability that the critical item is extracted before the icon has faded. Estes and Wessel (1966) found that latencies of correct detections, adjusted for guessing, increased with increases in the number of letters in the array, thus providing additional support for the serial scan model. Furthermore, Estes and Taylor (1966) found that Ss tended to perform similarly on successive presentations of the same array, as would be expected for a serial scan that followed a fixed spatial path.

There are some detection-paradigm data, however, which do not support the serial scanning conception. In a second experiment, Estes and Taylor (1966) compared detection accuracy for 16-letter arrays containing 1, 2, or 4 identical critical elements per array. As would be expected, Ss' accuracy improved with increases in the number of redundant critical elements. The degree of improvement, however, was underpredicted by the serial model, and well predicted by a parallel model in which individual critical items are processed independently of one another. The results of experiments by Wolford, Wessel, and Estes (1968) posed additional problems for the serial scanning model. As in Estes and Taylor (1966), the average probability of a correct detection for arrays containing two redundant critical items was well predicted by an independence model. The independence model also predicted the pattern of data for individual stimulus arrays: the probability of a detection, corrected for guessing, approximated $\Theta_1 + \Theta_2 - \Theta_1\Theta_2$, where Θ_1 and Θ_2 are the probabilities of detecting each of the two critical elements when presented singly in corresponding spatial locations; in contrast, a serial process which scans in a coherent or connected pattern would have predicted increasing detection accuracy with increasing spatial separation of the critical items. Secondly, Wolford et al. (1968) and Bjork and Estes (1970) found that the latency of true detections was invariant with the number of redundant critical elements in the array, in contradiction with a serial self-terminating conception. This invariance held true for each of a number of different methods used to estimate the latency of "true" detections. Wolford et al. defined a true detection as occuring when S expressed a high confidence in his response, or estimated true latency by means of an all-or-none correction for guessing applied to the correct response latencies; Bjork and Estes defined a true detection as occuring when S correctly identified the spatial location of the critical item(s). Summing up their results, these researchers concluded that the only conception supported was one in which array items are recognized - at least to the extent of being categorized as "critical" or not - independently of one another in a spatially parallel manner.

In the redundant-critical-elements experiments just discussed, a parallel processing model was inferred for arrays containing a fixed total number of items. On the other hand, some of the data in experiments involving number of array items as an independent variable - the decrease in detection accuracy (Estes and Taylor, 1966) and the increase in detection latency (Estes and Wessel, 1966) with increases in item numerosity - suggested a serial scanning model. The remainder of the present paper will consider a number of possible attempts to reconcile these two aspects of the detection data.

One conception potentially consistent with the two aspects is a serial scan that processes all array items exhaustively, rather than terminating upon extraction of a critical item. However, Wolford et al. rejected this conception as being incompatible both with Ss' instructions, training, and introspection, and with the invariance of error but not correct response latencies as a function of number of array items found by Estes and Wessel (1966).

A second conception consistent with the data is a limited-capacity parallel model such as Rumelhart's (1970). In the Rumelhart multicomponent model, features are extracted from array items during the stimulus exposure and its iconic persistence. The extraction process continues in a detection experiment until enough features have been extracted from the critical item for its recognition. All items in the same array are processed in an essentially independent, parallel manner, consonant with the redundant-critical-elements data cited above. The limited-capacity property is due to the fixed rate at which features are extracted from the array as a whole, so that the more items being processed, the slower the per-item rate of extraction; this is consonant with the data showing a decrease in detection accuracy and increase in detection latency with increases in total item numerosity. The only inconsistency is that the Rumelhart model predicts a decrease in true detection latency with increases in the number of redundant critical items, instead of the invariance actually found; the decrease it predicts, however, is rather small and might not be detectable in "noisy" RT data. Another important virtue of the Rumelhart model is its power in predicting the data in other paradigms - whole-report, partial-report, and certain masking and temporal judgement experiments - with similar parameter values.

One is tempted to stop at this point and accept the Rumelhart model as a satisfactory conception of the general properties of human character recognition in the tachistoscopic experiments reviewed, but two considerations suggest caution. The first is the small set of experiment results inconsistent with limited-capacity conceptions. The following discussion on this point, based partially on work by Townsend (1970),[3] requires that we reject a certain class of limited-capacity models in advance: models in which processing efficiency per item increases proportionally with the number of items to be processed. A serial scan that increases its speed with increases in the number of items to be processed would fall in this class, as would a limited-capacity parallel model that extracts a fixed amount of information per unit time but somehow increases the diagnosticity of the information with increases in the number of items to be processed. These conceptions - which involve greater processing efficiency for heavier processing loads - seem psychologically untenable in the context of experimental paradigms employing non-meaningful stimulus materials. The class of limited-capacity models remaining, however, can not predict the pattern of results in the following experimental paradigms.

(1) Donderi and Zelnicker (1969) exposed tachistoscopic arrays of small geometric forms (e.g., squares or circles); on half of the trials all forms were identical, and on the other half one of the forms - randomly chosen - was different from all the others. The Ss indicated which array type occurred on each trial, the exposure duration being sufficient to ensure error-free performance on this task. As the total number of forms per array was varied from 2 to 11 in one experiment and from 7 to 13 in another, RT

was essentially invariant for both "same" and "different" responses (see Fig. 3 in their article). The only conception which would predict this is an unlimited-capacity parallel model, either self-terminating or exhaustive, with a zero variance per-item processing time distribution. One note of caution involves the surprisingly long RT's found in this study - well over a second even for 2-form displays - that might reflect some factor independent of array size, such as the time of completion of iconic fading, which would spuriously produce the RT invariance found.

(2) Eriksen and Lappin (1967) tachistoscopically exposed from 1 to 4 letters in a uniquely controlled whole-report procedure described in a previous section. The results indicated that the probability of a letter being correctly recalled was invariant as a function of the number of other letters in the array. As mentioned above, a limited-capacity process - either letter-by-letter serial or parallel (but excluding the class we've rejected) - that extracts information from a brief and fading stimulus trace would predict a decrease in per-letter report accuracy with increases in the number of letters under these conditions. The invariance obtained is the unique prediction of a pure parallel model in which each array item has in effect its own processing "channel" (performance of channels could either be correlated or uncorrelated for this prediction to hold).

The second consideration which suggests caution in accepting limited-capacity parallel models such as Rumelhart's to reconcile the two aspects of the detection paradigm data, involves the possibility that certain methodological problems masked the operation of an unlimited-capacity parallel process in the detection experiments treating number of array items as an independent variable. Eriksen and Spencer (1969) have systematically reviewed these difficulties and have pointed out the peripheral input, short-term memory, and response output limitations that might mask pure parallel processing at the perceptual level. In the original Estes and Taylor (1964) experiment, the greater the number of items in an array the larger the visual angle it subtended. Estes and Taylor (1966) suggested that the confounding in this design between number of items and average acuity per item might have spuriously lowered detection accuracy for the larger arrays; these researchers therefore constructed arrays subtending a fixed visual angle, and varied the number of items by more densely crowding items in the "bigger" arrays. However, as Wolford, Wessel, and Estes (1968) pointed out, the confounding in this new procedure between number of items and inter-item spatial separation might itself have caused the decrease in detection accuracy for the arrays with more items. The decrease in perceptibility of visual forms caused by the interaction of adjacent forms is a reasonably well documented phenomenon, and occurs even for prolonged exposure conditions. Woodworth and Schlosberg (1954) cited early work on this topic by Korte and Woodrow. More recently, Flom, Weymouth, and Kahneman (1963) found a systematic decrease in acuity due to adjacent interference with increases in inter-item separation; they also showed an absence of interference for sufficiently large spatial separations, suggesting the operation of neural units with receptive fields of limited size. Adjacency effects under tachistoscopic exposure conditions have been demonstrated by Haber and Standing (1969) and by Collins (1969).

Another example of methodological difficulties in detection experiments should be mentioned. Shaw (1969) tachistoscopically exposed a horizontal row of letters, one of which was the critical item; as the location of this item varied from left to right, Ss' detection accuracy decreased, suggesting the operation of a left-to-right serial scan. However, Ss always fixated the left end of the row, and spatial location of the critical item was therefore confounded with the decrease in acuity from the center of the fovea outward. Shaw also inferred a two-component serial scan on the basis of a second phenomenon in which a blank space (i.e., a noise letter missing) on the right of the critical item greatly increased detection accuracy, whereas a blank space on the left had little or no effect. The manipulation of spaces in the stimulus array opened the possibility of confoundings due to adjacent interaction, especially considering that such interactions increase in strength at larger distances from the center of the fovea (cf., Alpern, 1954), that is, from the left to the right of Shaw's arrays. These criticisms, on the other hand, should not apply to an experiment by Estes and Wolford (1969) which found similar patterns of results but controlled for the retinal locus and assymetry problems of the original Shaw study. However, Estes and Wolford used a whole-report and not a detection procedure, and the question raised earlier in the paper on the applicability of whole-report data to inferences about character recognition processes may be raised here as well. Finally, Townsend[4] found that Shaw's results were duplicated under conditions in which Ss viewed the row of letters for as long as desired - even up to several seconds - without moving their eyes from the fixation point. This finding casts considerable doubt on the use of serial scan-fading trace models to explain the Shaw data.

The above discussion has served to emphasize the possibly confounding role of spatial interaction effects in the Estes and Taylor (1966) and Estes and Wessel (1966) detection experiments. The potential magnitude of these effects in tachistoscopic paradigms is further demonstrated by the results of Haber and Standing (1969). In their study, one letter of a horizontal row of 8 letters was cued for report with a simultaneously presented Averbach and Coriell-type bar marker. It was found that items in the center and at either end of the row were reported most accurately. When parenthesis marks were placed next to the end items, however, their report accuracy dropped from a 70% level to a 30% level. The greatly superior accuracy of end items and the large decrease in this superiority due to the presence of adjacent parentheses underscore the potency of spatial interactions and the need to control this factor in detection experiments. The decline in detection accuracy found by Estes and Taylor (1966) and the increase in detection latency found by Estes and Wessel (1966) with increases in the number of array items may not be taken as supporting a limited-capacity model - either a serial scan or a limited-attention parallel conception like Rumelhart's - unless it can be demonstrated that these data were not spuriously produced by confounded spatial interaction effects. Experiments I and II reported below attempted such a demonstration. The primary objective was to devise a detection task in which the number of array items could be varied without confounding either spatial interaction or acuity factors. Leaving the details in Chapter II, the Estes and Taylor pattern of declining performance was duplicated in these experiments, even with the new methodological controls. A potentially confounding factor for which there was ample evidence was therefore rejected as the source of the Estes and Taylor results, and an unlimited-capacity parallel model was not confirmed.

There is, however, yet one other factor - the decisional nature of S's task - which conceivably could have masked the operation of an unlimited-capacity parallel recognition process in the Estes and Taylor paradigm. This factor was mentioned by Wolford, Wessel, and Estes (1968), and the operation of an analogous factor was hypothesized by Eriksen and Spencer (1969) to explain results they obtained in a paradigm similar to the detection paradigm. Their Ss were presented with a rapid sequence of letters arranged in a circular array. Each letter was illuminated for a few milliseconds, with a 5 to 30 msec interval between consecutive letters. The Ss monitored each sequence for the presence or absence of a target letter, "A," a single "A" appearing in half of the sequences and no "A" - just "T" and "U" noise letters - appearing in the other half. It was found that detection accuracy as measured with a d' statistic declined wit increases in the total number of letters in the sequence, a result analogous to the performance decline in the Estes and Taylor paradigm. The Eriksen and Spencer data were thus consonant with Rumelhart's model and other limited-capacity conceptions. These researchers, however, suggested that the following unlimited-capacity conception could account for their results: each item in the sequence is processed by an independent (unlimited-capacity) parallel channel, and S bases every response on an aggregation of information from each channel; S responds "yes" only if the criterion for "A" (in a signal detection theory sense) is exceeded for one or more of the channels; the greater the number of "noise" letters in a sequence, the greater the probability that at least one of them will result in a false-alarm; if this occurs on an "A"-less sequence, S will respond incorrectly; if it occurs on a sequence that contains an "A," it can only increase the probability of S responding correctly (as he sometimes fails to detect the "A" actually present); it may be shown that this beneficial effect of false alarms on "A" trials is much smaller than the detrimental effect on "A"-less trials, and the net result is a decrease in d' with an increase in the number of letters in the sequence. This analysis was supported by examination of hit- and false-alarm rates on 1-letter "sequences," and on multi-letter sequences in which the interstimulus intervals were several seconds in order to produce true independence between successive items.

