THE EFFECT OF DISPLAY CONFIGURATIONS
IN VISUAL SEARCH TASKS

By

ROBERT H. RALSTON

Bachelor of Science in Industrial Engineering
Lehigh University
Bethlehem, Pennsylvania
1949

Master of Science in Industrial Engineering
University of Houston
Houston, Texas
1954

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1974

THE EFFECT OF DISPLAY CONFIGURATIONS

IN VISUAL SEARCH TASKS

Thesis Approved:

S. Keith Adams
Thesis Adviser

James E. Shamblin

M. P. Terrell

Robert J. Weber (by WE)

William W. Rambo

D. D. Durham
Dean of the Graduate College

PREFACE

This research primarily analyzes the effect of the trade-off between the width of the display and its speed of movement in dynamic visual search tasks. Secondarily, it studies the effect of small spacing variations in the arrays of stimulus material and the error patterns within each of the configurations. Missed target and false alarm error rates are used as a measure of comparison.

I wish to express my sincere appreciation to Dr. S. Keith Adams, my thesis adviser, for his guidance and constructive criticism throughout this research. Appreciation is also extended to my other committee members, Dr. James Shamblin, Dr. Palmer Terrell, Dr. William Rambo, and Dr. Robert Weber for their general assistance.

A special thanks is extended to Dr. Leroy Folks and Dr. Kenneth Stephens for their help and guidance on the statistical analyses.

Finally, I wish to express my gratitude to my wife, Ruth, and to our children, Rebecca, Robert, Jr., and Timothy, for their understanding and encouragement throughout this project.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

Perspective

In many industries today, the visual inspection of conveyorized components or products is a necessary adjunct to the manufacturing process. The ability of the inspector to search an array of moving objects and to discriminate properly between acceptable and non-acceptable quality is the determining factor as to the level of outgoing product quality. But more than this, the effectiveness with which the inspector performs his task has a significant bearing on both material and labor costs.

For years efforts have been directed toward optimizing the manual and man-machine systems of manufacturing operations. A widely-used tool in these efforts has been the proven principles of motion economy. Effective application of these principles has extended to the offices of industrial and governmental organizations, to the hospital operating room, to virtually everywhere that human beings are involved in manual or machine-associated tasks. More recently the concepts of human factors engineering have been used in the design and improvement of many man-machine systems, such as airplane cockpits and the monitoring consoles of automated systems.

The inspection task itself has experienced much change and improvement over the years. In numerous instances, the inspector who once visually scanned or measured a product for its sub-quality condition, has been replaced by the "inspector" who monitors displays covering entire automated systems for indications of out-of-control condition. The development of electronic inspection devices or servomechanisms that automatically control processes has drastically changed the nature of the inspection task, but it has not eliminated it.

Still today there exist many processes that depend heavily on the visual inspection of the product. In such instances, one usually finds the inspection task well engineered from virtually all aspects of the job. Comfort, freedom of movement, proper lighting, a minimum of distractions, and periodic rest periods are the type of considerations that normally have been built into the inspection task.

The one aspect of the inspection task that has been given relatively little attention is the psychological factor involving visual perception. It is common to find the rate of inspection to be a function of the rate of production throughput rather than be determined by the optimum effectiveness. Widths of conveyors carrying units to be inspected are often determined by operating considerations rather than by any inspection criteria.

One of the problems of visual search in a dynamic field is the interaction between the width of the stimulus presentation or display and its speed of movement. This problem can be readily visualized if one compares two extreme conditions for the scanning of a given quantity of stimulus material in a given time. In both conditions movement of the material is assumed to be toward the observer. This is frequently described as "top to bottom" movement.

At one extreme is a narrow band of stimulus material requiring no lateral eye movement. Movement of the visual field in this instance is relatively rapid. At the other extreme is a wide band of stimulus material requiring lateral, saccadic eye movement similar to that in the normal reading process. In order that the same quantity of material is scanned in a given time in both instances, this extreme requires movement of the visual field to be relatively slow. Vertical eye movement would be similar in both extremes and, therefore, is unimportant in the comparison. It would either be a series of alternating saccadic and smooth eye movements, as in the case of a vertically large or unrestricted viewing field, or virtually non-existent, as when a shallow, horizontal viewing aperture is utilized.

Purpose of the Research

The primary purpose of this research is to study the effect of the trade-off between the width of the display and its speed of movement in visual search tasks in a dynamic field. More specifically, this investigation seeks to determine whether or not there is an optimum display width - display speed combination at which the subject is better able to search for and locate a target than other display width - display speed combinations. Because of the vast scope of the problem, investigation has been confined to visual perception tasks in which the displays are observed through a shallow viewing aperture. Although such a restriction is uncommon in real world visual inspection tasks, justification for its use in this experimentation is based on two factors. First, many inspectors limit their scan to a relatively small depth, utilizing the unrestricted display depth solely to track a possible defect. Secondly, the experimentation has been made less complex by the elimination of the variable of vertical tracking.

Secondary purposes of this investigation include the following:

a) To examine the pattern of errors formed by the various target positions within each stimulus configuration.

b) To study the effect that the horizontal spacing of stimulus material has on the perceptual process within a configuration.

c) To study the effect that the vertical separation between rows of stimulus material in multi-row configurations has on the perceptual process.

It is expected that the findings of this research, presented herein, will be a worthwhile addition to existing knowledge of the subject of dynamic visual perception and that they will aid in advancing the task of visual inspection toward optimum effectiveness.

Description of the Experimentation

Four laboratory experiments were conducted in this research. In each of these, the subject's task was to search the stimulus material for the presence or absence of a predetermined target, and, if present, to locate properly the target within the various possible target positions. Movement of the visual field was from top to bottom in all experiments, and, as has been stated, viewing always took place through an aperture.

Throughout the experimentation, the data accumulated and analyzed were error rates. Errors were of two types, misses (Type I error) and false alarms (Type II error). A miss occurred when a target was present in a stimulus presentation and the subject either reported no target or reported a target in the wrong position. A false alarm, as defined in this paper, is the subject's reporting a target, there being no target present in the stimulus presentation. It seems advisable to caution the reader that other investigators may define misses and false alarms differently than defined above. For instance, in the work of Green (1970), a reported target had to be farther from the actual target than one target position to be classified as a miss. Likewise, some investigators consider a reported target position that is farther than several positions from an actual target position to be both a miss and a false alarm (Adams, 1970, and Green). The nature of this research prompted the definitions of misses and false alarms used herein.

In three of the four experiments conducted, selected capital letters, randomly positioned, were used as context, while the letter K was used as the target. The context-target combination used was the same as that used by Kaplan et al. (1966) under their classification of "high confusability level." In the remaining experiment, an entirely different type of target and context was used as a means of comparing results.

Experimental design centered around the primary purpose of the research, namely the investigation of the effect of trade-off between the width of the display and its speed of movement in a visual search task. In this regard, the writer hypothesized that error rates would be lowest on the widest display, and thus the slowest moving, that does not require saccadic eye movement. Experiment I was designed to test this hypothesis as well as produce findings on error patterns. The experiment was primarily a comparison of three different configurations of stimulus material using a display of eight capital alphabetic letters.

The configurations were: 1) a single, eight-letter row (1 X 8 configuration); 2) two rows of four letters each (2 X 4 configuration); and 3) four rows of two letters each (4 X 2 configuration). For interconfiguration comparisons, the speed of the moving field was adjusted so as to provide the same exposure time for each configuration. In addition, exposure time was treated as a variable to study its effect on perceptual behavior. Secondarily, Experiment I was an intraconfiguration analysis of error patterns by target position.

Experiment II was also primarily a comparison of three different configurations of stimulus material. The experiment tested the same hypothesis that Experiment I tested. Each display consisted of six dials, with dial settings in increments of 45° (see Figure 1). The configurations were 1 X 6, 2 X 3, and 3 X 2, the first numeral in each pair being the number of rows, the second, the number of units per row.

Figure 1. Example of the 1 X 6 Configuration of Dials in Experiment II

The target dial setting was also a variable in this experiment for the purpose of determining its effect, both within and between configurations, on performance. Lastly, as in Experiment I, an analysis was made of error patterns by target position within each configuration.

Experiments III and IV were designed to find the combination of factors that tend to minimize error rates in visual search tasks. Capital letters were used as stimulus material in both these experiments. Experiment III tested the hypothesis that lateral spacing (or sub-grouping) of the stimulus material is a factor that influences error rates in one- and two-row configurations. Experiment IV was a comparison of four configurations: 1 X 16, 2 X 8, 4 X 4, and 8 X 2. This experiment further tested the hypothesis tested by Experiments I and II, namely that error rates would be lowest on the widest and slowest display that does not require lateral saccades. Also, in addition to testing the hypothesis of Experiment III regarding lateral spacing, Experiment IV tested the hypothesis that the vertical separation between rows of multi-row configurations is an influencing factor in error rates. As in the first two experiments, Experiment IV included an analysis of error pattern by target position within each configuration.

A Listing of the Hypotheses

In summary, the hypotheses tested in this research along with the experiment numbers of each are listed below.

Hypothesis No.		Experiment No's.
1	In a display width-display speed trade-off, error rates are lowest on the widest display, and thus the slowest moving, that does not require saccadic eye movement.	I, II, IV

2	Lateral spacing of the stimulus material is a factor that influences error rates in one- and two-row configurations.	III, IV
3	Vertical separation between rows of multi-row configurations is an influencing factor in error rates.	IV

CHAPTER II

LITERATURE REVIEW

A great deal of significant research has been conducted in the area of perception in a static visual field. As there are apparent similarities, as well as differences, between static and dynamic field perceptual behavior, a search of the pertinent literature necessarily included the former.

Static Visual Field Perception

The Approaches to Analysis

Various approaches have been taken in the laboratory study of the perceptual process for a static visual field. One such approach utilizes tachistoscopic projections of stimulus material onto a screen for short durations. The subject's task may be to recall the stimulus material exactly as projected (Wagner, 1918) or to search the material for the presence or location of a predetermined target (Underwood, 1966).

Another approach requires the subject to scan a relatively large area containing stimulus material to search out a target (Baker et al., 1960). The major difference in the subject's attack of the problem between the two study approaches is that in the first, the eye remains fixed during stimulus exposure, while in the second, saccadic eye movement is a necessary part of the search procedure.

Studies Involving Tachistoscopic Projections

Woodworth (1938) reported that Wagner as early as 1918 found that in a series of eight alphabetic characters tachistoscopically projected for 100 milliseconds, the letters closer to the eye fixation point at the center of the series were recalled with the least accuracy. The accuracy increased as the letter position moved toward the extremities of the series. This was labeled a bow-shaped error function. Although similar results were obtained by Harcum (1957), Averbach and Coriell (1961) found that the greatest accuracy was in the central positions as well as at the extremities.

There is general agreement that the end positions in a series can be perceived more accurately because of a reduced masking effect from adjoining stimulus material. Green eliminated this variable by omitting the extremities as possible target positions. As did Averbach and Coriell, Green found the greatest accuracy in the central positions.

In another study (Crovitz and Schiffman, 1965), the centrally fixated line of stimulus material, capital letters, was split into two halves with a two-inch gap between. Results showed that, except for the sharply reduced error rate at the two extreme positions, no significant difference occurred in error rates among the target positions. This finding led the authors to submit that both primacy and recency, in a probable left to right scanning order, may be of more importance in recalling rapidly decaying traces than is the reduced masking effect.

In an investigation of the effect of spacing on accuracy in the recall of centrally fixated letter strings, Crovitz and Schiffman found no significance, the relative positions of the letters, not the absolute positions, being the important variable. The authors did find a bimodal error function, similar to that found by Averbach and Coriell. Harcum (1964), using blackened and open zeros as stimulus material, also found that accuracy for individual positions was a function of the relative, rather than absolute, position. He concluded that accuracy is determined by the interaction among elements of stimulus material and mnemonic organization, rather than by retinal sensitivity.

Mackworth (1965) applied signal detection theory to the problem of scanning a line of stimulus material for a target. The higher the confusability level between context and target the greater the noise. This noise affects both the peripheral and the foveal perception. As the noise level increases, the "useful field of view," according to Mackworth, decreases and a higher order of cognitive process must be utilized to recognize a target.

This reduction in the useful field of view is similar to that known in the field of optics as tunnel vision, which is caused by some physiological defect in the optic system. This would be one explanation for the type of error function obtained by Averbach, Green, and Crovitz on tachistoscopically projected material. Green, in comparing two levels of confusability, found a much more shallow error function at the lower confusability level. From this, it appears that the confusability level has a direct bearing on the "tunneling" effect commonly found in the error function.