Although the Eriksen and Spencer model was developed for a "yes-no" detection task and sequential stimulus arrays, an analogous model can be developed for the Estes and Taylor paradigm: each item in an array is processed by an independent (unlimited-capacity) parallel channel, and S bases every response on an aggregation of information from each channel; noise items are sometimes mis-recognized as target items (i.e., confusions occur); a simple set of decision rules may be postulated for S's response on a trial as a function of how many channel criteria have been exceeded for "B" and how many for "F" ("B" and "F" being the critical alternatives); a straightforward model of confusion and decision processes to be described in Chapter III indicates that these processes interact in such a way as to produce a decrease in detection accuracy with increases in the number of array items as found in Experiment I and II. The model, in short, postulates that the decisional structure of the detection paradigm masks the operation of a pure parallel recognition process. The occurrence of systematic confusions central to the model was strongly supported in data reviewed by Fisher, Monty, and Glucksberg (1969). They provided matrices of Ss' response to individual alphabet letters presented at short durations. The pattern of error responses for many letters could not be accounted for by an all-or-none model with a distribution for guessing over the alphabet. Similar evidence was obtained by Townsend (1970b) and by Keeley and Doherty (1968, 1969). The misperception of noise letters as target letters in a detection task was also postulated recently by Bjork and Estes (1970) in a subsequent analysis of the data in their redundant-critical-elements experiment previously cited; predictions of a model incorporating confusion errors were in close agreement with obtained response probabilities and latencies.

The situation is thus one in which two dissimilar conceptions - Rumelhart's limited-capacity parallel model and the unlimited-capacity parallel "confusions" model - predict identical declines in performance with increases in number of array items in the Estes and Taylor paradigm. Experiments III and IV attempted a critical test between the two conceptions. Discussion of these studies will be deferred until Experiments I and II, which deal with spatial interaction factors, have been described.

CHAPTER II

EXPERIMENTS I AND II

Introduction

In the Flom, Weymouth, and Kahneman (1963) study discussed in Chapter I, spatial interaction effects disappeared when adjacent forms were separated by certain minimum angular distances. This phenomenon was incorporated into Experiments I and II in an attempt to control for the potential spatial interaction confounding in the Estes and Taylor (1966) design. The critical issue for the present experiments was the minimum separation needed between simultaneous adjacent forms to insure freedom from interaction. Because Estes and Taylor permitted each _S_ to choose his own viewing distance from the 1 in. by 7/8 in. array used, it was not possible to specify the exact retinal locus and angular separation of stimulus letters in the experiment. Assuming a range of viewing distances between 12 in. and 24 in., the total width of the array would have been between approximately 1.8° and 3.5°, and the minimum horizontal separation between adjacent letters would have been between approximately .25° to .5°. Although the Flom _et al._ experiment involved acuity test forms and temporally unrestrained viewing conditions, similar work has been done under tachistoscopic conditions comparable to those used by Estes and Taylor. Collins (1969) exposed 2 different letters for _Ss_ to identify on the circumference of an imaginary circle centered on the point of fixation, and varied both the separation of letters (.25° to 1°) and the radius of the circle (.25° to 1.25°). The results indicated the occurrence of spatial interaction at the .25° and .5° separations for all radii, and of weaker interaction at .75° and 1° separation but for the larger radii only. This confirms that spatial interactions were potentially operative in the Estes and Taylor design. The central issue for Experiments I and II, again, was the minimum separation needed to insure freedom from these effects. The results of a multiple-identical-forms experiment by Eriksen and Lappin (1965) and a same-different-judgments experiment by Eriksen, Munsinger, and Greenspon (1966) suggested independence between adjacent forms separated by approximately .5° and located at equal distances from the point of fixation; the inferences involved, however, were indirect and rested on certain modeling assumptions. A number of other studies obtained evidence for spatial independence at various angular separations of greater than 1°; these include: a multiple-identical-forms study by Keeley and Doherty (1968, Experiment 2), whole-report paradigms by Collins and Eriksen (1967) and Eriksen and Lappin (1967), and a dot-detection paradigm by Wickelgren (1967). Considering the entire body of experimental evidence including the Collins (1969) work, minimum separations of 1° seemed advisable to insure freedom from interaction effects; separations of well over 1° were therefore used in the experiments below.

In Experiment I, stimulus arrays contained from one to four 4-letter clumps, adjacent clumps separated by a minimum of 1.4°. One clump in each array contained the critical letter and 3 noise letters, and any other clumps present contained only noise letters. This design permitted variation of the total number of stimulus letters with simultaneous control for both acuity and spatial interaction effects. Acuity confoundings were avoided in that individual clumps were equidistant from the point of fixation, and critical letters appeared in each possible location with equal frequency for 4, 8, 12, and 16-letter arrays. Although letters within any individual 4-letter clump were close enough to interfere with each others' perceptibility, spatial interaction effects were not confounded with the independent variable (total number of letters) as the presence or absence of adjacent clumps at the 1.4° distance should not have altered the perceptibility of the target letter within its own clump.

Experiment I

Method

Subjects.--Eight naive female Ss, students at the University of Michigan who had volunteered for the experiment, were paid $1.75 per one-hour session. All had normal or corrected-to-normal visual acuity. A ninth S failed to perform significantly above chance and did not serve beyond the practice session.

Stimuli and equipment.--Stimuli consisted of arrays of 4, 8, 12, or 16 upper-case consonants typed on white index cards. The electric typewriter used was equipped with Bulletin san-serif type and a disposable carbon ribbon which yielded a dense, black impression. The 4, 8, 12, and 16-letter arrays consisted of one, two, three, and four 4-letter clumps respectively, each clump appearing at one corner of an imaginary square (see Fig. 1). Adjacent clumps were separated by a minimum visual angle of 1.4°. Maximum array height and width were 2.7° and 2.6° respectively; individual consonants were approximately .2° in height.

Each array contained one of the two "target" letters "N" or "P," with the remaining "noise" letters chosen randomly without replacement from the other 18 consonants. There was one set of 32 different arrays for each of the four array sizes. Within each set, "N" and "P" were used as targets equally often and appeared in each of the 16 possible spatial locations with

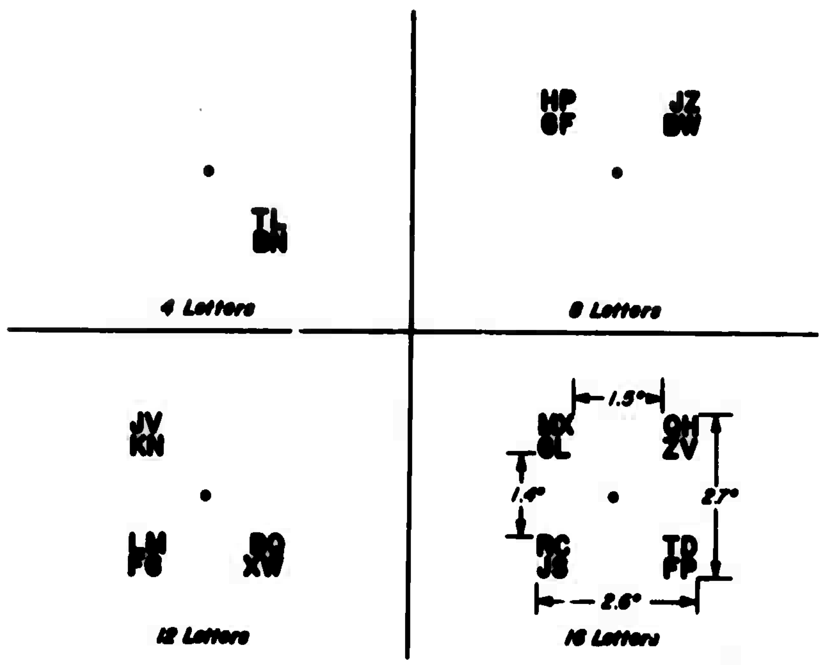

Fig. 1. Stimulus arrays used in Experiment I.

equal frequency; for 4, 8, and 12-letter arrays, each possible spatial configuration (the corner locations occupied by clumps on a single card) was used with approximately equal frequency. The above constraints were explained to Ss at the beginning of the practice session.

Stimulus arrays were exposed for 40 msec using a three-channel Scientific Prototype Model GB tachistoscope. They were preceded and followed by a white field containing a centered black fixation dot subtending 4'. Luminances, monitored hourly, were 40.2 mL and 6.2 mL for stimulus and pre-post fields respectively. Both channels had been modified to accept Gerbrands semi-automatic stimulus card holders which resulted in a 117 cm viewing distance.

The experimental room was dark except for a small work light on E's side of the tachistoscope.

Procedure.--Each S served in an initial practice session and two experimental sessions. The practice session consisted of 128 exposure trials - four runs, in alternating forward and backward order, through a special 32-card practice deck. This deck contained 8 cards of each array size scattered randomly through the deck; Ss were not told the array size in advance of each exposure. Practice decks involved the same constraints on target letters and locations as described above for the main stimulus decks.

Each experimental session consisted of 160 exposure trials - an initial run through the practice deck, followed by one run through each of the four main stimulus decks, one deck for each array size; the order of presentation of the four array sizes was counterbalanced across Ss for each session using latin squares. Cards in the four stimulus decks had been pre-ordered so that target letter, target location, and spatial configuration of letter clumps (for 4, 8, and 12-letter arrays) varied randomly from trial to trial; the first and second experimental sessions involved forward and backward sequences respectively through the pre-ordered decks.

On every trial, S waited for E's ready signal, centered his gaze on the fixation dot, and initiated the stimulus exposure by pressing a hand-held microswitch. Trials were self-paced, with a minimum of 7 sec between exposures. The Ss were instructed to report whether each array contained an "N" or a "P" and to indicate the degree of confidence in their choice with a rating from a 1 to 3 scale on which 1 corresponded to a pure guess and 3 corresponded to virtual certainty; the instructions urged that detection accuracy be 95% or better on high confidence trials. To maintain stable use of the confidence ratings, Ss were told the correct target letter after they had given their response on each trial. At the end of every 32-card deck, Ss were told the total number of correct responses they had made, and the proportion of correct responses for each of the three confidence ratings. Each session was preceded by approximately 10 min of dark adaptation and incorporated a 5 min rest period halfway through the hour.

Results

As Fig. 2 indicates, the proportion of experimental trials on which the target letter was correctly identified decreased monotonically with increases in the number of letters in the stimulus array. A Friedman analysis of variance

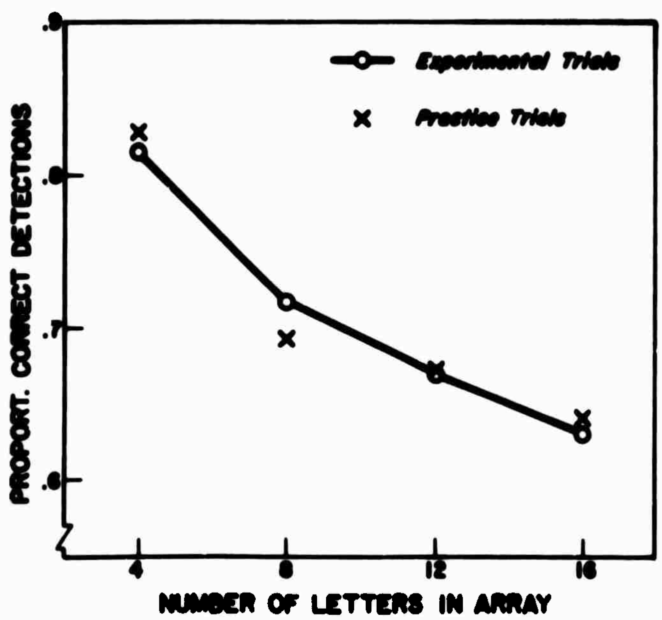

Fig. 2. Detection accuracy as a function of the number of letters in the stimulus array in Experiment I.

by ranks (Siegel, 1956) showed this decline in performance to be significant, $\chi_r^2 = 17.8$, $df = 3$, $p < .001$. Frequency of use of the high confidence rating also decreased with increases in the number of stimulus letters, as did detection accuracy on high-confidence trials (see Table 1); only the frequency trend was significant, $\chi_r^2 = 19.8$, $p < .001$.

TABLE 1

HIGH CONFIDENCE TRIALS: EXPERIMENT I

Item	Number of Letters in Array			
	4	8	12	16
Frequency (out of 512 trials)	123	64	43	23
Accuracy (proportion correct)	.951	.922	.907	.913

At the end of the last experimental session, one S volunteered that, on some of the trials, she had not been fixating the dot as instructed; furthermore, her tendency to deviate increased with increases in the number of letters in the array. Exclusion of this S's data did not alter the trends or significances reported above. However, the data from experimental session practice trials were analyzed for all Ss as a check on the possibliity that the performance decline in the main data was an artifact due to changes in fixation strategy with changes in the number of stimulus letters; on practice trials, Ss could not vary fixation as a function of the number of stimulus letters as this value was varied randomly from trial to trial. The data, shown in Fig. 2, indicated the same performance decline ($\chi_r^2 = 14.7$, $p < .005$) as found for the main experimental trials and therefore ruled out the possiblity of a confounding due to fixation changes.

Experiment II

Experiment II was similar to Experiment I, except that it involved 1, 2, 3, and 4-letter arrays which permitted greater separation between adjacent forms. It was also intended to investigate detection performance on stimulus material not exceeding the spans of apprehension and immediate memory (cf., Sperling, 1960), and was a necessary precursor to Experiment III below.

Method

Subjects.--Eight naive female Ss, student volunteers, were paid $1.75 per one-hour session. Vision requirements were the same as in Experiment I.

Stimuli and equipment.--Stimuli consisted of arrays of 1, 2, 3, or 4 consonants typed on white index cards as in Experiment I. Each consonant, analogous to an individual 4-letter clump in Experiment I, appeared at one corner of an imaginary square (see Fig. 3). Adjacent consonants were separated by at least 1.8° visual angle; maximum array height and width were both 2.3°.

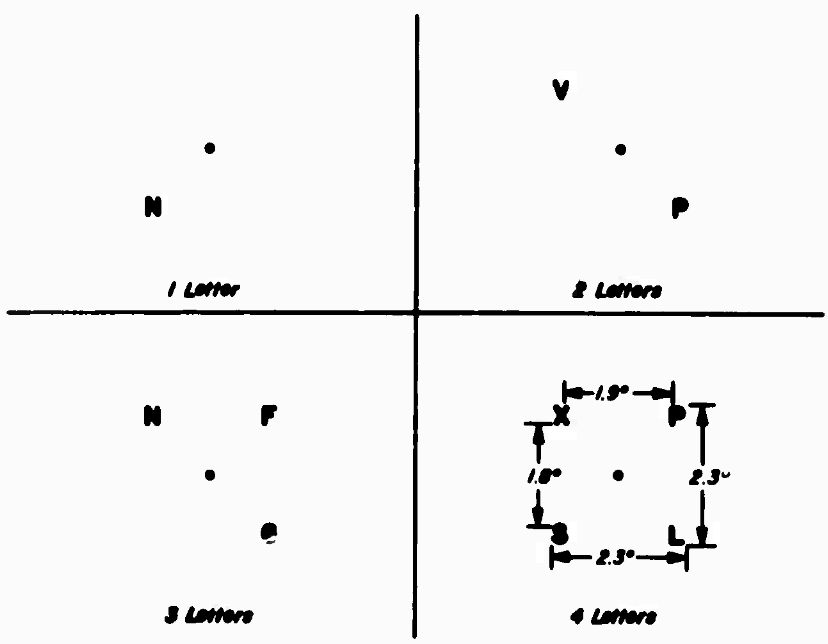

Fig. 3. Stimulus arrays used in Experiment II.

One 32-card deck was prepared for each of the four array sizes. Within each deck, "N" and "P" were used as target letters equally often and appeared in each of the four possible spatial locations with equal frequency; for 1, 2, and 3-letter arrays, each possible spatial configuration (the corner locations occupied on a single card) was used with approximately equal frequency.

Stimuli were exposed for 7.0 msec using the same tachistoscope and centered fixation dot arrangement as in Experiment I; luminances were 20.7 mL and 6.2 mL for the stimulus and fixation fields respectively.

Procedure.--Each S served in an initial practice session and two experimental sessions. The practice session consisted of 128 exposure trials - four runs, in alternating forward and backward order, through a special 32-card practice deck analogous in design to the practice deck of Experiment I. Each experimental session consisted of 160 exposure trials - an initial run through the practice deck, followed by one run through each of the four main stimulus decks.

On every trial, Ss fixated the dot, initiated the exposure, reported "N" or "P" and a confidence rating, and received feedback from E. All other procedural details were analogous to those in Experiment I.

Experiment II-A

Because the results for practice trials in Experiment II were ambiguous, Experiment II-A was conducted as a fixation control.

Subjects.--Four different female Ss served as paid volunteers.

Stimuli, equipment, and procedure.--The four main decks of stimulus cards from Experiment II were equally distributed into four new main decks in which number of stimulus letters varied randomly from card to card. All other details were identical to those in Experiment II.

Results

As in Experiment I, the proportion of experimental trials in Experiment II in which the target letter was correctly identified showed a significant, monotonic decrease with increases in the number of letters in the stimulus array, $\chi_r^2 = 15.6$, $p < .005$ (see Fig. 4). Frequency of use of the high

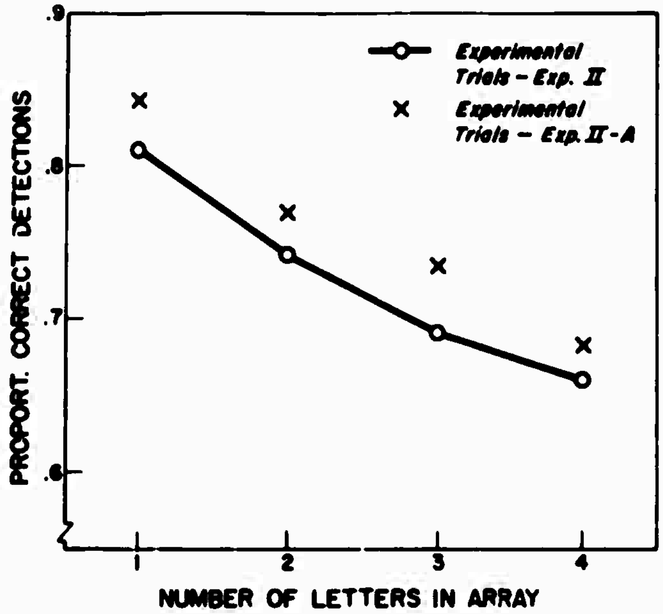

Fig. 4. Detection accuracy as a function of the number of letters in the stimulus array in Experiment II.

confidence rating also decreased with increases in the number of stimulus letters, $\chi_r^2 = 16.7$, $p < .001$; detection accuracy on these trials showed a similar, although non-significant decline (see Table 2).

The failure to find a monotonic decrease in detection accuracy in the practice-trials data (Table 3) prompted the running of Experiment II-A. The

TABLE 2

HIGH CONFIDENCE TRIALS: EXPERIMENT II

Item	Number of Letters in Array 1	2	3	4
Frequency (out of 512 trials)	126	76	56	38
Accuracy (proportion correct)	.968	.947	.911	.895

results of this additional experiment, however, closly followed the pattern of performance decline found in Experiment II (Fig. 4, $\underline{\chi r}^2 = 7.8$, $\underline{p} < .036$), and thus rule out a possible confounding due to eye fixations.

TABLE 3

PROPORTION OF CORRECT DETECTIONS:

FIXATION CONTROLS

Item	Number of Letters in Array 1	2	3	4
Experiment II Practice trials	.742	.742	.617	.695
Experiment II-A Main trials	.844	.770	.734	.683

Discussion: Experiments I and II

Notwithstanding the controls for spatial interaction effects included in Experiments I and II, the results indicated a pattern of decreasing detection accuracy with increases in the number of array items similar to that found by Estes and Taylor (1966). These data thus reject the possiblity that a confounding of spatial interactions and item numerosity in the Estes and Taylor design masked the operation of an unlimited-capacity process. Rumelhart's (1970) limited-capacity parallel conception remains a viable explanation of the numerosity and redundancy aspects of the detection paradigm data discussed in Chapter I.

The decrease in overall detection accuracy was paralleled by a decrease in the accuracy and frequency of use of the highest confidence rating. These ratings were intended to assess the applicability of multi-state high-threshold conceptions that possess an unlimited-capacity property in the operation of their high-threshold states.[5] Such a property is exemplified by the following extension of the Krantz (1969) three-state low- and high-threshold model to the detection paradigm: S responds with essentially perfect accuracy if he enters the high-threshold state (D*) corresponding to the correct critical item on a given trial; the probability of this occurring is invariant with the number of letters in the array; this invariance holds true even through Ss' detection accuracy measured with an overall percent correct score can decrease with increases in item numerosity due to changes in the probabilities of his entry into the two remaining states (confusions between critical and noise items might mediate these changes). If it is assumed that S's use of the highest confidence rating reflects his entry into the D* state, however, the obtained results do not support the unlimited-capacity property of such a conception.

Lastly, the similarity of the results of Experiments I and II suggests a similarity in the underlying processing in this paradigm of stimulus materials that exceed the spans of immediate memory and apprehension, and materials that do not. This finding tends to confirm the validity of the detection technique - as stressed by Estes and Taylor (1964, 1966) and Wolford, Wessel, and Estes (1968) - in assessing the properties of perceptual processes independent of the confounding effects of short-term retention factors.

CHAPTER III

EXPERIMENTS III AND IV

Introduction

Although Experiments I and II indicated that spatial interaction effects were not the source of the decrease in detection accuracy with increases in item numerosity in the Estes and Taylor (1966) experiment, it is possible that the decrease was caused by the decisional structure of Ss' task. In the detection paradigm, S must monitor array items until the critical item is identified, but retains and reports only a single unit of information on each trial. These features are responsible for the technique's success in avoiding the contaminating effects of short-term retention factors. The same features, however, could mask the operation of an unlimited-capacity perceptual process, as occurs in the unlimited-capacity "confusions" model discussed in Chapter I. The present chapter will describe this model in more detail and will propose experiments to test between it and the Rumelhart limited-capacity conception.

The Unlimited-Capacity-Parallel-Processing-with-Confusions (UCC) Model

Perceptual processing.--The UCC model assumes that each item in an array is processed by an independent (unlimited-capacity) parallel channel. Each channel registers its best estimate of the identity of the item it is processing by taking on one of v different endstates, where v is the size of the vocabulary of stimulus items used. For the channel that is processing the critical item, the locus of which changes randomly from trial to trial, three exhaustive and mutually exclusive classes of endstates are defined:

Critical Correct (CC): The critical item is correctly perceived (e.g., a "B" endstate is registered, assuming "B" and "F" are the two alternative critical items and "B" is the one present on the trial in question).