Visual Search Over a Large Area

Neisser (1964), using capital letters as stimulus material, studied the task of scanning a list to search out a target. He found that the level of confusability between context and target was a highly significant factor affecting a subject's scanning speed and accuracy. Other investigations (Gibson and Yonas, 1966; Kaplan et al., 1966), using the same stimulus material, capital letters, verified Neisser's findings. Kaplan further found that acoustic confusability, the level of confusability when the stimulus material is presented acoustically, had no detrimental effect in a visual search task.

In an earlier study, Neisser (1963) found that the time required to scan a given amount of stimulus material was greater when each row contained only two letters than when each row contained six letters. Two possible explanations for this have been submitted. First, more eye movement is required to cover the material presented in two-letter rows than in six-letter rows, due to there being three times as many rows. Secondly, in the two-letter rows, the foveal visual field is utilized much less efficiently.

Brown and Strongman (1966) found that in searching for a target letter within a string of capital letters, search time was faster for horizontal than for vertical strings.

Results of investigations involving complex displays (Baker et al., 1960) showed that both search time and the quantity of errors increased as a function of the number of irrelevant forms on the target display. Another study pertaining to complex displays (Steedman and Baker, 1960) indicated that neither search time nor the quantity of errors is affected by target size for targets subtending over 12 minutes of visual angle; however, for targets below this, performance deteriorates.

Summary

These and similar investigations into the perceptual process in a static visual field and their results have strongly influenced the investigations covered by this dissertation. As has been mentioned, the primary inquiry in this research concerns the effect of pattern or configuration of stimulus material in a dynamic field on perceptual accuracy.

Dynamic Visual Field Perception

Overview

Much of the research that has been conducted in the area of perception in a dynamic visual field has been directed toward either: 1) determining the deterioration in visual acuity at various angular velocities of the test object, or 2) correlating or differentiating between static and dynamic visual acuity (DVA).

Dynamic visual acuity (DVA) has been defined by Burg and Hulbert (1961) as the ability of an observer to discriminate an object when there is relative movement between the observer and the object.

Angular Velocities Causing Deterioration in DVA

Ludvigh and Miller (1958), using Landolt rings as test objects and a rotating mirror to effect their movement, found that DVA deteriorates significantly as the angular velocity of the test object is increased beyond 40 to 50 degrees per second. The authors show evidence for their hypothesis that the deterioration is caused by the movement of the image on the retina due to imperfect pursuit movements of the eye rather than by extra-foveal location of the image. In another study (Lippert, 1963), the mean angular velocities for the criterion of 100 percent legibility were found to be 10 and 16 degrees per second viewed through two- and twenty-inch apertures, respectively. The stimulus material in this investigation consisted of single-column, alphanumeric symbols and display movement was from top to bottom.

Visual Search Over a Large Area

Decrements in the performance of visual search tasks in which the observer must scan a relatively large area, begin to take place at lower speeds. Williams and Borow (1963), using a continually present display consisting of an 18 X 18-inch array of alphabetic characters, found that angular velocities of over eight degrees per second were associated with decrements in the performance of visual search. Erickson (1964a), from a study using a Landolt ring for a target in a group of solid rings, found that the deterioration in performance over a range of angular velocities was a function of the density of target area. Lippert and Lee (1965), using alphanumeric characters, verified these findings. Erickson hypothesized that peripheral vision plays a more important role than foveal vision in search tasks for field velocities up to five degrees per second; whereas for field velocities greater than seven degrees per second, foveal vision dominates. In another study (1964b), the same author reported a strong correlation between visual search time in a static field and peripheral visual acuity measured at angles up to 4.8 degrees from fixation. At six degrees from fixation, no correlation existed.

Relationship Between Static Visual Acuity and DVA

A review of the literature points out the controversy as to the relationship between static visual acuity and DVA. Ludvigh and Miller, in their study on Landolt rings, found a slight relationship, if any at all, between the two. Weissman and Freeburne (1965), on the other hand, found a strong correlation between static acuity and DVA with field speeds up to 120 degrees per second. Above this speed, no correlation was demonstrated. They also used Landolt rings as test objects. Several possible reasons exist for the differences in findings. First, Ludvigh and Miller used the Snellen chart and ratings for static acuity and also compared static and dynamic acuity monocularly. Weissman and Freeburne used the same test and target presentation for static acuity, or zero degrees per second, as for DVA, and their comparison was binocular. Second, the former study used relatively young naval personnel with a minimum static visual acuity of 20/20 uncorrected. The latter study used a more heterogeneous group of subjects, the majority of which wore corrective lenses.

In still another study (Burg and Hulbert, 1961), a low but significant correlation was found between static acuity and DVA, the correlation diminishing as the speed of the target increased. Again, a heterogeneous group of subjects and the similarity between the static and DVA tests (measured by the Bausch and Lomb Ortho-Rater) were submitted as reasons for the conflicting results from those of Ludvigh and Miller.

Factors Other Than Angular Velocity Affecting DVA

Miller (1958) found that the deterioration in visual acuity is similar whether the test objects are moving horizontally or vertically, or whether the subject is rotated horizontally past stationary test objects. Williams and Borow, on the other hand, found that in a visual search, horizontally moving displays result in less decrement in performance than vertically moving displays. Miller further found that DVA can be substantially improved by high intensities of illumination. This feature does not hold for static acuity, the author points out, since significant improvements cannot be effected by levels of illumination above 5-10 foot candles.

On his experiments on dynamic visual field perception, Green reported results similar to his experiment on perception in a static field. The level of confusability between context and target had a marked effect on the error rate when locating a target letter from among a row of moving capital letters viewed through an aperture. Green also found a similar tunneling effect in the error function across target positions. Orientation of viewing aperture (horizontal or vertical) and direction of movement (top to bottom or bottom to top, in the case of the horizontal viewing aperture; left to right or right to left in the case of the vertical viewing aperture) had little effect on performance.

In other studies in which the stimulus material was viewed through an aperture, Adams reported similar tunneling effects in the error functions. One study utilized vertically-oriented, 3/8-inch brass washers, appropriately notched for context and target. Another used horizontally-oriented capital letters, similar to the study of Green. Adams further found that the error rate increased significantly when the viewing angle was decreased below 45 degrees with the plane of the display. A change in viewing angle above this, had no appreciable effect on performance.

Qualifying Tests for Conveyor-Paced Inspection Tasks

Static and normal dynamic visual acuity (DVA) tests were found by Nelson (1969) to be inadequate for predicting the success of individuals on conveyor-paced inspection tasks. He developed a two-test battery for such purpose. First in the battery was a test of DVA to measure the effect of speed of target movement and target spacing on performance. The second test was a test of recognition visual acuity to measure the effect of the product and the inspection task on performance. Both tests used Landolt rings as stimulus material. The former test is similar to others previously discussed. The latter projected the material statically at various out-of-focus levels. The theory behind the recognition test is that errors in the eye pursuit movements in a dynamic field perception task cause blurring of the image similar to an out-of-focus image.

Summary

In summarizing the literature on perception in a dynamic visual field, one finds very little that has a direct bearing on the investigation covered by this dissertation. As previously stated, this research investigates the effect of stimulus configuration on dynamic field perception. It is a continuation of research by Green and Adams. As in their investigations, perception took place through a viewing aperture. All experiments conducted in this research were at visual field speeds of eight degrees per second or less. Thus, speeds were below the critical angular velocity at which decrements in performance due to imperfect tracking become significant according to the findings of Ludvigh and Miller, Williams and Borow, and Miller. However, the findings of Lippert suggest that, because of the restricted height of the viewing aperture used, the speed providing the criterion of 100% legibility was doubtlessly surpassed from time to time throughout this experimentation.

CHAPTER III

THE EFFECT OF STIMULUS CONFIGURATION ON PERCEPTION -- EXPERIMENT I

General

General agreement has been reached in the field of visual perception that the higher the angular velocity of a visual field, the greater the decrement in search performance, at least above a certain critical speed. Just what this critical speed is depends on the circumstances of the search task involved. For instance, a search task in which the subject is able freely to track the stimulus material (Ludvigh and Miller) would have a higher critical speed than a task having a restricted ability to track the material due, for instance, to the use of a viewing aperture (Lippert).

The experiments composing this research virtually eliminated the ability to track the material since the height of the aperture, in most instances, was only 1/4 inch and in the remaining instance was 3/8 inch. For this reason, the results can, with reservation, be compared to many perception studies in which tachistoscopic projections were used.

Experiment I was a study of the interaction between the width of display and the speed of movement required to provide equivalent exposure time. It further treats exposure time as a variable to determine its effect on the relative advantages of the various configurations in perceptual accuracy.

Method

Stimulus Material

Each display consisted of eight capital letters. The target was the letter K and the context, randomly presented, was made up from the following letters: F, H, L, N, R, V, X, and Y. No letter was presented more than once in any display. As previously mentioned, this target-context relationship is considered one of high confusability (Kaplan et al.). The letters were typed with an IBM electric typewriter on long sheets of white paper, and the letters were an executive type, 1/8 inch in height, single spaced. For each configuration the ratio of displays containing a target to the total number of displays presented was 2/3, so that for every 24 displays, the target was randomly found in each of the eight letter positions twice. The rows of the multi-row configurations were so positioned to provide a blank space of 5/16 inch between rows. The widths of the stimuli for the 1 X 8, 2 X 4, and 4 X 2 configurations were approximately 1 1/8, 9/16, and 9/32 inches, respectively.

Equipment

The sheets of paper containing the stimulus material were taped to a wide continuous belt conveyor. The belt was driven by a variable speed motor and the range of speeds vastly increased by the use of various size gears. The height of the viewing aperture was 1/4 inch throughout the experiment. The aperture width for the 1 X 8 displays was two inches, and this width was so reduced for the other configurations that the blank space on either side of the centrally-positioned display was approximately the same throughout the experiment. Vision shields, painted a low-gloss white, were installed to preclude the subject's being able to see peripherally any belt or display movement and to reduce visual distractions from the assigned task. A tape was drawn across the work station at forehead level to restrict the subject either to a minimum of 15 inches from the aperture or to a maximum angular velocity of eight degrees per second, whichever was the greater distance. The level of eight degrees per second was used as a maximum to be certain that the range of angular velocities was below that level at which a decrement in performance normally appears (Ludvigh and Miller; Williams and Borow). A photograph of the equipment is shown in Figure 2.

Velocities and Exposure Times

In the 1 X 8 configuration, conveyor speeds of 0.45 and 0.60 inches per second were used. The slower speed provided an exposure time of 0.833 seconds, and the faster, an exposure time of 0.625 seconds. Throughout this experiment these exposure times are respectively referred to as long and short exposure times. Exposure time, in this dissertation, is considered to be the time from the start of appearance of the stimulus material in the aperture until its total disappearance from view. It is this definition of exposure time that, for comparative purposes, has been equated in all the configurations. Exposure time of total displays, that is, the time from total appearance until start of disappearance varied between the configurations from 0.246 to 0.278 seconds for the long exposure time and from 0.185 to 0.208 seconds for the short exposure time. Figure 3 shows the three configurations of stimulus material relative to their viewing apertures just prior to