Critical Incorrect (CI): The critical item is misperceived as the incorrect critical alternative (an "F" endstate is registered).

Critical Other (CO): The critical item is misperceived as a letter other than either critical alternative (neither "B" nor "F" endstates are registered).

For each of the channels processing noise items, three exhaustive and mutually exclusive endstates are defined:

Noise Correct (NC): The noise item is misperceived as the correct critical alternative ("B" endstate is registered).

Noise Incorrect (NI): The noise item is misperceived as the incorrect critical alternative ("F" endstate is registered).

Noise Other (NO): The noise item is perceived as a letter other than either critical alternative (neither "B" nor "F" endstates are registered).

Decisional processing.--After perceptual processing is complete for all channels, S decisionally processes the resulting endstates and arrives at a single response for the trial. One possible decision rule would be for S to respond "B" if one or more channels registered a "B" endstate and none registered an "F" endstate; to respond "F" if one or more channels registered an "F" endstate and none registered a "B" endstate; and to guess if no channels have registered either "B" or "F" endstates, or if one or more "B" and one or more "I" endstates have been registered simultaneously for the same array. Using these decision rules, S will respond correctly on a given trial with probability 1.0 if:

(1) The critical-item channel registered a CC endstate and no noise channels registered an NI endstate,

or if: (2) The critical-item channel registered a CO endstate and at least one noise channel registered an NC endstate and no noise channels registered an NI endstate.

The S will respond incorrectly with probability 1.0 if:

(3) The critical-item channel registered a CI endstate and no noise channels registered an NC endstate,

or if: (4) The critical-item channel registered a CO endstate and at least one noise channel registered an NI endstate and no noise channels registered an NC endstate.

The S will guess (probability of a correct response = .5) if any event other than one of the above four occurs, that is if:

(5) The critical-item channel registered a CO endstate and all noise channels registered an NO endstate,

or if: (6) A conflict occurs:

--CC and at least one NI

--CI and at least one NC

--CO and at least one NI and at least one NC.

The probability of a correct response on any given trial, therefore, equals the probability that either of the unequivocal correct response events [(1) or

(2)] occurs plus one-half the probability that either of the equivocal events [(5) or (6)] occurs, i.e.:

$$P_{corr.} = P[(1) \text{ or } (2)] + 1/2\{1 - P[(1) \text{ or } (2)] - P[(3) \text{ or } (4)]\}$$
$$= 1/2 + 1/2P[(1) \text{ or } (2)] - 1/2P[(3) \text{ or } (4)].$$

Expressed in terms of endstate probabilities (assuming P_{NC}, P_{NI}, and P_{NO} are constant across all channels processing noise items):

$$P_{corr.} = 1/2 + 1/2(P_{CC} + P_{CO})\,(1 - P_{NI})^{n-1} - 1/2(P_{CI} + P_{CO})\,(1 - P_{NC})^{n-1},$$

where n = the number of items in the array.

Using reasonable and internally consistent parameter values, the data from Estes and Taylor (1966), and Experiments I and II are fit well by the UCC model. The reason why this unlimited-capacity model predicts the decrease in detection accuracy with increases in n may be intuited as follows: on trials on which the critical item is not perceived as either possible alternative, i.e., a CO is registered, the misperception of noise items should not affect S's detection accuracy as NC and NI endstates presumably occur with equal frequency; on trials on which the critical item is misperceived as the incorrect alternative (CI is registered), the occurrence of confusions among noise items will sometimes "overrule" the CI and can only increase detection accuracy; on trials on which the critical item is perceived correctly (CC is registered), the occurrence of confusions among noise items will sometimes overrule CO and can only decrease detection accuracy; as the critical item is more often correctly perceived than incorrectly perceived (presumably $P_{CC} > P_{CI}$), the harmful effect of noise confusions on CC trials is greater than the beneficial effect on CI trials; furthermore, as n increases, the probability of at least one NC or NI increases, thus amplifying the effect of confusions and lowering overall detection accuracy.

In another reasonable decision rule for the UCC model, S tallies the number of channels registering "B" endstates and "F" endstates, responds "B" ("F") if the "B's" ("F's") outnumbered the "F's" ("B's"), and guesses if the "B's" equalled the "F's." This decision rule predicts a decrease in detection accuracy with increases in n similar to that predicted by the first rule.

A signal-detection version of the UCC model also may be postulated.[6] The S is conceptualized as drawing one sample from every array item, each sample being a value on an underlying unidimensional "B-F" axis. Samples can come from one of three distributions: samples originating from noise items come from the "noise" distribution which lies at the middle of the B-F axis; the sample originating from the critical item comes either from the "B" distribution which lies toward the "B" end of the axis, or from the "F" distribution which lies toward the "F" end. One possible decision rule would be for S to respond "B" ("F") if the most extreme sample came from the "B" ("F") side of a criterion point at the center of the axis. Alternatively, S could tally the number of samples that fell to either side of the central criterion and respond "B" ("F") if the number falling on the "B" ("F") side exceeded those on the "F" ("B") side. The greater the number of items in the array, the more samples taken from the central noise distribution, the greater the expected number of nonveridical samples (i.e., samples falling to the "B" ("F") side of the central criterion when "F" ("B") was the critical item actually present), and the lower the probability of a correct response.

For the discrete-endstate-tally and the signal-detection versions of the UCC model, it is easy to intuit predictions made for redundant-critical-items experiments such as the Wolford, Wessel, and Estes (1968) study discussed in Chapter I. In the discrete-endstate-tally version, the presence of additional critical items tends to increase the number of channels registering the endstate for the correct critical alternative and decrease the number registering the incorrect critical alternative. In the signal-detection version, the presence of additional critical items increases the number of samples taken from the correct critical alternative distribution and decreases the number from the noise distribution. In both cases, the probability of correct detection would increase with the number of redundant critical items, in agreement with the data obtained. True detection latency would be invariant with the number of critical items, also in agreement with the data obtained, as the processing of all array items is completed before a response is selected.

Finally, mention again should be made of the independent evidence for the occurrence of the confusions postulated in the UCC model (see Chapter I). The Ss in Experiments I and II frequently volunteered evidence for such confusions (as, for example, when S objected to feedback indicating his response was incorrect, insisting that there was a "F" in an array corner that actually contained an "R"); the Ss also described decisional strageties similar to those postulated above.

Possible Experimental Tests Between the UCC and Rumelhart Models

The Rumelhart and UCC models both predict data obtained in the detection paradigm but are logically different conceptions. In the Rumelhart model, detection accuracy decreases with increases in the number of array items due to a limitation of perceptual processing capacity; in the UCC model, detection accuracy decreases due to a decisional process that masks the operation of an unlimited-capacity perceptual process. The remainder of this paper will explore possible experiments to test between these two conceptions.

Manipulating the confusability of noise items.--If the UCC model is correct, manipulation of the degree to which noise items are confused as critical alternatives in the Estes and Taylor paradigm should have an effect on detection accuracy; the predicted decrease in accuracy with increases in the number of array items becomes more extreme the greater the tendency for such confusions to occur (i.e., confusability should interact with *n*). This prediction was recently confirmed by McIntrye, Fox, and Neale (1970, Experiment 3). Their *S*s were presented with 8- or 14-letter arrays containing a single "T" or "F" as the critical item; noise items were drawn from the remaining alphabet of letters in the "random" condition and from a 2 or 3 letter vocabulary of vowels in the "redundant" condition. The results showed lower detection accuracy for 14 vs. 8-letter arrays, and, as predicted, the difference between them was more extreme in the "random" than the "redundant" condition.

Unfortunately, however, it may be demonstrated that the Rumelhart and UCC models make very similar predictions for this experiment. In the Rumelhart model, increases in inter-item confusability should increase the parameter *c* - the number of features that have to be extracted from the critical item before it can be recognized; an increase in *c*, in turn, tends to accentuate the limited-capacity property and result in a greater fall-off in detection accuracy with increases in number of array items. The similarity of predictions made by the two models is illustrated in Fig. 5. The solid lines show the predictions of the Rumelhart model for low- and high-confusability

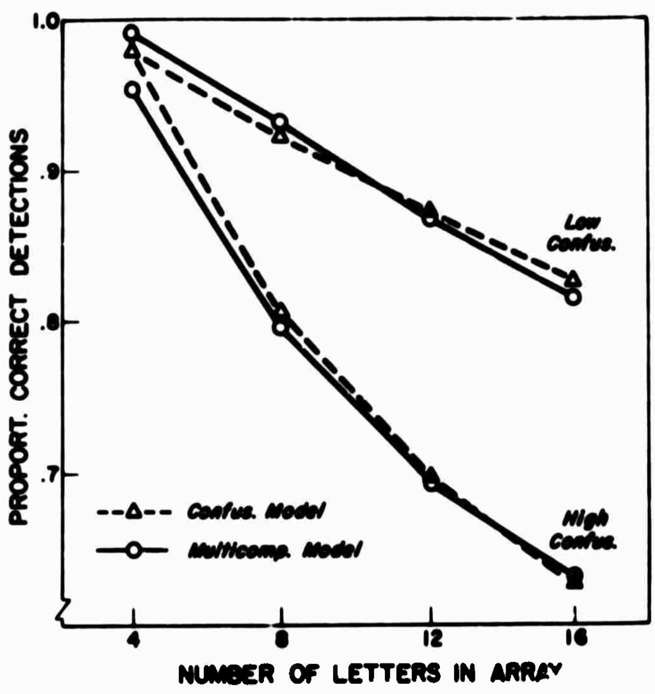

Fig. 5. Predictions of the Rumelhart and UCC models.

noise items. Parameter assignments were $v[T + \mu] = 16$ (approximately the quantity estimated for the Estes and Taylor experiment by Rumelhart, 1970, p. 202), with $\underline{c} = 1$ for low confusability and $\underline{c} = 2$ for high confusability conditions. The dotted lines show the predictions of the UCC model. The following parameter values were chosen to provide a good "eyeballed" fit to the Rumelhart curves; values for the two confusability conditions differ only in the probability that a noise item is misperceived as one of the critical alternatives:

Low Confusability: $P_{CC} = .97$, $P_{CI} = .01$; $P_{NC} = P_{NI} = .12$

High Confusability: $P_{CC} = .97$, $P_{CI} = .01$; $P_{NC} = P_{NI} = .36$

To simplify calculations, the predictions were generated from the UCC formulas by treating n's of 4, 8, 12, and 16 as n's of 1, 2, 3, and 4 respectively. This approach is also in line with the design of Experiment I which results in a non-independence of processing for letters within the same 4-letter clump. Each clump is thus treated as a unit which is perceived as a composite. The simplifying assumption results in the identity of high- and low-confusability points for n = 4, although this would not be borne out in actual data.

Eliminating noise item-critical alternative confusions by selection of the stimulus population.--The similarity of the predictions shown in Fig. 5 suggests that the manipulation of noise item-critical alternative confusability in an Estes and Taylor paradigm can not provide a critical test between the two models in question. There is, however, one exception to this conclusion. Because of the limited feature extraction rate in the Rumelhart model, the probability that c features are extracted from the critical item before iconic fading, and thus the probability of correct detection, must decrease with increases in n. This holds true even if noise items are never misperceived as one of the critical alternatives; (note in this context that c cannot meaningfully take on a value less than 1). In the UCC model, on the other hand, a total lack of noise item-critical alternative confusions, i.e., $P_{NC} = P_{NI} = 0$, would imply that the perceptual endstates for noise items never affect Ss' decisions, and detection accuracy would be invariant with n. A test between the Rumelhart and UCC models can thus be performed in an Estes and Taylor paradigm designed so that noise items are never misperceived as either of the critical alternatives. Examinations of the confusion matrices presented by Fisher, Monty, and Glucksberg (1969) suggests that this could be accomplished by a careful selection of the vocabulary of noise and critical letters. However, most of these matrices were generated using single-letter stimuli, and it is questionable whether noise item-critical alternative confusions can be totally eliminated in multi-letter arrays presented under conditions sufficiently impoverished to avoid perfect detection accuracy. Evidence supporting this line of reasoning was obtained in some pilot experimentation; also, the results of a study by Keeley and Doherty (1969) suggest that confusions occur even for certain simple geometric stimulus forms. Assuming a decrease in detection accuracy with increasing _n_ were found for an allegedly confusion-free set of stimulus items, rejection of the UCC model would require independent experimental verification of the lack of noise item-critical alternative confusions under the exact conditions employed.

Eliminating noise item-critical alternative confusions with prolonged stimulus exposures.--Under the UCC model, consistently perfect detection accuracy implies perfect accuracy in the perceptual processing of critical items plus a total lack of noise item-critical alternative confusions. A test between the UCC and Rumelhart models might therefore employ stimulus exposures of sufficient duration to insure error-free detection performance, and use a response latency measure as the dependent variable. This is similar to the Atkinson, Holmgren, and Juola (1969) paradigm discussed in Chapter I, and unfortunately involves similar problems of model identifiability. For example, assuming that each stimulus array in the proposed critical experiment were exposed until _S_ executed a response, data in which RT increases linearly with n would be predicted by a serial scanning model and the Rumelhart model and the UCC model for certain underlying per-item processing time distributions (see Gumbel, 1954, and the discussion in Chapter I).

Use of a whole-report paradigm.--Considering the above difficulties, an attempt to eliminate noise item-critical alternative confusions - either by selection of the stimulus vocabulary or by prolonged stimulus exposure - did not seem to be an optimal strategy for a test between the models. Experiments III and IV relied on a more feasible experimental approach based on the following rationale. The decrease in detection accuracy with increases in n predicted by the UCC model for the Estes and Taylor paradigm is a result of the decisional structure of Ss' task: the selection of a single response on the basis of information from a number of processing channels. However, if Ss were able to make a single identifying response for each stimulus item in an array, predicted per-item accuracy would be invariant with n. The Rumelhart model, on the other hand, would predict a decrease in per-item identification accuracy with increases in n due to its limited-capacity property, just as in detection tasks. The critical experiment proposed here is thus a whole-report paradigm. This strategy requires freedom from the effects of non-perceptual factors (e.g., the properties of retention and response processes) that might vary with n to mask performance invariance at the perceptual level; traditional whole-report paradigms, as discussed in Chapter I, have been considered questionable because of their lack of freedom from just such contaminating effects. There is one important exception, however. The invariance of per-item identification accuracy with increases of n found by Eriksen and Lappin (1967) is prima facie evidence for the adequate control of non-perceptual factors in their whole-report design. Furthermore, this invariance, together with the performance decrease with increases in n found in detection paradigms, is exactly the pattern of results predicted by the UCC model but not the Rumelhart model.

There are, however, two reasons for not accepting the Eriksen and Lappin study as a completely satisfactory critical test between the two models. The first is the spatial uncertainty objection raised by Rumelhart and discussed in Chapter I. The second involves the lack of sufficient parallel between the Eriksen and Lappin, and Estes and Taylor designs. The former experiment employed 1 - 4 letter arrays, and the obtained results and those in the Estes and Taylor study are consonant with a limited-capacity conception that processes up to 4 letters in a pure-parallel manner (for example, the Rumelhart model with a slightly modified definition of a stimulus "item"). Confirmation of the UCC model and the explanation it entails for existing detection data requires the juxtaposition of appropriate results in the two paradigms - detection data showing a decrease in accuracy with increases in n, plus whole-report data showing an invariance in per-letter accuracy with increases in n - collected in experiments using comparable stimulus arrays. Experiment II was the first step in this strategy; it demonstrated a decrease in accuracy with increases in n in a detection paradigm employing 1 - 4 letter arrays arranged in the Eriksen and Lappin spatial configuration. Experiment III reported below was intended as the next step; it employed the Eriksen and Lappin whole-report procedure, plus stimulus arrays and vocabulary similar to those used in Experiment II. The final step was to be a control experiment designed to obviate the spatial uncertainty objection raised by Rumelhart;

previous evidence (see Chapter I and Appendix) had indicated a lack of spatial uncertainty effects in similar tachistoscopic experiments.

Experiment III

Method

Subjects.--Four naive female Ss, student volunteers, were paid $1.75 per one-hour session. Vision requirements were the same as in Experiments I and II.

Stimuli and equipment.--Stimuli consisted of arrays of 1, 2, 3, or 4 randomly selected consonants typed on white index cards, each consonant appearing at one corner of an imaginary square as in Experiment II (see Fig. 3). Consonants were separated by at least 1.8°; maximum array height and width were both 2.3°.

Two 32-card decks, designated A and B, were constructed for each of the four array sizes. Within the 64 cards of any given array size, each consonant occurred in each corner position with approximately equal frequency; for 1, 2, and 3-letter arrays, each possible spatial configuration was used with approximately equal frequency. In each multi-letter array individual letters were selected independently, so that the probability of any letter appearing in a given position was unaffected by the other letter(s) appearing on the card. All of the above constraints were explained to Ss at the beginning of the practice session.

Stimuli were exposed for 22 msec using the same tachistoscope and centered fixation dot arrangement as in Experiments I and II. Luminances were 21.2 mL and 6.2 mL for stimulus and fixation fields respectively.

Procedure.--Each S served in an initial practice session and four experimental sessions. The practice session consisted of 128 exposure trials - a foreward and backward run through each of two special 32-card practice decks. These decks contained 8 cards of each array size, cards of the same array size grouped together; other constraints were identical to those on the main stimulus decks.

Each experimental session consisted of 160 exposure trials - an initial run through one of the practice decks, followed by one run through four main stimulus decks, one deck for each array size; order of presentation of the four array sizes was counterbalanced across Ss for each session using latin squares. All of the main decks had been pre-ordered so that consonants and their spatial location, as well as overall spatial configuration of the 1, 2, and 3-letter arrays, changed randomly from trial to trial; the first, second, third, and fourth experimental sessions employed, respectively, A decks, B decks, A decks - card orders reversed from original randomizations, and B decks - reversed orders.

On every trial, S waited for E's ready signal, fixated the dot, and initiated the stimulus exposure by pressing a microswitch. Trials were self-paced with a minimum of 7 sec between exposures. The Ss were instructed to report the contents of each of the four corners of the stimulus array, guessing where necessary and reporting "blank" for any corner perceived as not containing a letter. Report sequences began with the upper right-hand corner followed by the other corners in clockwise order. The Ss always knew in advance the number of letters appearing in a stimulus array, and were required to include the same number of letters in their report. Trial-by-trial feedback consisted of repeating back to S those letters he had correctly reported; a letter was considered correct only if it was named in its correct spatial position. At the end of every 32-card deck, Ss were told the percentage of letters they had correctly reported. Each session was preceded by approximately 10 min of dark adaptation and incorporated a 5 min rest period half-way through the hour.

Results

The proportion of correctly named and located stimulus letters was computed for each array size; for example, if on the average three letters were correctly reported from the 4-letter arrays, the score for this array size would be .75. The above proportion corresponds to the average probability of a single stimulus letter being identified correctly. As Fig. 6 indicates,

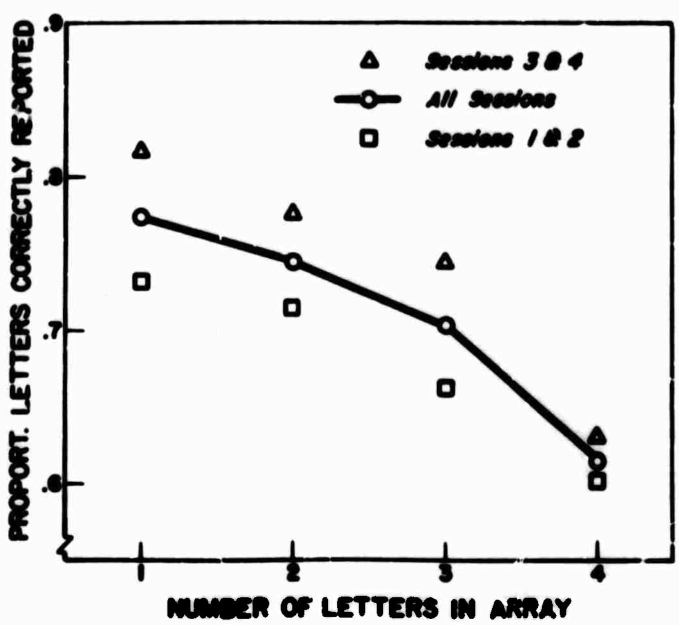

Fig. 6. Proportion of letters correctly reported as a function of the number of letters in the stimulus array in Experiment III.

this probability declined as a function of the number of letters in the array, $\chi_r^2 = 9.9$, $p < .007$. Furthermore, the decline in performance did not appear to be lessened by practice; the decline was as great in the last two experimental sessions - even though the overall level of performance was better - as it was in the first two experimental sessions. Friedman χ_r^2 values were 10.8, $p < .002$ and 9.3, $p < .012$ for the first two and last two sessions respectively.

It is conceivable that perceptual efficiency does not decline as a function of the number of letters in the stimulus array, but Ss' accuracy in spatially locating letters does decline. As a check on this possibility, the data were reanalyzed for correct reports irrespective of indicated location. When using this procedure, scores due to chance alone increase with increases in the number of letters guessed, thus spuriously decreasing the slope of the data function. However, even without a correction for guessing these data showed a significant decline in performance like that found with the more stringent scoring procedure ($\chi_r^2 = 9.9$, $p < .007$, see Table 4).

TABLE 4

PROPORTION OF LETTERS CORRECTLY REPORTED,

LENIENT SCORING: EXPERIMENT III

	Number of Letters in Array			
Item	1	2	3	4
Sessions 1 & 2	.731	.723	.675	.640
Sessions 3 & 4	.816	.775	.753	.669
All Sessions	.773	.749	.714	.654

Discussion

The invariance of per-item identification accuracy found by Eriksen and Lappin was not duplicated in Experiment III. Such an invariance, juxtaposed with the performance decline with increasing n found in Experiment II, would have been required to support the UCC model vs. the Rumelhart model. There were several design differences between Experiment III and the Eriksen and Lappin experiment that might have caused the difference in results. Some, such as the stimulus type-face used and the design of the fixation field, would not seem likely sources of the difference. A more probable source is the size of the stimulus vocabulary - 3 vs. 20 letters. Data cited by Miller (1956) indicates a smaller span of immediate memory for stimulus strings drawn from larger vocabularies, in line with the poorer performance for larger n's in Experiment III. On the other hand, Collins and Eriksen (1967) found evidence for the invariance of per-item identification accuracy in an Eriksen and Lappin paradigm using a 5-letter vocabulary, suggesting that vocabulary size is not a critical factor. As confirmation of the original Eriksen and Lappin data, followed by an experiment obviating spatial uncertainty objections, would be sufficient for a critical test between the UCC and Rumelhart models, an appropriate next step was to attempt an exact replication of the Eriksen and Lappin paradigm.

Experiment IV

Experiment IV was an exact replication of the Eriksen and Lappin (1967) 85% condition.

Method

Subjects.--Four female Ss, student volunteers, were paid $1.75 per one-hour session. All had normal or corrected-to-normal visual acuity. The Ss had received 5 - 7 hours of practice in a previous tachistoscopic experiment involving straight line segments, and had been selected for their day-to-day performance consistency and high degree of motivation.