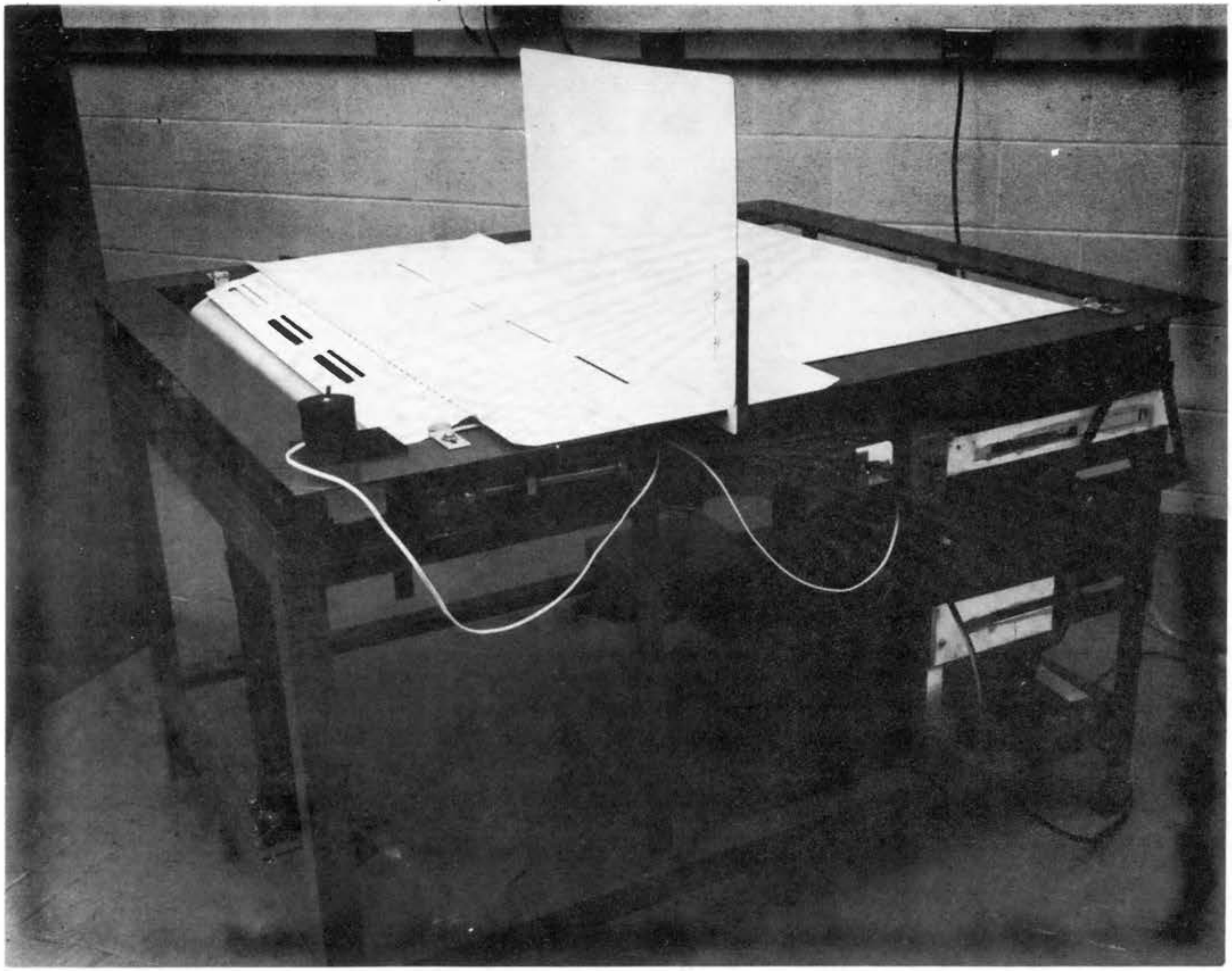
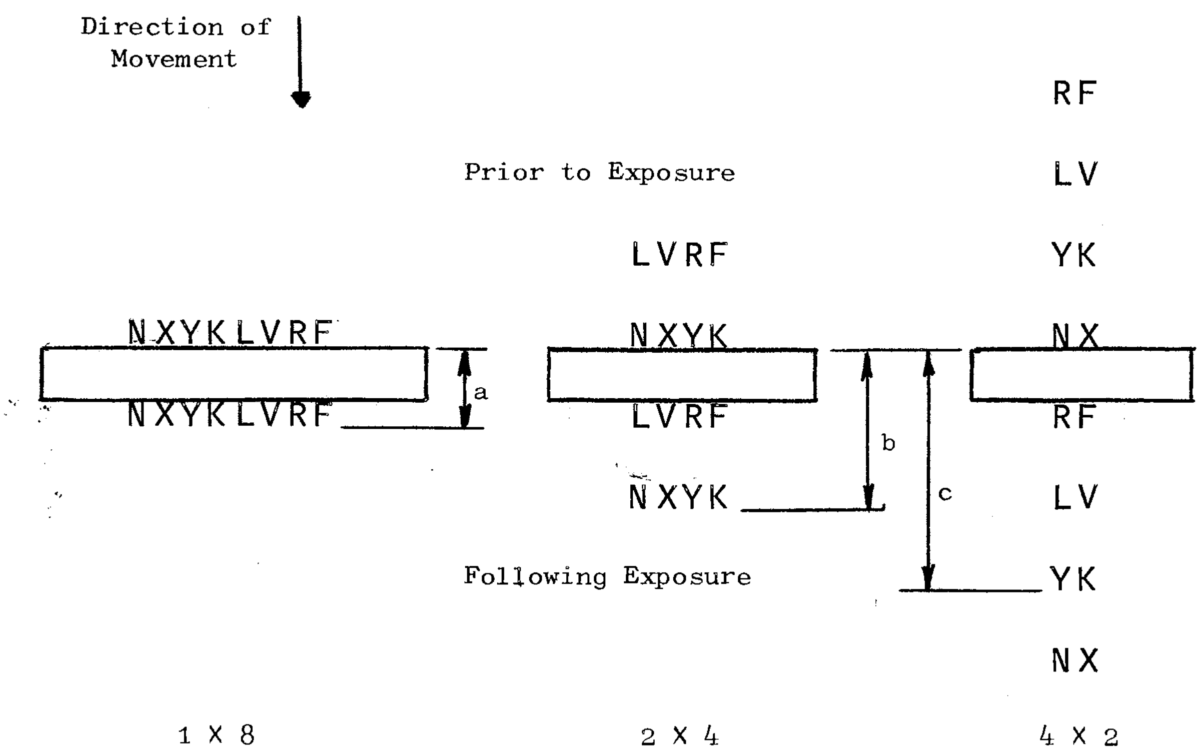


Figure 2. A Photograph of the Experimental Equipment



NOTE: Distances a, b, and c are distances travelled during exposure time.

Figure 3. Each of the Three Configurations Immediately Prior to and Following Exposure

and just following exposure. Table I shows the linear velocities and maximum angular velocities of the displays by configuration under both the long and the short exposure times. Sample computations are included as Appendix A.

TABLE I

LINEAR AND MAXIMUM ANGULAR VELOCITIES BY CONFIGURATION

	Exposure Time	
	Long	Short
Exposure Time in seconds (from start of appearance until final disappearance)	0.833	0.625
Linear Velocity in inches/second:		
Configuration		
1 X 8	0.45	0.60
2 X 4	0.98	1.30
4 X 2	2.03	2.70
Maximum Angular Velocity in degrees/second:		
Configuration		
1 X 8	1.7	2.3
2 X 4	3.7	5.0
4 X 2	7.7	8.0*

*Restriction tape 19 inches from aperture; fifteen inches in all other instances.

Experimental Design

This experiment had two aspects. One was a comparison of the three configurations of stimulus material. The second was the intra-configuration analysis of error pattern. The design for the first aspect was a completely randomized experiment with a split plot. Configuration was the main plot treatment, it being a between-subject variable. Exposure time was the split plot treatment and was within subjects. For the second aspect of the experiment factorial designs were used. The design for the 1 X 8 configuration was a 2 X 8 X 10 factorial. The variables in this instance were exposure time, target position, and subject. Similar designs were used for the other configurations.

Subjects

Thirty volunteer subjects, both male and female, between the ages of 18 and 45 participated in this experiment. All subjects successfully passed a test for normal near vision using Federal Aviation Administration form #2917. Three randomized groups, one for each configuration, were formed such that each group had approximately the same number of females and the same number of subjects over 30 years of age.

Procedure

As each subject arrived to participate in the experiment he was pretested, as explained above, and shown the equipment layout. The experimenter then read to him the appropriate instructions, an example of which is included as Appendix B.

After hearing the instructions and having any questions answered, the subject was comfortably seated at the conveyor and given a trial experimental run. The trial run consisted of 24 displays, presented at both long and short exposure time, in the configuration to which the subject would be exposed during the experiment. The series of trial displays had targets randomly positioned in each of the eight target positions and also contained displays bearing no target, randomly presented. After the presentation of each display, the subject orally responded as to the observed position of target, if any, and the experimenter informed subject if answer was correct. If not, the same display was presented a second time. The experimenter controlled the display presentations. All subjects improved their performances throughout the trial runs, and before the trial was over each subject had displayed a reasonable ability (less than 50% misses under the short exposure time) to perform the task.

After the subject had completed his trial run the test began. A horizontal black line appeared in the viewing aperture as a ready signal one second before the appearance of each stimulus. After disappearance of each stimulus, the experimenter stopped the conveyor allowing the subject ample time to record his response on a tally form. When the subject's attention was redirected to the viewing aperture, the conveyor was restarted for presentation of the next stimulus. The frequency of presentation of the stimuli was approximately four to eight seconds. Sufficient space was provided on the paper between the stimuli to assure that the conveyor had reached operating speed prior to the appearance of the ready line.

For each configuration, 48 letter-group stimuli were presented to each of the ten subjects under each of the two exposure times. Depending on the configuration, the stimuli were listed in from four to eight columns, requiring as many different viewing apertures to be used throughout the test. These columns were randomly assigned to long or short exposure time presentations and these in turn were presented in random order.

Each response was scored as being correct, a miss (Type I error), or a false alarm (Type II error). As defined in Chapter I, a miss occurred when a target was present in a stimulus presentation and the subject either reported no target or reported a target in the wrong position. One exception to this definition occurs in the 1 X 8 configuration. To compare some of the findings of this research with that of another investigation, a more liberal definition of a miss, in which the response was greater than one target position from actual, was also used. As previously defined, a false alarm occurs when the subject reports a target being present and, in fact, no target exists in the stimulus presentation. The experimenter then compiled and analyzed the rates of the Type I and Type II errors.

Transformation of Data

In factorial experiments, transformations of data are frequently performed for any of several reasons. One important reason is the skewness in the distribution of errors of the basic data. This skewness tends to produce too many significant results in F-tests (Snedecor and Cochran, 1967, page 325). Percentage data, such as used in these experiments, are commonly transformed prior to analysis for this reason. The transformation developed for basic observations that are in the form of percentages or proportions is the arcsin square root transformation (Winer, 1962, page 221), written

$$X'_{ijk} = \arcsin \sqrt{X_{ijk}}$$

where X_{ijk} is a proportion. For conservatism, this transformation has been made before analysis on all the data obtained in this research. An example follows:

$$\text{Basic Datum} = 30\%$$

$$X = 0.30$$

$$X' = \arcsin \sqrt{0.30} = 0.58.$$

Results

Missed Target Errors

Interconfiguration Comparison. Figure 4 shows the rates of missed targets by configuration for both long and short exposure times. It may be noted that the 2 X 4 configuration has the lowest error rate regardless of exposure time.

A summary of the analysis of variance (ANOVA) on the transformed data of this completely randomized design with a split plot and the calculated F ratios are given in Table II. As might be expected, the F test revealed that exposure time was a highly significant variable ($p < 0.01$), and the variable configuration was also significant ($p < 0.05$). A Newman-Keuls (N-K) test on the configuration means under each exposure time showed no evidence of any significant difference at the 5% level; however, with exposure times combined, the 1 X 8 and the 2 X 4 mean values were just barely insignificant at the same level.

Repeated Measures Analysis. The possibility existed that a significant change in a subject's performance took place during the course of the test. Such change, known as order or sequence effect, could be due to a number of things, among which are practice and fatigue. If sequence effects were significant, and no accounting made for them,

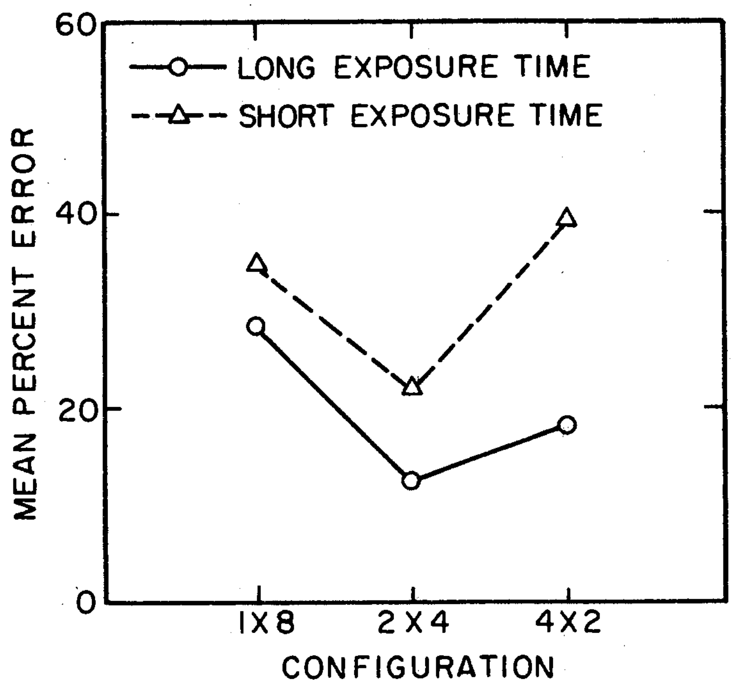


Figure 4. Missed Target Error Rates by Configuration and Exposure Time

TABLE II

ANOVA FOR MISSED TARGET ERRORS--ALL CONFIGURATIONS

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	0.427	0.214	4.16*
Subject w. C	27	1.386	0.051	
Sub Plot				
Exposure Time (E)	1	0.458	0.458	33.90**
C X E	2	0.080	0.040	2.95
Sub-Plot Error	27	0.365	0.014	
TOTAL	59	2.715		

*Significant at 0.05 level.

**Significant at 0.01 level.

they would tend to confound the treatment effects, in this case, configuration and exposure time (Winer, page 301). To determine the significance of sequence effects, a repeated measures analysis was performed on the data. Each subject's test results for each exposure time were divided into trial 1 data and trial 2 data. Trial 1 data were the results of the first 24 stimulus presentations under each exposure time, trial 2 the last 24. Figure 5 shows graphically the results of this analysis. Table III summarizes the analysis of variance (ANOVA).

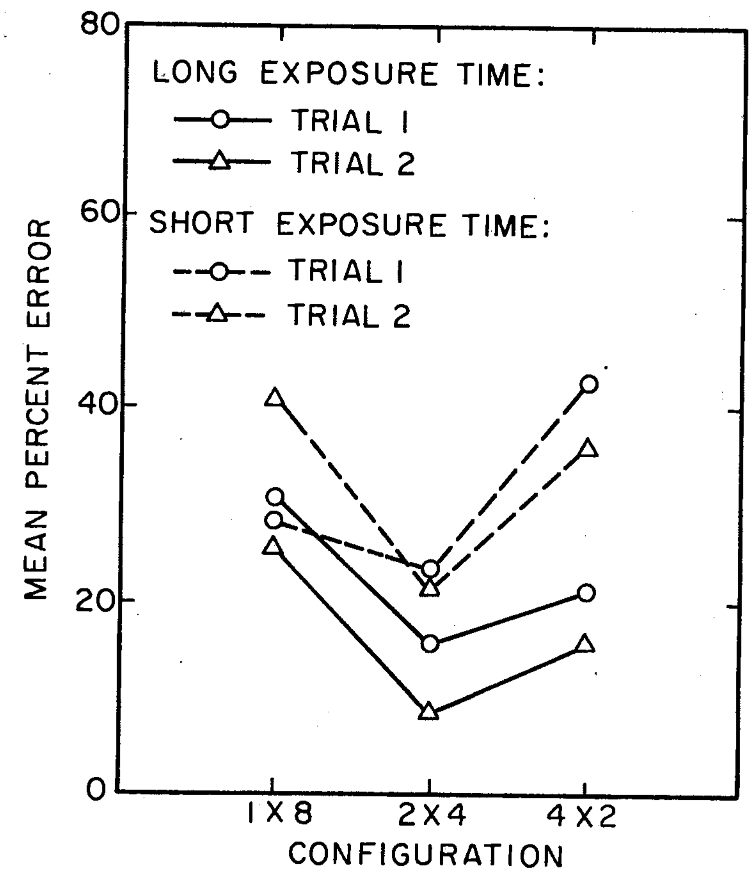


Figure 5. Repeated Measures Analysis of Missed Target Error Rates by Configuration

TABLE III

ANOVA FOR MISSED TARGET ERRORS USING REPEATED MEASURES

Source	d.f.	S.S.	M.S.	F
Between Subjects:				
Configuration (C)	2	1.032	0.516	4.63*
Error	27	3.011	0.112	
Within Subjects:				
Exposure Time (E)	1	1.024	1.024	44.32**
Trial (T)	1	0.048	0.048	2.09
E X T	1	0.138	0.138	5.97*
E X C	2	0.168	0.084	3.64*
T X C	2	0.060	0.030	1.31
E X T X C	2	0.057	0.029	1.24
Error	81	1.872	0.023	
TOTAL	119	7.411		

*Significant at 0.05 level.

**Significant at 0.01 level.

The F test once again showed exposure time and configuration to be significant variables. However, the sequence effect was insignificant. Because of the insignificance of sequence effect in this experiment and for the two reasons listed below, a repeated measures analysis was not made routinely throughout this research. Such an analysis was again made for Experiment 4 and will be appropriately reported on.

1) The order of administration of all the experiments was randomized, thus preventing any sequence effects from being confounded with only one or a select few of the treatment effects.

2) The primary interest of this research is in the effect of the treatments rather than in learning or sequence effects (Winer, page 301).

The F test also shows significant ($p < 0.05$) interactions between trial and exposure time and between configuration and exposure time. These interactions are expressed graphically in Figures 6 and 7. The interaction between configuration and exposure time has practical significance. A much steeper decrement in performance due to the short exposure time is found in the 4 X 2 configuration than in either of the other two configurations. This is undoubtedly due to a parabolic relationship between conveyor speed and error rate. It should be noted, however, that in the original ANOVA (Table II), which involved fewer variables and less degrees of freedom, the configuration-exposure time interaction was statistically insignificant.

The 1 X 8 Configuration. Figures 8 and 9 show the rates of missed target errors by letter position and exposure time under the 1 X 8 configuration. The difference between the two graphs is in the definition of a missed target. In Figure 8, a missed target consisted of a reported target, greater than one letter position from the actual target (Liberal Definition of Miss). This definition of a missed target differs from that used throughout this experimentation, and reported in Chapter I. The graph in Figure 8 is presented here solely as a comparison of the work of Green, who used experimental conditions similar to those used in this phase of the experiment. In Figure 9, as elsewhere throughout this research, a missed target occurred when the actual target position was not the position reported as containing the target (Conservative Definition of Miss).

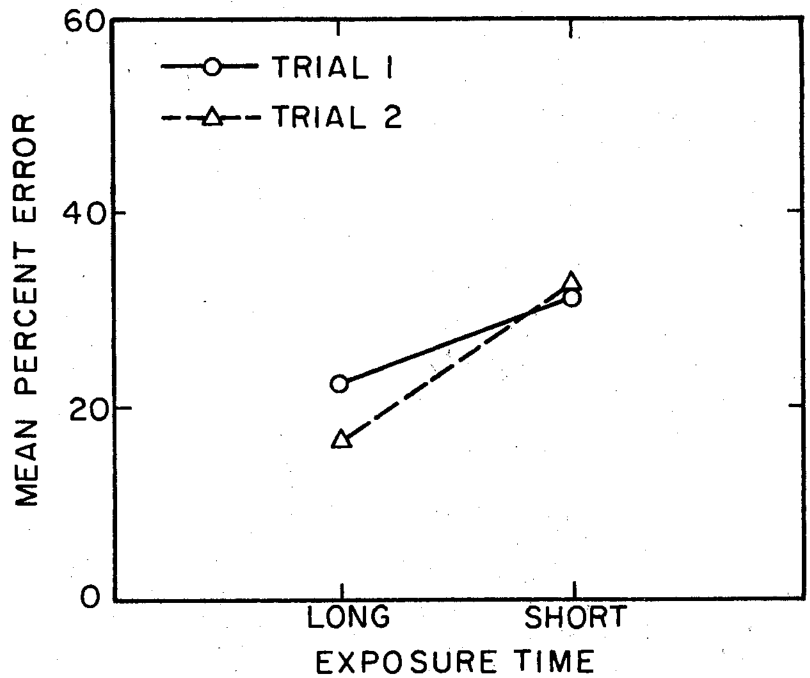


Figure 6. Missed Target Error Rates Showing Trial-Exposure Time Interaction

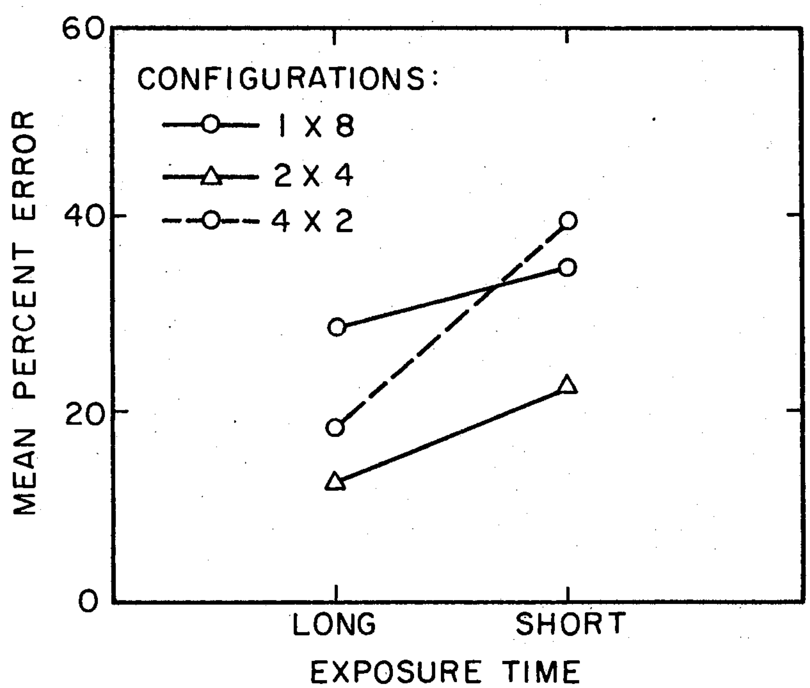


Figure 7. Missed Target Error Rates Showing Configuration-Exposure Time Interaction

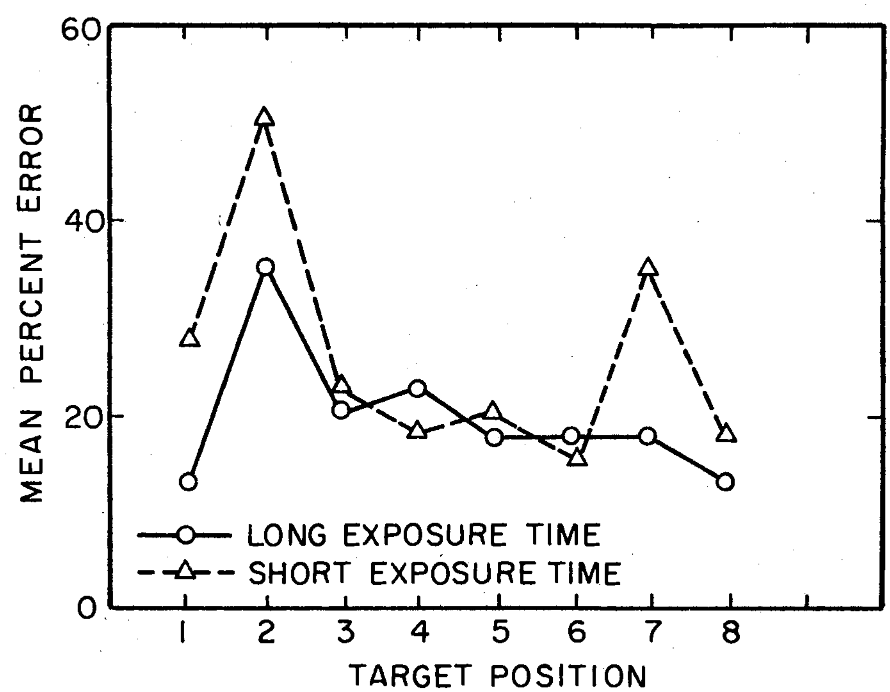


Figure 8. Missed Target Error Rates in 1 X 8 Configuration by Target Position Under Liberal Definition of Miss

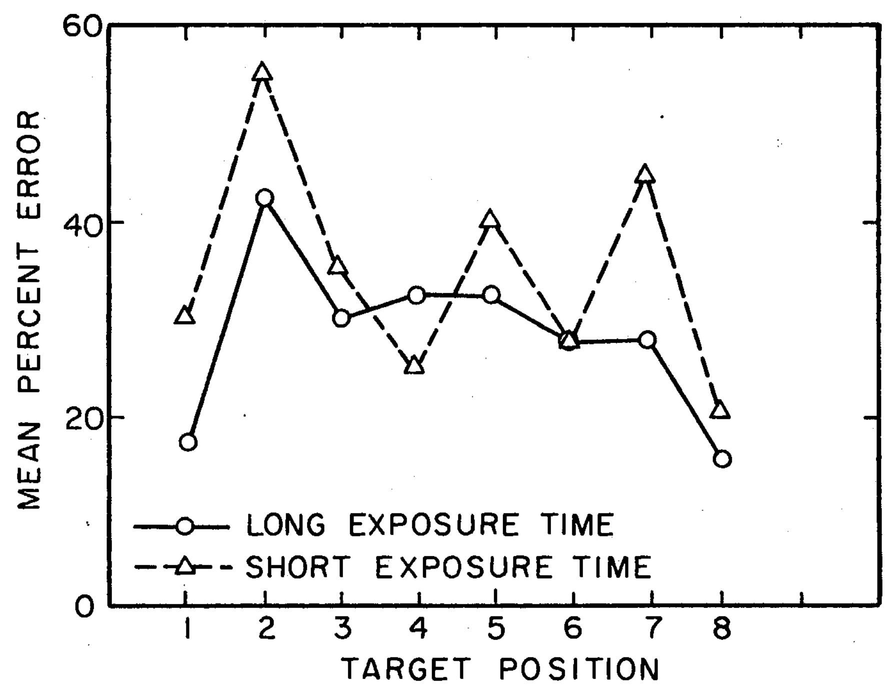


Figure 9. Missed Target Error Rates in 1 X 8 Configuration by Target Position Under Conservative Definition of Miss

Figure 8 shows the error pattern under short exposure time to have the same tunnel effect that Green found. In this case, target position Nos. 3 through 6 had a relatively low error rate, as did the extreme positions, Nos. 1 and 8, while position Nos. 2 and 7 had very high rates. This result is similar to the findings of Averbach and Coriell. As has been mentioned, Green eliminated the extreme positions, Nos. 1 and 8, as target positions because of the reduced masking effect at these positions. The error pattern under the long exposure time has the same general shape, except that position seven did not show an increase in error rate. This would indicate a reduced depth in the tunnel effect, especially on the right-hand side of the stimulus row, as exposure time is increased. This is similar to the effect of a decrease in the confusability level between target and context as found by Green.