Stimuli and equipment.--Stimuli consisted of arrays of 1, 2, 3, or 4 letters, each letter appearing at one corner of an imaginary square as in Experiments II and III (see Fig. 7). The letters used were upper case "A's,"

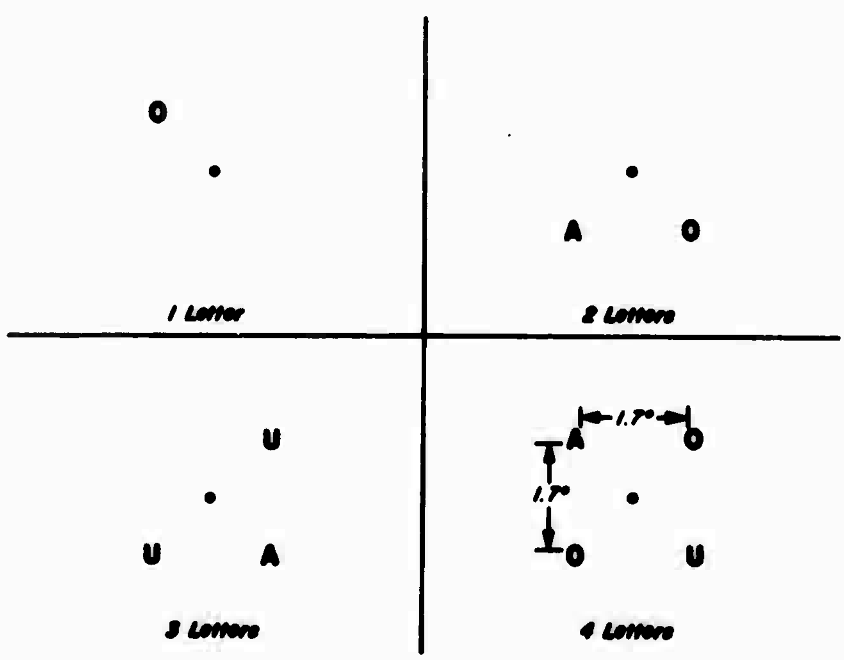

Fig. 7. Stimulus arrays used in Experiment IV.

"O's," and "U's" in Para-Tipe (style 11316) lettering applied to white index cards and sprayed with Krylon (1302) clear fixative. Individual letters were approximately .2° in height, and adjacent letters were separated by 1.7°.

Two 24-card decks of 1-letter arrays, two decks of 2-letter arrays, and four decks each of 3 and 4-letter arrays were constructed. Within every deck, each of the three letters occurred in each corner location with equal frequency; for 1, 2, and 3-letter arrays, each possible spatial configuration was used with equal frequency. In multi-letter arrays individual letters were selected independently, so that the probability of any letter appearing in a given position was unaffected by the other letter(s) appearing on the card. Five 12-card practice decks, each containing 3 consecutive cards of each array size, were also constructed within similar constraints. All of the constraints were explained to Ss at the beginning of the first session.

Stimulus arrays were exposed in the same tachistoscope used in Experiments I - III. They were preceded and followed by a dark field containing a centered, dim, neon fixation dot. The dot subtended approximately .1° and appeared at the same viewing distance as the stimulus cards. Stimulus luminance, monitored hourly, was .20 mL; to achieve this level of luminance it was necessary to introduce a neutral density filter (2.0) at the eyepiece.

Procedure.--Each S served in two initial practice sessions and two 4-session experimental blocks. The first practice session and both experimental blocks were preceded by one or two 168-trial "exposure" sessions in which a stimulus duration was determined that yielded approximately 85% report accuracy for 1-letter arrays; average durations, determined by a modified up-and-down method, were 33.1, 29.1, and 26.2 msec for the practice, first experimental, and second experimental blocks, respectively.

Practice and experimental sessions consisted of 108 exposure trials - a run through one of the practice decks, followed by one run through four main decks, one deck for each array size. Order of array size within sessions was counterbalanced for each S and for each 4-session experimental block by means of latin squares; choice of card deck representing a given array size was counterbalanced for each block. Stimulus cards within a deck were randomized before each use.

On every trial, S waited for E's ready signal, fixated the dot, and initiated the stimulus exposure. As in Experiment III, Ss reported the contents of each corner of the array in clockwise order beginning with the upper right-hand corner; they were instructed to guess when necessary and to report "blank" for any corner perceived as not containing a letter. The Ss knew in advance the number of letters in each stimulus array and were required to include the same number of letters in their report. Trial-by-trial feedback was given throughout the two practice sessions and for the practice deck in each experimental session; it consisted of the full correct report for the array, i.e., a corner-by-corner description of its contents. In addition, Ss received an overall percent correct score at the end of each experimental session. Trial-by-trial feedback was given for the first half of the initial exposure-duration session and for the first 12 trials of subsequent exposure-duration sessions.

Every session was preceded by approximately 10 min of dark adaptation and incorporated a 5 min rest period half-way through the hour. All other procedural details were the same as in Experiment III.

Results

The probability of a single stimulus letter being identified correctly (i.e., the proportion of correctly named and located letters) was computed for each array size. The results, shown in Fig. 8, indicated that this probability

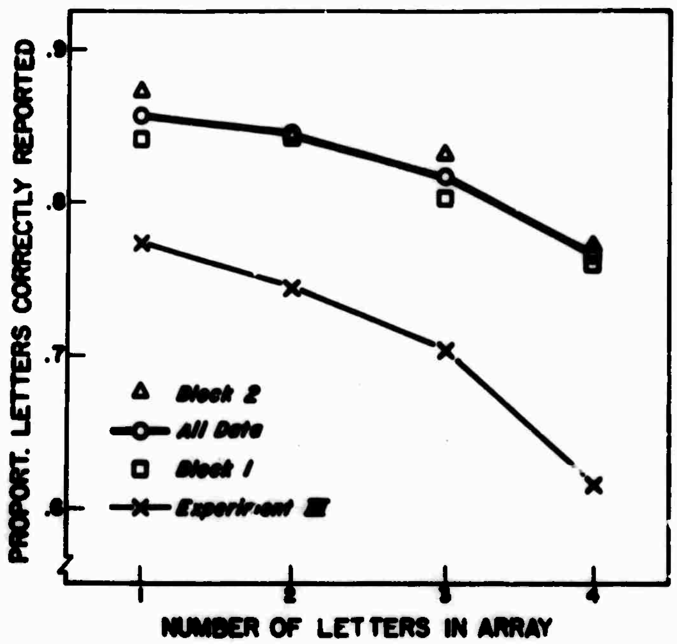

Fig. 8. Proportion of letters correctly reported as a function of the number of letters in the stimulus array in Experiment IV.

declined with increases in the number of letters in the array as in Experiment III ($\underline{\chi_r}^2 = 10.2$, $\underline{p} < .003$), although the overall decrease in performance was not as great in the present experiment. A further similarity to Experiment III was the failure of practice to lessen the downward trend in performance; this trend was as great or greater in the second experimental block as in the first. Friedman $\underline{\chi_r}^2$ values were 9.9, $\underline{p} < .007$ and 8.1, $\underline{p} < .033$ for the first and second block respectively.

The data were reanalyzed for correct reports irrespective of indicated spatial location. When using this procedure, scores due to chance alone increase with increases in the number of letters guessed, thus spuriously decreasing the slope of the data function. (For example, the average "lenient" score when guessing one letter is .33 but when guessing two letters is .96; if a pure-parallel-independent channels model were assumed and the probability of correctly perceiving each letter was .5, the average score would be (1 + .33)/2 = .67 for 2-letter arrays and (2 + .96)/4 = .74 for 4-letter arrays). However, even without a correction for guessing, these data showed a marginally significant decline in performance like that found with the more stringent scoring procedure (Xr^2 = 7.5, p < .052, see Table 5). As in

TABLE 5

PROPORTION OF LETTERS CORRECTLY REPORTED,

LENIENT SCORING: EXPERIMENT IV

Item	Number of Letters in Array 1	2	3	4
Block 1	.841	.859	.828	.812
Block 2	.872	.857	.852	.828
All Data	.857	.858	.840	.820

Experiment III, this result tended to rule out the possibility that the downward performance trend in the stringently-scored data was due to a decrease, with increasing array size, in the accuracy of letter localization but not in the efficiency of letter recognition per se.

Discussion

Experiment IV clearly failed to replicate the invariance of per-item identification accuracy reported by Eriksen and Lappin (1967), even though the methodology and degree of practice were essentially identical in the two experiments; the only differing procedural details were the sex of Ss and the shape of the fixation mark (dot vs. cross) - both rather unlikely sources of the difference in results. The discrepancy, however, might have been partially due to the data analyses employed. Eriksen and Lappin inferred performance invariance from the lack of significant deviation between frequency distributions of the number of correctly reported letters for each n value and the predictions of a binomial formula that assumed independent channels for each letter in an array. The present E replotted the means from the original Eriksen and Lappin data to conform to the format of Fig. 8, i.e., per-item identification accuracy as a function of n. This revealed a 5% superiority of performance on 1-letter arrays versus 2, 3, and 4-letter arrays for the results of the 20.4 msec and 29.5 msec exposure conditions averaged together. Although data for individual Ss were not available to permit a statistical test, the 5% superiority is a sizeable effect considering the total range of 9% between 1 and 4-letter array accuracy found in Experiment IV.[7] Combining the results of the two experiments, it seems reasonable to conclude that per-item identification accuracy decreases with increases in the number of array items in the Eriksen and Lappin paradigm, as predicted by the Rumelhart model and in contradiction to the UCC model.

Overview and Conclusions: Experiments I - IV

This paper has emphasized the sensory, decision, and retention factors that are potential sources of confounding in research on the spatial characteristics of perceptual processes, and the consequent difficulty to be expected in verifying the presence of an unlimited-capacity mechanism. Experiments I - IV were intended to evaluate potential confoundings of methodology and of task structure in the prior detection experiments in which number of array items was treated as an independent variable.

Experiments I and II demonstrated that spatial interaction effects were not the source of the decrease in detection accuracy with increasing n in the Estes and Taylor (1966) study. Experiments (II), III, and IV attempted to evaluate a second potential source of the decrease in detection accuracy - the decisional structure of Ss' task. The UCC model formalized this decisional factor and the effects upon it of noise item-critical alternative confusions. It was reasoned that a properly controlled whole-report paradigm could provide a test between the UCC model and the Rumelhart (1970) limited-capacity conception. The Eriksen and Lappin (1967) study had yielded an invariance of per-item identification accuracy as predicted by the UCC model, and suggested the appropriate strategy. Experiment II was the first step in bridging the gap between prior detection paradigms and the Eriksen and Lappin whole-report paradigm; it demonstrated a decrease in accuracy with increases in n in a detection task employing 1 - 4 letter arrays arranged in the Eriksen and Lappin spatial configuration. Experiment III was similar to Experiment II, but employed the Eriksen and Lappin whole-report procedure; however, it failed to yield the invariance of per-item identification accuracy reported in the Eriksen and Lappin study. Experiment IV was an exact replication of the original Eriksen and Lappin paradigm, but also failed to yield an invariance of per-item identification accuracy. The results obtained were therefore consonant with the Rumelhart conception, but not the UCC conception.

Reviewing the evidence discussed in Chapter I and the results of Experiments I - IV, the Rumelhart multicomponent model appears to have survived every experimental test applied. The Donderi and Zelnicker (1969) RT study is a single exception, but it involves certain interpretational difficulties. The viability of the multicomponent model is also enhanced by its power in predicting the experimental results in a broad range of paradigms - whole-report, partial-report, detection, masking, and temporal order - and by its ready incorporation into an overall model of perception and memory (Norman and Rumelhart, 1970). The Rumelhart model thus remains a dominant theoretical conception in the visual information processing area.