In Figure 9, under the more conservative definition of a missed target, the same general error patterns were found that were found under the liberal definition of a missed target. It is of interest to note that under the short exposure time, the error pattern was more random, as evidenced by the fluctuation in rates among the central target positions. This is mainly due to the difficulty in pinpointing the target when it was actually in position 5. The error rate for this position actually doubled from 20% to 40%, in going from the liberal definition of a missed target (Figure 8) to the conservative definition (Figure 9).

Table IV summarizes the ANOVA for this factorial design of the 1 X 8 configuration under the conservative definition of a missed target error. The statistical model used here, and in all intraconfiguration analyses throughout this research, is the fixed model. The decision to

TABLE IV

ANOVA FOR MISSED TARGET ERRORS -- 1 X 8 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Preliminary Test:				
Subject (S)	9	5.414	0.602	
Target Position (P)	7	3.131	0.447	
Exposure Time (E)	1	0.312	0.312	
S X P	63	10.465	0.166	1.77*
S X E	9	0.737	0.082	0.87
P X E	7	0.548	0.078	0.84
S X P X E	63	5.905	0.094	
TOTAL	159	26.512		
Final Test:				
Subject(S)	9	5.414	0.602	6.61**
Target Position (P)	7	3.131	0.447	4.91**
Exposure Time (E)	1	0.312	0.312	3.43
S X P	63	10.465	0.166	1.83**
Residual	79	7.190	0.091	
TOTAL	159	26.512		

*Significant at 0.05 level.

**Significant at 0.01 level.

treat the variable subject as a fixed variable was prompted by the assumption that each subject has his own set of abilities. Thus, in the F test all main effects are tested against the experimental error and any conclusion reached about one effect is uncontaminated by any other effect (Ostle, 1963, pages 324-327). It can be seen from Table IV that the ANOVA is divided into a preliminary test and a final test. The latter is the result of pooling all insignificant interactions into the residual or experimental error. This pooling technique (Winer, pages 202-207) has been used in all factorial designs throughout this analysis. Hereafter, only the final test of each ANOVA of the factorial designs will be shown.

The F test showed that subject and target position were the main effects having significant differences and the subject-target position interaction was the sole significant first order interaction, all at the 0.01 level. Subject as a variable was found statistically significant, not only in this test, but in all tests throughout this research. So were many of the first-order interactions involving subject, just as the subject-target position interaction was found to be significant in this case. Such significance clearly shows that the lack of homogeneity in the cognitive processes of subjects is a problem to be reckoned with. An N-K test on individual means, showed that a significant difference existed only between the means of target positions 2 and 8, and this at the 0.05 level when both long and short exposure times were combined.

Several points need to be made to explain, at least partially, the seeming inconsistency between the results of the F test and the Newman-Keuls test. First, the N-K test is a moderately conservative procedure. Had a less conservative procedure been used, e.g., Duncan's test or

Least Significant Difference (LSD), more significance in the individual means would, undoubtedly, have been indicated. Secondly, the N-K test makes use of the studentized range statistic and thus utilizes much less of the experimental data than does the F test. When the distribution of the data does not approach normality, which is the situation here, the two tests may not lead to the same conclusion (Winer, pages 77-78).

The ANOVA for the data under the liberal definition of a missed target position has not been summarized in this paper. However, it is of interest to know that the F test on that data revealed the same significance of main effects and interactions as that under the conservative definition of a missed target position, reported above.

<u>The 2 X 4 Configuration.</u> Figure 10 shows the rates of missed target errors by letter position and exposure time for the 2 X 4 configuration. It can be noted that no significant error pattern revealed itself across the target positions of the top row. Also, exposure time appears to have had little effect on performance in that row. However, in the bottom row, exposure time appears highly significant and a pattern of decreased performance as target position moves from left to right seems to emerge.

A summary of the ANOVA for the missed positions under this configuration is shown in Table V. The F test revealed exposure time as well as subject to be significant at the 0.01 level, the former by virtue of the bottom row, to be sure, and group (in this case bottom and top rows) to be significant at the 0.05 level, by virtue of the short exposure time. All first order interactions involving subject were significant, thus showing even less homogeneity in the cognitive processes in this test than in the others. The statistical significance

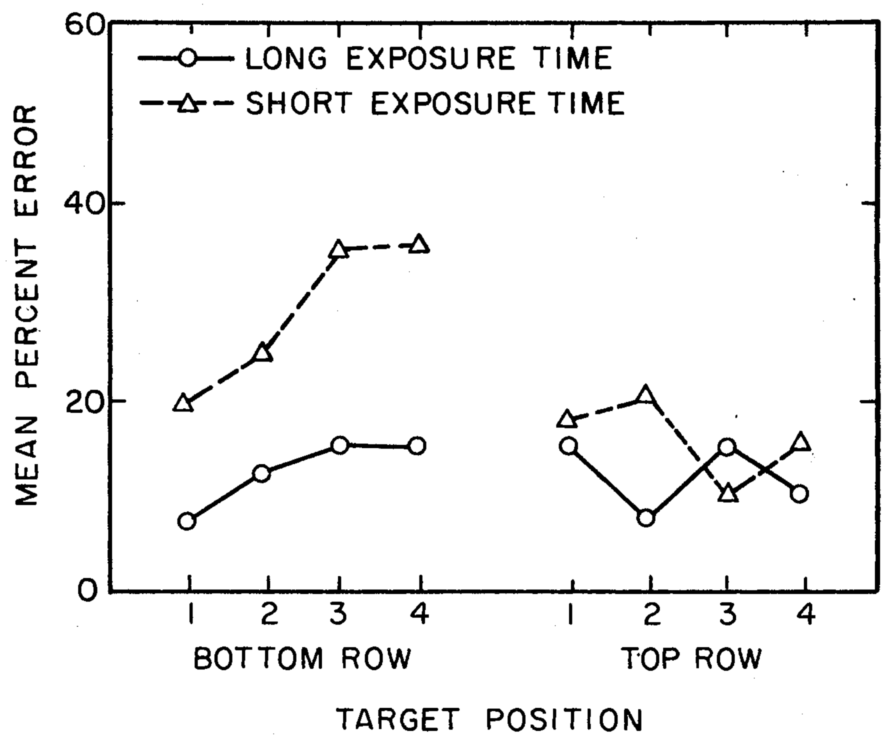


Figure 10. Missed Target Error Rates in 2 X 4 Configuration by Target Position

TABLE V

ANOVA FOR MISSED TARGET ERRORS -- 2 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	4.567	0.507	10.80**
Group (G)***	1	0.312	0.312	6.64*
Target Position (P)	3	0.039	0.013	0.28
Exposure Time (E)	1	1.296	1.296	27.57**
S X G	9	0.951	0.106	2.25*
S X P	27	4.095	0.152	3.22**
S X E	9	1.527	0.170	3.61**
G X E	1	0.312	0.312	6.65*
S X P X E	27	3.098	0.115	2.44**
Residual	72	3.384	0.047	
TOTAL	159	19.581		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Bottom row and top row.

of the subject-exposure time interaction ($p < 0.01$) was purely coincidental inasmuch as two of the ten subjects performed better under the short exposure time. The interaction has no practical significance. The group-exposure time interaction has both statistical ($p < 0.05$) and practical significance. The decrement in performance due to the shorter exposure time was limited to the bottom row (see Figure 10). This would indicate that recency, used here as the ability to recall the most recent stimulus more accurately than other stimuli, plays a more important role at the shorter than at the longer exposure time. No further practical significance exists for the statistically significant interactions.

The 4 X 2 Configuration. Figure 11 shows the rates of missed target errors by letter position and exposure time for the 4 X 2 configuration. A distinct bow-shaped error pattern was present in both the left- and right-hand columns. The F test showed that all four main effects, namely subject, group (in this case left- and right-hand columns), target position, and exposure time, were significant at the 0.01 level. See Table VI for a summary of the ANOVA. The significant differences in target position and exposure time are readily seen by a glance at Figure 11. The significance of the variable group is not as obvious. The mean error rates by group better revealed this significance: mean error rate of left-hand column was 33.1%, of right-hand column was 24.1%. Subject-target position, subject-exposure time, and group-exposure time were the only significant interactions, the first being at the 0.01 level. The statistical significance of the latter interaction is due to the substantial increase in error rate of the short over the long exposure time in the left-hand column while only a

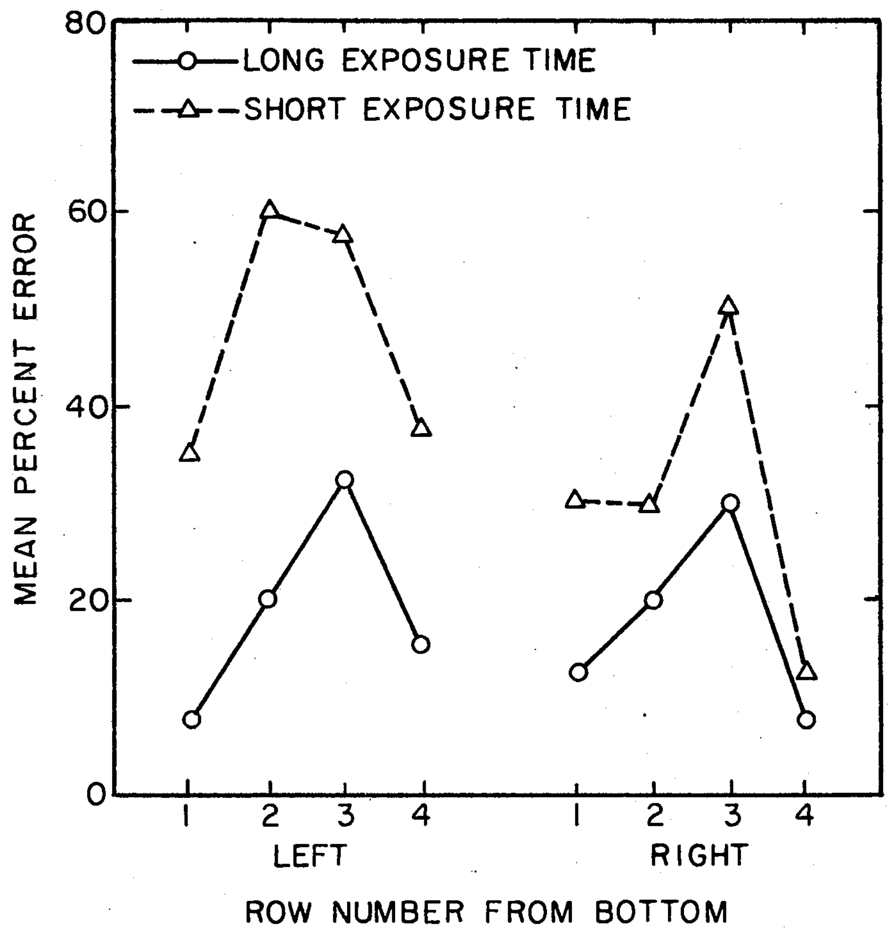


Figure 11. Missed Target Error Rates in 4 X 2 Configuration by Target Position

nominal increase in the right-hand column. The practical significance of this finding is not apparent.