Despite the fact that Experiments I - IV were unanimous in their support of a limited-capacity model, however, it appears difficult to dismiss completely the UCC conception. The involvement of noise item-critical alternative confusions in detection paradigms is a striking phenomenon to many Ss, and is supported by the experimental evidence reviewed in Chapter I; the effects of such confusions would be expected to interact with n in the manner predicted by the UCC conception. Furthermore, support of the UCC model on the basis of the data from Experiments III and IV required the acceptance of null hypotheses. Considering the range of factors that limit Ss' performance in tachistoscopic paradigms and that are potential sources of confounding, the UCC model would seem to merit some additional investigation. In accounting for the results of Experiment III and IV, the present E questions the success of efforts to equate memory load for 1, 2, 3, and 4-letter arrays in the Eriksen and Lappin technique. The Ss in these studies volunteered that retention seemed easier for arrays containing fewer letters. For example, a frequent strategy for 1-letter arrays was to remember the name of the stimulus letter plus a single cue for its spatial location; the response sequence - e.g., "blank, U, blank, blank" - was not retained, but was reconstructed at the time of report. It might be argued that this differential in memory load could not be a confounding factor as four items are well within the short-term memory span, insuring perfect retention for 4-letter arrays. Memory span, however, is determined under conditions in which perceptual processing is perfectly veridical and does not place heavy attentional demands on S. This certainly is not the case for the impoverished stimulus exposures in the Eriksen and Lappin paradigm. As there is ample evidence that short-term retention is interfered with by concurrent information processing (cf., Posner & Rossman, 1965), the adequacy of control for the effects of memory load may be questioned.

Possible Future Directions

There are several approaches that may be pursued in further efforts to resolve the limited- vs. unlimited-capacity controversy. Two involve attempts to eliminate all noise item-critical alternative confusions, a strategy previously deferred in favor of the whole report approach of Experiments III and IV. One proposal was to eliminate confusions by means of careful selection of the stimulus population. It was pointed out, however, that a decrease in detection accuracy with increasing n found with an allegedly confusion-free set of stimulus items would not reject the UCC model without independent experimental verification of the lack of noise item-critical alternative confusions under the exact conditions employed. On the other hand, a single success in obtaining an invariance of detection accuracy with increasing n would pose problems for the Rumelhart model in its present form. Further attempts at selecting confusion-free stimulus populations therefore have potential and are currently underway.

A second strategy was to eliminate noise item-critical alternative confusions by means of stimulus exposures of sufficient duration to insure error-free detection performance, employing response latency as the dependent variable. As previously pointed out, however, this is similar to the Atkinson, Holmgren, and Juola (1969) design and involves similar problems of model identifiability. Results in which RT increases with n may be accounted for by serial, limited-capacity parallel, and unlimited-capacity parallel models. An invariance of RT with increases in n, on the other hand, is the unique prediction of one version of an unlimited-capacity model (excluding the class of limited-capacity conceptions discussed in Chapter I). Data of this form were obtained in the Donderi and Zelnicker experiment which involved an unusual decisional task: S judged the homogeneity of arrays of small geometric shapes. Future work should be directed at extending this design, and as a first step, the source of the surprisingly long RT's should be investigated. Further research could explore the generality of the RT invariance for other and more complex stimulus vocabularies, including alpha-numeric characters.

Another approach, and one with perhaps a greater likelihood of success than those above, would be to devise completely new experimental paradigms.

Existing whole-report tasks tend to confound perceptual with retention factors, whereas detection and other single-report tasks trade this confounding for problems of decisional structure. Obviously, a paradigm is needed that avoids both sets of problems at the same time. An example of a promising approach of this type appears in the Reicher (1969) experiment discussed in Chapter I. A single letter or word was briefly exposed and followed by a noise masking field; the S attempted to decide which of two alternative letters had appeared in a designated location of the stimulus array. The results, replicated and extended by Wheeler (1970), indicated that a given letter was detected more accurately if it was part of a 4-letter word than when it was presented singly. This design incorporated careful controls on a number of potentially confounding factors, including guessing strategies in which S infers the identity of letters he has failed to perceive in a word on the basis of other letters successfully perceived. Note also that S reported only a single item of information on each trial, that both 1-letter and 1-word stimuli involved a single "chunk" of material to be retained before response selection, and that S's decision was always based on one specified stimulus letter regardless of the total number of letters in the array. The involvement of meaningful stimulus materials in the Reicher-Wheeler design complicates the evaluation of the UCC and Rumelhart models on the basis of the results obtained. The main point to be made here, however, is the potential suggested by these experiments for new paradigms in further efforts to understand the spatial capacity properties of perceptual processes.

APPENDIX

An additional small experiment, run concurrently with Experiment I, was intended to assess the effect of spatial uncertainty in detection paradigms involving changes in the locus of stimulus letters from trial to trial. As discussed in Chapter I, Rumelhart suggested that this uncertainty could spuriously result in no decline in performance with increases in the number of stimulus letters even if perceptual capacity were truly limited. The uncertainty might force S to spread attention evenly over all four corners, even though some corners are not occupied in the 4, 8, and 12-letter arrays of Experiment I; the amount of processing capacity allocated to the target letter - and the efficiency with which it is perceived - would therefore be constant for all array sizes.

However, Garner and Flowers (1969) and Haber, Standing, and Boss (1970) found no effect of spatial uncertainty in tachistoscopic discrimination and repetition experiments, respectively. Furthermore, Rumelhart (1970) did not object to the uncertainty in the Estes and Wessel (1966) experiment. Rumelhart also postulates a rapid shift of attention to stimulus rows cued with a simultaneous or succeeding auditory tone in the Sperling (1960) partial-report paradigm; a similar shift might allow the S to quickly focus attention to stimulus letters, thus counteracting negative effects due to uncertainty in their location. In any case, this experiment was intended to evaluate a possible spatial uncertainty artifact should the results of Experiment I show no decline in performance with increases in the number of letters in the stimulus array.

Method

Subjects.--Four naive female Ss, student volunteers, were paid $1.75 per one-hour session. Vision requirements were the same as in Experiment I.

Stimuli and equipment.--Two 32-card decks of 8-consonant arrays were used. One (Deck A) was the 8-letter deck from Experiment I, in which the spatial location of the two clumps of 4 letters changed randomly from card to card. The other (Deck B) was similar except that letter clumps were located in upper-left and lower-right corners for the first 16 cards, and lower-left and upper-right corners for the second 16 cards. Equipment, duration, and luminances were identical to those in Experiment I.

Procedure.--Each S served in an initial practice session and one experimental session. The practice session consisted of four 32-exposure blocks - Deck A in forward order, Deck A in backward order, Deck B forward, Deck B backward; sequences of the four blocks were counterbalanced across Ss using a latin square.

The experimental session was identical to the practice session except that four-block sequences were reversed, and Ss were first given 32 warm-up trials - 16 involving spatial uncertainty and 16 involving no uncertainty (8 of each clump orientation).

As in Experiment 1, Ss fixated the dot, initiated the exposure, reported "N" or "P" and a confidence rating, and received feedback on each array. During spatial certainty conditions, Ss always knew in advance which two corners would contain the letter clumps. Other procedural details were the same as in Experiment I.

Results and Discussion

As Appendix Table 1 indicates, the proportion of correct detection trials was virtually identical for certainty and uncertainty conditions.

APPENDIX TABLE 1

CONTROL EXPERIMENT

Item	Condition: Spatial Uncertainty	Condition: Spatial Certainty
Proportion of correct detections	.660	.660
Frequency of use of high confidence rating	41	45
Accuracy of high confidence rating trials	.829	.844

The frequency and accuracy of high confidence ratings were also highly similar for both conditions. Rumelhart's hypothesis regarding spatial uncertainty effects was therefore not supported; the lack of an effect also extends the conclusions of Garner and Flowers (1969) and Haber, Standing, and Boss (1970) to the detection paradigm.

REFERENCES

Alpern, M. Metacontrast. Journal of the Optical Society of America, 1953, 43, 648-657.

Atkinson, R. C., Holmgren, J. E., & Juola, J. F. Processing time as influenced by the number of elements in a visual display. Perception & Psychophysics, 1969, 6, 321-326.

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In Spence, K. W., & Spence, J. T. (Eds.), The psychology of learning and motivation. New York: Academic Press, 1968. Pp. 69-195.

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

Bamber, D. Reaction times and error rates for "same"-"different" judgments of multidimensional stimuli. Perception & Psychophysics, 1969, 6, 169-174.

Bjork, E. L., & Estes, W. K. Detection and placement of redundant signal elements in tachistoscopic displays of letters. Perception & Psychophysics, 1970, in press.

Briggs, G. E., & Blaha, J. Memory retrieval and central comparison times in information processing. Journal of Experimental Psychology, 1969, 79, 395-402.

Broadbent, D. E. Perception and communication. London: Pergamon, 1958.

Bryden, M. P. Accuracy and order of report in tachistoscopic recognition. Canadian Journal of Psychology, 1966, 20, 262-272.

Burrows, D., & Murdock, B. B., Jr. Effects of extended practice on high-speed scanning. Journal of Experimental Psychology, 1969, 82, 231-237.

Collins, J. F. Independence of sensitivity on different foveal areas. Unpublished doctoral dissertation, University of Illinois, 1969.

Collins, J. F., & Eriksen, C. W. The perception of multiple simultaneously presented forms as a function of foveal spacing. *Perception & Psychophysics*, 1967, 2, 369-373.

Donderi, D. C., & Zelnicker, D. Parallel processing in visual same-different decisions. *Perception & Psychophysics*, 1969, 5, 197-200.

Egeth, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics*, 1966, 1, 245-252.

Eriksen, C. W., & Collins, J. F. Some temporal characteristics of visual pattern perception. *Journal of Experimental Psychology*, 1967, 74, 476-484.

Eriksen, C. W., & Lappin, J. S. Internal perceptual system noise and redundancy in simultaneous inputs in form identification. *Psychonomic Science*, 1965, 2,351-352.

Eriksen, C. W., & Lappin, J. S. Independence in the perception of simultaneously presented forms at brief durations. *Journal of Experimental Psychology*, 1967, 73, 468-472.

Eriksen, C. W., Munsinger, H. L., & Greenspon, T. S. Identification versus same-different judgment: An interpretation in terms of uncorrelated perceptual error. *Journal of Experimental Psychology*, 1966, 72, 20-25.

Eriksen, C. W., & Rohrbaugh, J. Visual masking in multielement displays. *Journal of Experimental Psychology*, 1970, 83, 147-154.

Eriksen, C. W., & Spencer, T. Rate of information processing in visual perception: Some results and methodological considerations. *Journal of Experimental Psychology Monograph*, 1969, 79 (No. 2, Part 2).

Estes, W. K., & Taylor, H. A. A detection method and probabilistic model for assessing information processing from brief visual displays. Proceedings of the National Academy of Sciences, 1964, 52, 446-454.

Estes, W. K., & Taylor, H. A. Visual detection in relation to display size and redundancy of critical elements. Perception & Psychophysics, 1966, 1, 9-16.

Estes, W. K., & Wessel, D. L. Reaction time in relation to display size and correctness of response in forced-choice visual signal detection. Perception & Psychophysics, 1966, 1, 369-373.

Estes, W. K., & Wolford, G. L. Effects of spaces on report from tachistoscopically presented letter strings. Communications in Mathematical Psychology, Rockefeller University, 1970.

Fisher, D. F., Monty, R. A., & Glucksberg, S. Visual confusion matrices: Fact or artifact. The Journal of Psychology, 1969, 71, 111-125.

Flom, M. C., Weymouth, F. W., & Kahneman, D. Visual resolution and contour interaction. Journal of the Optical Society of America, 1963, 53, 1026-1032.

Freeburne, C. M., & Goldman, R. D. Left-right differences in tachistoscopic recognition as a function of order of report, expectancy, and training. Journal of Experimental Psychology, 1969, 79, 570-572.

Garner, W. R., & Flowers, J. H. The effect of redundant stimulus elements on visual discrimination as a function of element heterogeneity, equal discriminability, and position uncertainty. Perception & Psychophysics, 1969, 6, 216-220.