TABLE VI

ANOVA FOR MISSED TARGET ERRORS -- 4 X 2 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	4.206	0.467	4.15**
Group (G)***	1	0.867	0.867	7.70**
Target Position (P)	3	3.475	1.158	10.29**
Exposure Time (E)	1	3.392	3.392	30.14**
S X P	27	6.103	0.226	2.01**
S X E	9	2.342	0.260	2.31*
G X E	1	0.651	0.651	5.79*
Residual	108	12.156	0.113	
TOTAL	159	33.191		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Left column and right column.

An N-K test showed that on the right-hand side the mean error rate of target position No. 3 was significantly greater (0.05 level) than that of position No. 4 when both exposure times were combined. No other means were significantly different. Another N-K test revealed that position No. 3 was significantly greater than both position Nos. 1 and 4 and position No. 2 was significantly greater than position No. 4 when both groups and exposure times were combined.

False Alarm Errors

Interconfiguration Comparison. Figure 12 shows the rate of false alarm errors by configuration for both long and short exposure times. Note that the mean rates range from 12 to 30 percent. Compared to other research in similar areas these rates may seem excessive; therefore, a word of explanation is deemed appropriate. First, the level of confusability between target and context was, by design, high, and the exposure times or display speeds so established that error rates would be plentiful. Both these factors would tend to cause relatively high rates of false alarms. Secondly, the context letters were mistaken for the target in varying degrees. For instance, in the 1 X 8 configuration the letters X and V were mistaken for the target much more often than the other context letters; in the 4 X 2 configuration it was the letters X and F that were mistaken much more often. (Results of this analysis are presented later in this chapter.) This variability in the confusion level between the target and the various context letters precludes a high level of random guessing.

A summary of the ANOVA is given in Table VII. The F test on this completely randomized design with a split plot showed that exposure time was the only variable exhibiting a significant difference ($p < 0.05$). The calculated F ratio for configurations was < 1.0, compared to a tabulated $F_{0.05}$ of 3.35. Because of this disparity in F values, the hypothesis that there is no difference in the mean false alarm rates between configurations cannot be rejected.

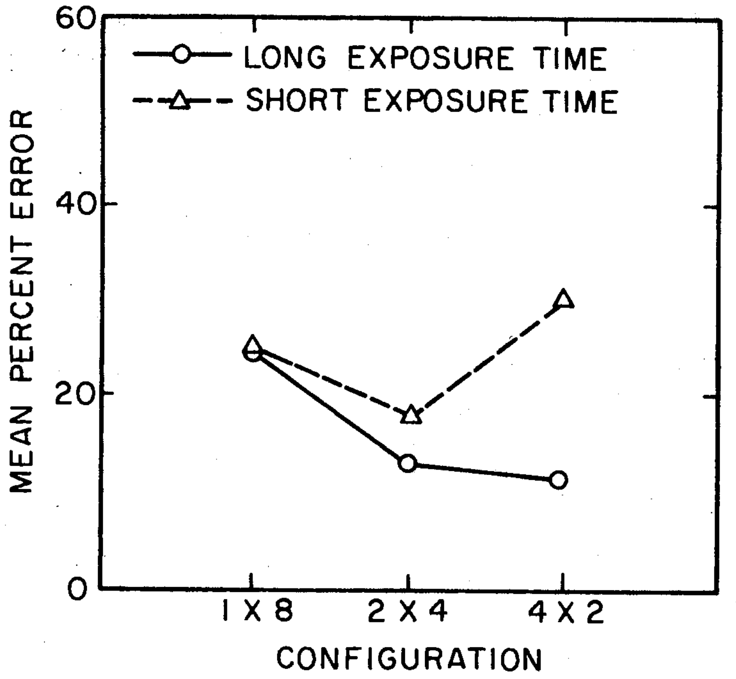


Figure 12. False Alarm Error Rates by Configuration and Exposure Time

TABLE VII

ANOVA FOR FALSE ALARM ERRORS -- ALL CONFIGURATIONS

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	0.168	0.084	0.67
Subject w. C	27	3.455	0.128	
Sub Plot				
Exposure time (E)	1	0.179	0.179	7.01*
C X E	2	0.162	0.081	3.18
Sub-Plot Error	27	0.689	0.026	
TOTAL	59	4.652		

*Significant at 0.05 level.

Intraconfiguration Analyses. Figures 13, 14, and 15 show the rates of false alarm errors by reported target position and exposure time for the 1 X 8, 2 X 4, and 4 X 2 configurations, respectively. The reader must realize that the mean percent error rate for a reported target position is the number of false reports at a given position divided by the total number of displays containing no target (X 100). Thus, it can be seen that, for a given configuration, the summation of the eight error rates by reported position equals the mean false alarm error rate for that configuration. For example, the sum of the error rates under long exposure time in Figure 13 equals the error rate reported in Figure 12 under the same exposure time for the 1 X 8 configuration.

The 1 X 8 Configuration. The graph of the 1 X 8 configuration (Figure 13) reveals no recognizable error pattern, except for the extreme left hand position (No. 1) having the lowest rate. The F test on this data (ANOVA not shown) showed that the variable subject was the only significant main effect ($p < 0.01$) and that the subject-reported target position ($p < 0.05$) was the only significant interaction.

The 2 X 4 Configuration. The graph of the 2 X 4 configuration (Figure 14) shows for each of the two rows a bow-shaped error pattern that was not revealed in the comparable graph of missed target error rates (Figure 10). A summary of the ANOVA is presented in Table VIII. Note that none of the interactions were significant, and all became a part of the residual under the statistical technique of pooling. Subject and reported target position were significant at the 0.01 level and group (in this case, bottom row and top row) was significant at the 0.05 level.

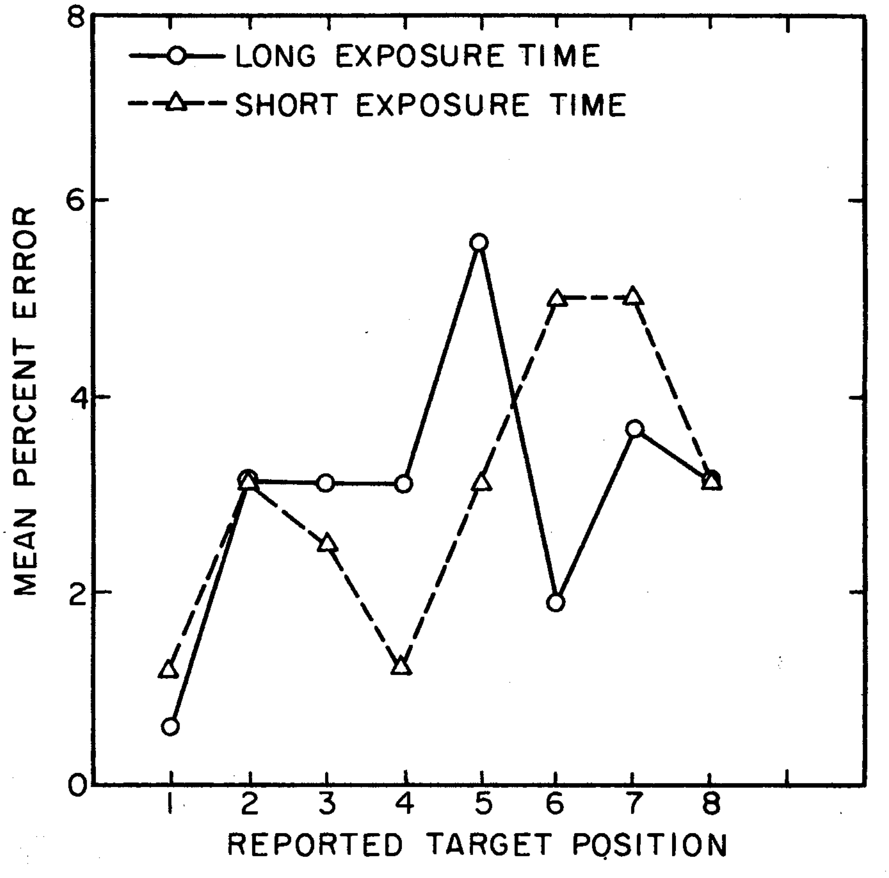


Figure 13. False Alarm Error Rates in 1 X 8 Configuration by Reported Target Position

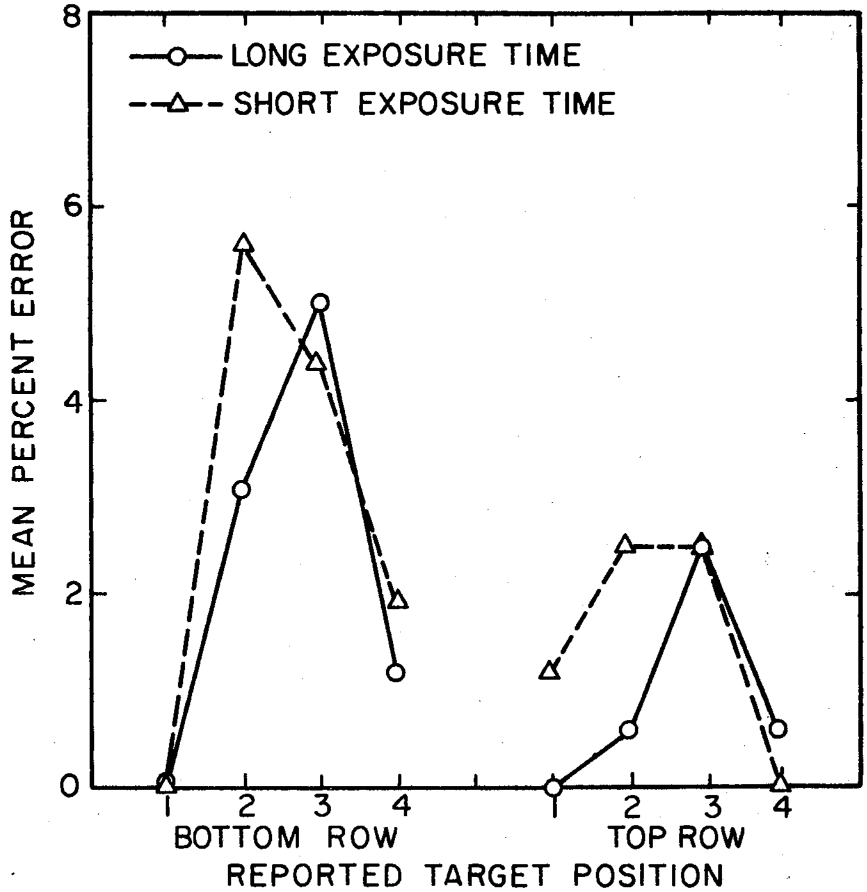


Figure 14. False Alarm Error Rates in 2 X 4 Configuration by Reported Target Position

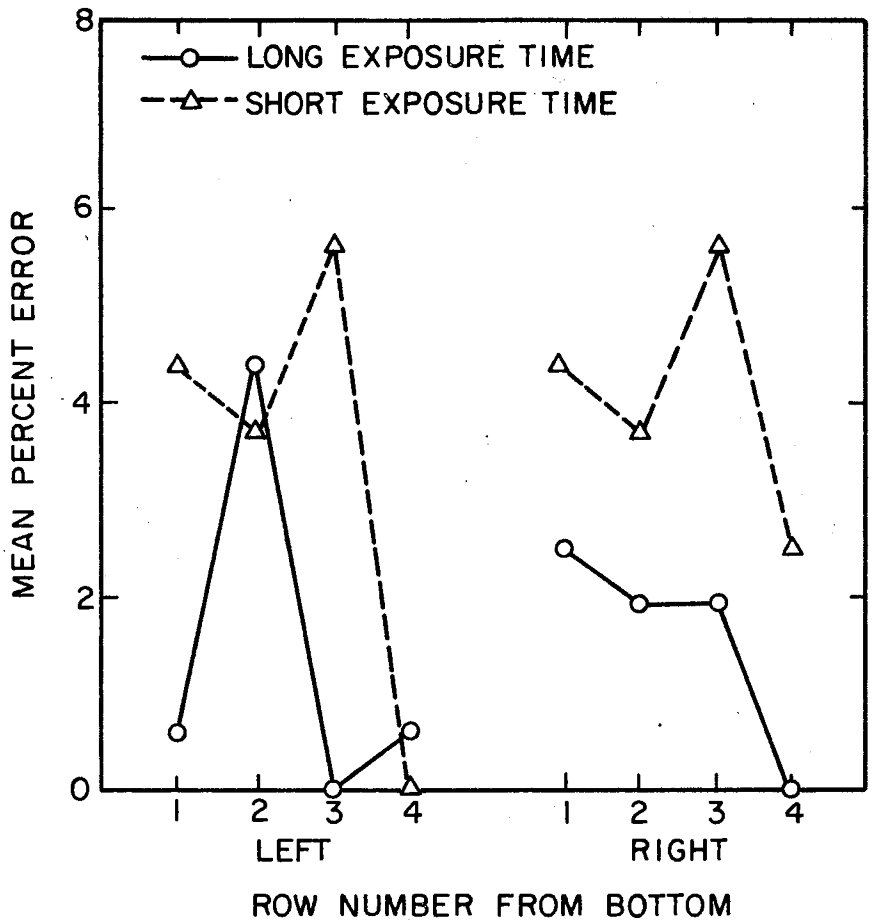


Figure 15. False Alarm Error Rates in 4 X 2 Configuration by Reported Target Position

TABLE VIII

ANOVA FOR FALSE ALARM ERRORS -- 2 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	0.616	0.068	6.08**
Group (G)***	1	0.066	0.066	5.86*
Reported Target Position (P)	3	0.295	0.098	8.75**
Exposure Time (E)	1	0.012	0.012	1.10
Residual	145	1.631	0.011	
TOTAL	159	2.620		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Bottom row and top row.

The 4 X 2 Configuration. No pronounced error pattern emerged in the 4 X 2 configuration (Figure 15). Reported target position No. 3 (in this case row three) had a high error rate under the short exposure time, and position No. 4 (row four) had a correspondingly low error rate at both exposure times. The F test (ANOVA not shown) indicated that subject, reported target position, and exposure time were all significant ($p < 0.01$), as was the subject-reported target position interaction ($p < 0.05$).

Analysis of Errors by Context Unit. Of equal importance to the reported target positions in the false alarm error analysis and to any error pattern that may have emerged are the error rates that were caused by the various context units (in this case, letters). Figure 16 contains

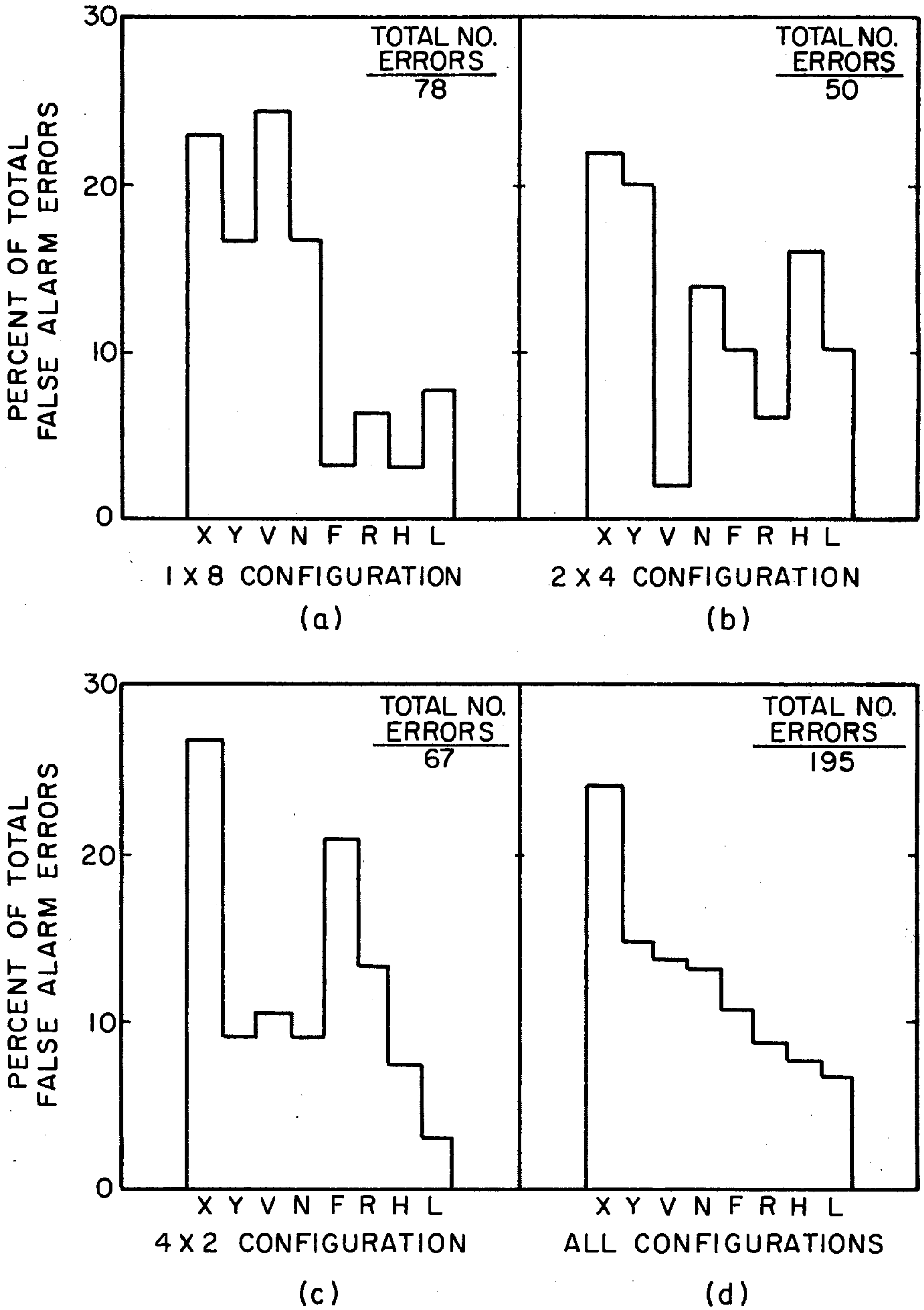


Figure 16. Percentage of False Alarm Errors by Mistaken Context Letter by Configuration

bar charts showing by configuration the rates at which the various context letters were mistaken for the target. As can be seen, the context letters are presented in a descending order of confusability in all configurations combined, namely X, Y, V, N, F, R H, and L. It is reasonable to believe, however, that in some of the instances of false alarms, the subject actually reported the wrong position for the context letter that he had mistaken for the target. If, for example, he had mistaken for the target the letter X, which actually was in position No. 5, but he reported it in position No. 4, some other context letter would have appeared as the mistaken letter. Thus, caution must be exercised in utilizing the data found in these charts.

Chi-square tests were performed on the number of errors by configuration (and in all configurations combined) to test the hypothesis that all letters were equally likely to be mistaken for the target. Results show that in the 1 X 8 and 4 X 2 configurations and in all configurations combined this hypothesis can readily be rejected. In the 2 X 4 configuration, however, insufficient evidence (at the 0.05 level) exists for rejection. Table IX summarizes the results of these tests.

TABLE IX

RESULTS OF CHI-SQUARE TESTS ON CONTEXT LETTERS MISTAKEN FOR TARGET

	Configuration			
	1 X 8	2 X 4	4 X 2	All
Total No. Errors	78	50	67	195
Chi-Squared	34	13	23	34
Probability of Greater No.	< 0.005	0.05-0.10	< 0.005	< 0.005

Discussion

The Primary Purpose

The primary purpose of this experiment was to determine the effect of display configuration on visual performance. Analysis showed that configuration was a significant variable in the rate of missed target errors and that the 2 X 4 configuration resulted in the lowest level of Type I errors of the three configurations studied.

Several possible explanations for these results exist and are herein developed. Each of the subjects confronted with the 1 X 8 displays was asked following his test to verbally state the viewing technique that he had used. The majority of subjects (six) claimed they either scanned the display, usually from left to right, or had two fixation points within the display. Two subjects stated that they focused centrally (only one fixation point). The remaining two subjects scanned the display on the long exposure time presentations, but having insufficient time to scan on the short exposure time presentations, they focused centrally. No significant differences in performance between the groups were apparent. All subjects confronted with the 2 X 4 and 4 X 2 configurations focused centrally.

The technique of scanning the 1 X 8 display produced a higher error rate than was produced with the 2 X 4 configuration probably because of the inability to perceive detail during saccadic eye movement (Adler, 1950), which utilizes a significant amount of the available exposure time. Because the technique of focusing centrally on the 1 X 8 display was also less effective than in the 2 X 4 configuration, it can be concluded that the peripheral viewing of the extremities of the 1 X 8 string was more detrimental to performance than the faster display speeds of the 2 X 4 configuration. One must bear in mind, however, that with central fixation on the 1 X 8 display, all letters in the string could be perceived foveally, the string subtending a visual angle of less than four degrees.

Why then would performance on the 2 X 4 configuration be better than on the 4 X 2 configuration? One answer to this question lies in the fact that in the 4 X 2 configuration the point of diminishing returns had been exceeded; that is, the visual field had reached speeds at which decrements in performance more than offset any advantage of the narrower display width. Another is that in the 4 X 2 configuration, the display is so narrow that much of the foveal visual field is not utilized in the search task. The foveal visual field is utilized much less efficiently than in the 2 X 4 configuration and at the expense of higher display speeds.

Hence, the optimum trade-off between width of stimulus material and speed of the visual field appears to be that combination of width and speed that barely provides the subject with effective perception without the need for saccadic eye movement. A wider but slower display either would require the less effective saccadic eye movement or would cause decrements in performance due to the increased distance of the display extremities from fixation. A narrower but faster display would actually waste some perceptual ability at the expense of a higher speed of the visual field.

These findings support, but do not prove, the first hypothesis, which states that in a display width-display speed trade-off, error rates are lowest on the widest display, and thus the slowest moving, that does not require saccadic eye movement.

Besides having the lowest level of Type I errors, the 2 X 4 configuration also had the lowest average level of Type II errors (Figure 12). Additional support for the above hypothesis is not strong, however, due to the lack of statistical significance of the variable configuration in the analysis of false alarm error rates.

As one would expect, a decrease in the display exposure time is associated with an increase in both the missed target and the false alarm error rates. Although statistical significance is lacking, analysis shows that the increase in error rates (both Types I and II) associated with a decrease in exposure time is greater under the 4 X 2 configuration than under the other two configurations analyzed. Evidence of this is shown in Figures 4 and 12.

The Secondary Purpose

The secondary purpose of this experiment was to analyze error patterns by target position within each configuration. Results of the 1 X 8 configuration under the short exposure time revealed the typical μ shape error pattern of missed target errors (Averbach and Coriell, Crovitz and Schiffman). The error rates of position Nos. 2 and 7 were high, position Nos. 3 through 6 moderately low, and position Nos. 1 and 8 very low. Under the long exposure time, the error rate of position No. 7 dropped to the approximate level of the middle group of positions (Figure 9). It seems reasonable to conclude, therefore, that the shorter the exposure time the deeper the tunnel effect, and as exposure time is increased, the tunnel effect drops off more rapidly on the right-hand side. Analysis of the false alarm error pattern in the 1 X 8 configuration (Figure 13) indicated no particular correlation between error rate and target position except that the left-most position (No. 1) was extremely low.

No tunnel effect emerged in the Type I error rates in either row of the 2 X 4 configuration (Figure 10). The bottom row exhibited a rising error pattern reading from left to right; the pattern of the top row was random. The shorter exposure time adversely affected performance of the bottom row only. Analysis of Type II error pattern (Figure 14) showed that a masking effect was dominant in each row as the extreme positions (Nos. 1 and 4) had much lower rates than the internal positions (Nos. 2 and 3).

In the 4 X 2 configuration, the Type I error pattern showed that the rates were significantly lower in the bottom and top rows (Figure 11). This would indicate that the masking effect of adjacent context material is strong in the direction of visual field movement at the relatively high rates of speed that were found in this part of the experiment. The Type II error pattern was quite random except that the top row had very low rates under both exposure times (Figure 15).

Summary

In summary, this experiment supports the contention that in a task of searching a given amount of stimulus material through an aperture, perception is more accurate at the slowest display speed, and thus at the greatest display width, that requires no saccadic eye movement. The experiment also shows that some of the error patterns within the various configurations are random and do not have distinct designs. The missed target error pattern of the 1×8 configuration shows a combination of the tunnel effect and the masking effect as had been found by other experimenters. The tunnel effect diminishes as exposure time increases. In the 4×2 configuration, the missed target error pattern also shows a masking effect; however, instead of being within a horizontal string, the masking effect in this case is within each vertical column.

CHAPTER IV

THE EFFECT OF STIMULUS CONFIGURATION ON PERCEPTION -- EXPERIMENT II

General

Several questions arose on the subject of the trade-off between display width and display speed that could not be answered by analysis of the results of Experiment I. Seeking answers to these questions led to the development of the present experiment. Would the same general results of Experiment I be obtained if:

a) the display were composed of other than eight stimulus units?

b) the widths of the displays were greater than those of Experiment I?

c) the physical relationship of the target and context were vastly different than that found in Experiment I?