Gumbel, E. J. Statistical theory of extreme values and some practical applications. National Bureau of Standards Applied Mathematics Series, No. 33, February 12, 1954.

Haber, R. N. Nature of the effect of set on perception. Psychological Review, 1966, 73, 335-351.

Haber, R. N., & Standing, L. Clarity and recognition of masked and degraded stimuli. Psychonomic Science, 1968, 13, 83-84.

Haber, R. N., & Standing, L. Location of errors with a post-stimulus indicator. Psychonomic Science, 1969, 17, 345-346.

Haber, R. N., Standing, L., & Boss, J. Effect of position and typeface variation on perceptual clarity. Psychonomic Science, 1970, 18, 91-92.

Harcum, E. R. A note on "Some artifactual causes of perceptual primacy." Psychonomic Science, 1967, 8, 67-68.

Hubel, D. H., & Wiesel, T. N. Receptive fields and functional architecture in two nonstriate visual areas (18 and 19) of the cat. Journal of Neurophysiology, 1965, 28, 239-290.

Kahneman, D. Method, findings, and theory in studies of visual masking. Psychological Bulletin, 1968, 70, 404-425.

Keeley, S. M., & Doherty, M. E. Simultaneous and successive presentations of single-featured and multi-featured visual forms: Implications for the parallel processing hypothesis. Perception & Psychophysics, 1968, 4, 296-298.

Keeley, S. M., & Doherty, M. E. A note on the parallel processing of single-featured forms. Perception & Psychophysics, 1969, 6, 81-82.

Kinsbourne, M., & Warrington, E. K. The effect of an aftercoming random pattern on the perception of brief visual stimuli. Quarterly Journal of Experimental Psychology, 1962, 14, 223-234. (a)

Kinsbourne, M., & Warrington, E. K. Further studies on the masking of brief visual stimuli by a random pattern. Quarterly Journal of Experimental Psychology, 1962, 14, 235-245. (b)

Krantz, D. H. Threshold theories of signal detection. Psychological Review, 1969, 76, 308-324.

Lappin, J. S., & Ellis, S. H. The span of apprehension: Form identification as a function of amount of information displayed. Perception & Psychophysics, 1970, 7, 65-72.

Liss, P. Does backward masking by visual noise stop stimulus processing? Perception & Psychophysics, 1968, 4, 328-330.

Mackworth, J. G. The relation between the visual image and post-perceptual immediate memory. Journal of Verbal Learning and Verbal Behavior, 1963, 2, 75-85.

Mathewson, J. W., Jr., Miller, J. C., Jr., & Crovitz, H. F. The letter span in space and time. Psychonomic Science, 1968, 11, 69-70.

McIntyre, C., Fox, R., & Neale, J. Effects of noise similarity and redundancy on the information processed from brief visual displays. Perception & Psychophysics, 1970, 7, 328-332.

Mewhort, D. J. K., Merikle, P. M., & Bryden, M. P. On the transfer from iconic to short-term memory. Journal of Experimental Psychology, 1969, 81, 89-94.

Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 1956, 63, 81-97.

Neisser, U. Decision time without reaction time: Experiments in visual scanning. American Journal of Psychology, 1963, 76, 376-385.

Neisser, U. Cognitive psychology. New York: Appleton-Century-Crofts, 1967.

Nickerson, R. S. Response times with a memory-dependent decision task. Journal of Experimental Psychology, 1966, 72, 761-769.

Norman, D. A., & Rumelhart, D. E. A system for perception and memory. In D. A. Norman (Ed.), Models of human memory. New York: Academic Press, 1970.

Posner, M. I., & Rossman, E. Effect of size and location of informational transforms upon short-term retention. Journal of Experimental Psychology, 1965, 70, 496-505.

Reicher, G. M. Perceptual recognition as a function of meaningfulness of stimulus materials. Journal of Experimental Psychology, 1969, 81, 275-280.

Rumelhart, D. E. A multicomponent theory of the perception of briefly exposed visual displays. Journal of Mathematical Psychology, 1970, 7, 191-218.

Shaw, P. Processing of tachistoscopic displays with controlled order of characters and spaces. Perception & Psychophysics, 1969, 6, 257-266.

Siegel, S. Nonparametric statistics. New York: McGraw-Hill, 1956.

Spencer, T. J. Some effects of different masking stimuli on iconic storage. Journal of Experimental Psychology, 1969, 81, 132-140.

Sperling, G. The information available in brief visual presentations. Psychological Monographs, 1960, 74 (11, Whole No. 498).

Sperling, G. A model for visual memory tasks. Human Factors, 1963, 5, 19-31.

Sperling, G. Successive approximations to a model for short-term memory. Acta Psychologica, 1967, 27, 285-292.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Scanning a persisting visual image versus a memorized list. Paper presented at the meeting of the Eastern Psychological Association, Boston, April, 1967. (a)

Sternberg, S. Two operations in character-recognition: Some evidence from reaction-time measurements. Perception & Psychophysics, 1967, 2, 45-53. (b)

Townsend, J. T. Some results concerning the identifiability of parallel and serial processes. Unpublished manuscript, Purdue University, 1970. (a)

Townsend, J. T. Manuscript. Perception & Psychophysics, 1970, in press. (b)

Weisstein, N. Backward masking and models of perceptual processing. Journal of Experimental Psychology, 1966, 72, 232-240.

Wheeler, D. D. Processes in word recognition. Cognitive Psychology, 1970, 1, 58-85.

White, M. J. Laterality differences in perception: A review. Psychological Bulletin, 1969, 72, 387-405.

Wickelgren, W. A. Strength theories of disjunctive visual detection. Perception & Psychophysics, 1967, 2, 331-337.

Wolford, G. L., Wessel, D. L., & Estes, W. K. Further evidence concerning scanning and sampling assumptions of visual detection models. Perception & Psychophysics, 1968, 3, 439-444.

Woodworth, R. S., & Schlosberg, H. Experimental psychology. (2nd ed.) New York: Holt, 1954.

FOOTNOTES

1. Eriksen and Lappin also cite supporting evidence from other tachistoscopic experiments.

2. D. Rumelhart, personal communication, 1969.

3 Also: J. Townsend, personal communication, 1970.

4. J. Townsend, personal communication, 1970.

5, 6. The conception was suggested by D. Krantz; the author gratefully acknowledges this assistance.

7. Dr. C. W. Eriksen kindly provided summary data from the original Eriksen and Lappin (1967) experiment. He also reported that subsequent unpublished experimentation tended to confirm the superior per-item identification accuracy for 1 versus 2-item arrays, and thus failed to support the original inference of performance invariance.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Michigan, Human Performance Center Department of Psychology, Ann Arbor, Michigan	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

SPATIAL PROCESSING CHARACTERISTICS IN THE PERCEPTION OF BRIEF VISUAL ARRAYS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Gerald T. Gardner

6. REPORT DATE August 1970	7a. TOTAL NO. OF PAGES ?9 plus viii	7b. NO. OF REFS 71
8a. CONTRACT OR GRANT NO. AF 49(638)-1736 (ARPA)	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 23 08773-64-T	
b. PROJECT NO. 461		
c. 61101D	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFOSR-TR-71-0438	
d. 681313		

10. DISTRIBUTION STATEMENT
1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES THESIS University of Michigan, Human Performance Center, Department of Psychology, Ann Arbor, Michigan	12. SPONSORING MILITARY ACTIVITY Air Force Office of Scientific Research 1400 Wilson Boulevard (NL) Arlington, Virginia 22209

13. ABSTRACT

In the Estes & Taylor (1964, 1966) "detection" experiments, subjects (Ss) saw a brief array containing "noise" letters plus one of two critical letters, and attempted to determine which critical letter appeared; accuracy decreased as the number of noise letters increased. This was interpreted by Estes & Taylor and by Rumelhart (1970) as demonstrating a limitation of perceptual capacity. However, the experiments involved confoundings: stimulus arrays with more letters were either larger in visual angle or involved greater inter-letter crowding, both of which factors are known to decrease letter perceptibility.

Exps. I and II in the present study were patterned after the Estes & Taylor paradigm, but controlled both angular size and crowding factors by means of specially designed stimulus arrays. In both Expers., Ss' performance decreased with increases in the number of letters, thus supporting limited-capacity models. However, a model incorporating perceptual confusion phenomena was found to predict the obtained data due to decisional factors, even though the perceptual stage embodied no limitation of capacity. Exp. III was similar to a whole-report experiment by Eriksen & Lappin (1967) and attempted a critical test between limited-capacity models and the unlimited-capacity confusions (UCC) model. The results failed to duplicate the invariance of per-item accuracy found by Eriksen & Lappin. Such an invariance, along with the decrease in accuracy found in Exp. II, would have been required by the UCC model. Exp. IV was an exact replication of Eriksen & Lappin (1967), but failed to yield performance invariance. It was concluded that, notwithstanding the methodological and theoretical considerations of Exps. I - IV, limited-capacity models remain viable conceptions.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Visual information processing						
2. Tachistoscopic perception						
3. Limited attentional capacity						
4. Serial vs. parallel processing						
5. Detection paradigm						
6. Alpha-numeric arrays						

TECHNICAL REPORTS

1. Phillips, L. D. Some components of probabilistic inference. January 1966.
2. Egeth, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. January 1966.
3. Biederman, I. Human performance in contingent information processing tasks. October 1966.
4. Peterson, C. R. & Beach, L. R. Man as an intuitive statistician. November 1966.
6. Smith, E. E. Choice reaction time: An analysis of the major theoretical positions. January 1967.
7. Reicher, G. M. Perceptual recognition as a function of meaningfulness of stimulus material. February 1968.
8. Ligon, E. The effects of similarity on very-short-term memory under conditions of maximal information processing demands. May 1968.
9. Triggs, T. J. Capacity sharing and speeded reactions to successive signals. August 1968.
10. Tversky, B. G. Pictorial and verbal encoding in short-term memory. October 1968.
11. Lively, B. L. The Von Restorff effect in very-short-term memory. December 1968.
12. Greeno, J. G. How associations are memorized. December 1968.
13. Swensson, R. G. The elusive tradeoff: Speed versus accuracy in choice reaction tasks with continuous cost for time. December 1968.
14. Bjork, R. A. Repetition and rehearsal mechanisms in models for short-term memory. May 1969.
15. Hamlet, A. S. Processing of sequentially presented signals in information-combining tasks. June 1969.
16. Pollatsek, A. W. Rehearsal, interference, and spacing of practice in short-term memory. July 1969.
17. Garskof, M. H. The effect of spacing and variation of repetition in short-term memory. August 1969.
18. Shulman, H. G. Presentation rate, retention interval, and encoding in short-term memory for homonyms, synonyms, and identical words. September 1969.
19. Du Charme, W. M. A responsive bias explanation of conservative human inference. December 1969.
20. McCormack, P. D. Monitoring eye movements during the learning of paired-associate lists. March 1970.
21. Goodman, B. C. Risky decisions by individuals and groups. June 1970.
22. Wattenbarger, B. L. The representation of the stimulus in character classification. August 1970.

MEMORANDUM REPORTS

1. Fitts, P. M. Cognitive factors in information processing. February 1967.
2. Melton, A. W., Sameroff, A., & Schubot, E. D. Short-term recognition memory. May 1967.
3. Martin, E. Responses to stimuli in verbal learning. October 1967.
4. Melton, A. W. First annual report: Human information handling processes. June 1968.
5. Jahnke, J. C. The Ranschburg paradox. July 1968.
6. Greeno, J. G. Theory of graphs on sets with applications to problem solving and understanding. October 1968.
7. Edwards, W. A bibliography of research on behavioral decision processes to 1968. January 1969.
8. Melton, A. W. Second annual report: Human information handling processes. June 1969.
9. Greeno, J. G. A cognitive interpretation of negative transfer and forgetting of paired associates. November 1969.
10. Martin, E. Associative interference theory and spontaneous recovery. November 1969.