As was Experiment I, this experiment was a study of the interaction between the width of display and the speed of movement required to provide equal exposure time. Each display consisted of only six stimulus units and the display width for the one-row configuration was 2.0 inches, as compared to 1 1/8 inches for the comparable display in Experiment I. Moreover, the target was treated as a variable in this experiment to test the hypothesis that each had its own confusability level in each of the various configurations.

Method

Stimulus Material

Each display consisted of six dials, with dial settings in increments of 45°, randomly presented. Dial diameter was 0.22 inches with a horizontal distance of 1/8 inch between dials. Three different targets were used; namely, , , and , and these shall be referred to as the six-o'clock, three-o'clock, and ten-thirty targets, respectively. No dial setting was presented more than once in any display. For each configuration the ratio of displays containing a target to the total number of displays presented was 3/4, so that for every 24 displays, the target was randomly found in each of the six dial positions three times. As in Experiment I, a blank space of 5/16 inch was provided between rows of the multi-row configurations. The widths of the stimuli for the 1 X 6, 2 X 3, and 3 X 2 configurations were approximately 2, 1, and 5/8 inches, respectively.

Equipment

The same equipment was used for this experiment that was used for Experiment I with but one slight modification. The widths of the viewing aperture were wider in this experiment due to the added widths of the display. The aperture width for the 1 X 6 configuration was 2 1/2 inches, and the width was so reduced for the other configurations that the blank space on either side of the centrally positioned display was approximately the same throughout the experiment. Actually, there was approximately 3/16 inch less blank space on each side of the display in this experiment than that of Experiment I. The height of the viewing aperture remained at 1/4 inch.

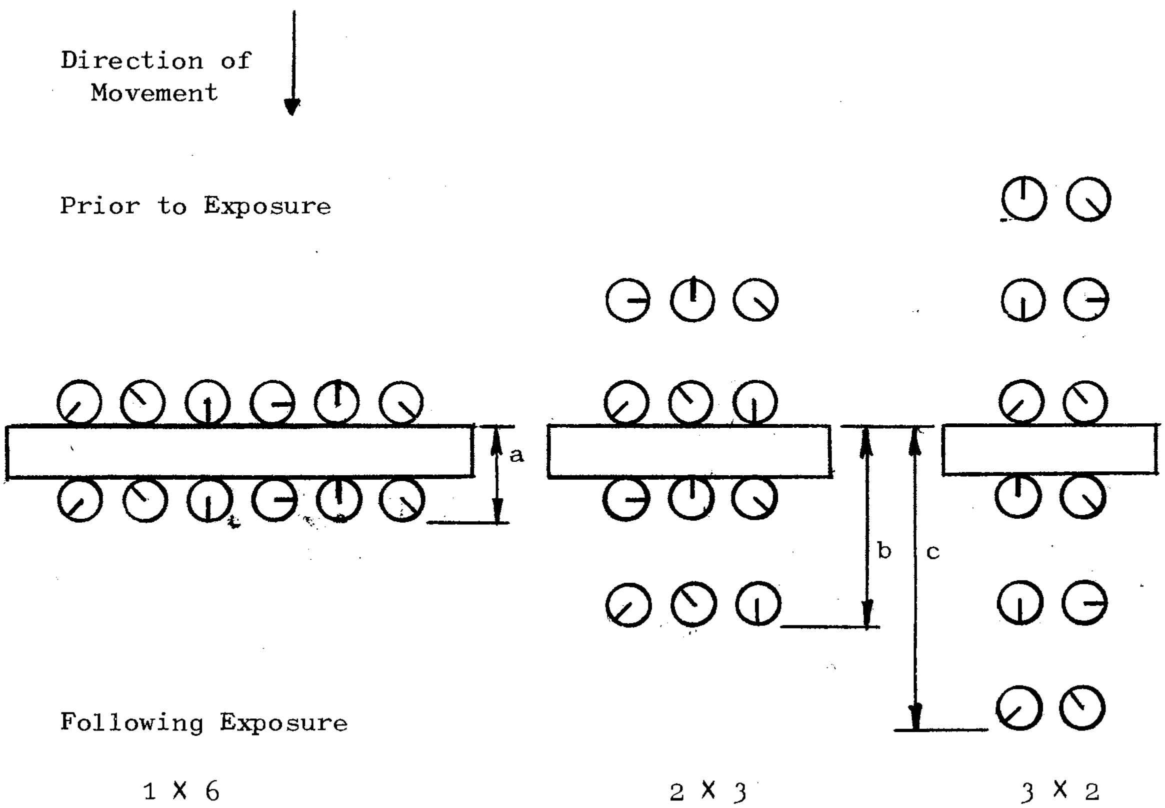
Velocities and Exposure Time

A conveyor speed of 0.60 inches per second was used for the 1 X 6 configuration. This provided an exposure time, defined as the time from start of appearance of stimulus material until its total disappearance, of 0.782 seconds. Figure 17 shows the three configurations of stimulus material relative to their apertures just prior to and just following exposure. Table X shows the linear velocities and maximum angular velocities of the displays by configuration. As in Experiment I, the angular velocities shown are maximum velocities due to the restriction that prevented the subject from getting closer than 15 inches from the display.

TABLE X

LINEAR AND MAXIMUM ANGULAR VELOCITIES BY CONFIGURATION

Exposure Time in Seconds	0.782
Linear Velocity in inches/second:	
Configuration	
1 X 6	0.60
2 X 3	1.28
3 X 2	1.96
Maximum Angular Velocity in degrees/second:	
Configuration	
1 X 6	2.3
2 X 3	4.9
3 X 2	7.5



NOTE: Distances a, b, and c are distances travelled during exposure time.

Figure 17. Each of the Three Configurations Immediately Prior to and Following Exposure

Experimental Design

As in the previous experiment, the first aspect of Experiment II, a comparison of visual performance by configuration, was a completely randomized experiment with a split plot. The main plot treatment was configuration, a between-subject variable. The split plot treatment was the within-subject variable target. The second aspect of the experiment was again the intraconfiguration analysis of error pattern. The design for the 1 X 8 configuration was a 3 X 6 X 10 factorial, in which the variables were target, target position, and subject. For the other configurations, similar factorial designs were used.

Subjects

The same 30 volunteer subjects that participated in Experiment I also participated in this experiment. Both experiments were run intermittently on a randomized basis. Explanations of the pretest given and subject grouping arrangement have already been given.

Procedure

The trial run for this experiment consisted of 16 displays, presented once for each of the three targets in the appropriate configuration. Again, each subject showed a reasonable ability to perform the task before the test began. As in Experiment I, a ready signal appeared in the aperture prior to appearance of each stimulus, and following its disappearance the experimenter stopped the conveyor to allow the subject time to record his response. For each configuration, 48 dial-group stimuli were presented to each of the ten subjects for each of the three targets. The sequence of target presentations was randomized. More detail of the procedure can be found under the appropriate sub-heading of Experiment I. The data compiled and analyzed were missed target (Type I) error rates and false alarm (Type II) error rates.

Results

Missed Target Errors

Interconfiguration Comparison. Figure 18 shows the Type I error rates by configuration for each of the three targets used. A summary of the analysis of variance (ANOVA) on the transformed data (arcsin square root transformation used, as explained earlier) is given in Table XI. The F test revealed that target was a highly significant variable ($p < 0.01$) and configuration-target was a significant interaction ($p < 0.05$). Note that although the 2 X 3 configuration has an error rate as low as or lower than the other configurations with any of the targets used, the variable configuration was not statistically significant.

The 1 X 6 Configuration. The Type I error rates by target and target position for the 1 X 6 configuration are shown in Figure 19. The same tunnel effect is found in the error pattern that Green and Adams found with their stimulus strings. The pattern is also similar to that of Experiment I except that in the extreme target positions (in this case, Nos. 1 and 6) the error rates were generally high rather than low. Only with the three-o'clock target at position No. 6 was there a decline in error rate. Apparently the reduction in masking

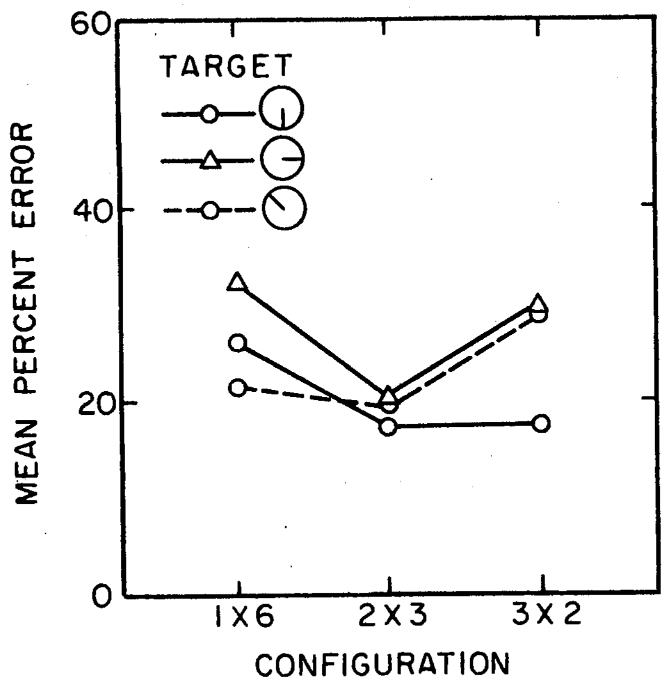


Figure 18. Missed Target Error Rates by Configuration and Target

TABLE XI

ANOVA FOR MISSED TARGET ERRORS -- ALL CONFIGURATIONS

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	0.096	0.048	0.69
Subject w. C	27	1.875	0.069	
Sub Plot				
Target (T)	2	0.110	0.055	5.19**
C X T	4	0.123	0.031	2.90*
Sub-Plot Error	54	0.574	0.011	
TOTAL	89	2.778		

*Significant at 0.05 level.

**Significant at 0.01 level.

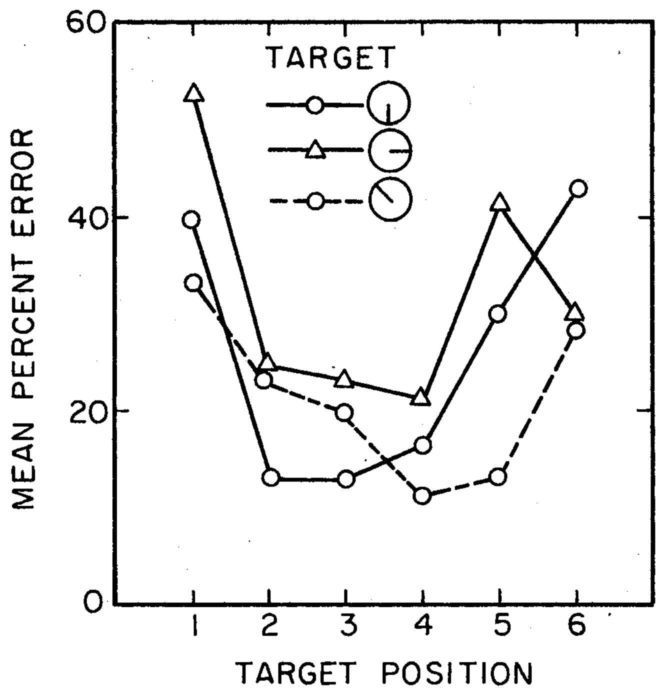


Figure 19. Missed Target Error Rates in 1 X 6 Configuration by Target Position

of the target by the context at the extreme target positions, which was evident in a string of letters, was not a factor with this display.

Table XII summarizes the ANOVA for the factorial design of the 1 X 6 configuration. The F test showed that subject and target position were the significant main effects and that subject-target position was the only significant interaction, all at the 0.01 level. A Newman-Keuls (N-K) test on the individual means showed that target position No. 1 was significantly greater at the 0.05 level than position Nos. 2, 3, and 4 when the three targets were combined.

TABLE XII

ANOVA FOR MISSED TARGET ERRORS -- 1 X 6 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
<u>Final Test</u>:				
Subject (S)	9	4.864	0.540	6.37*
Target Position (P)	5	3.642	0.728	8.58*
Target (T)	2	0.403	0.201	2.37
S X P	45	7.773	0.173	2.04*
Residual	118	10.018	0.085	
TOTAL	179	26.699		

*Significant at 0.01 level.

<u>The 2 X 3 Configuration</u>. Type I error rates for the 2 X 3 configuration by target and target position can be found in Figure 20. The general pattern was a tunnel effect or V-shape for each row,

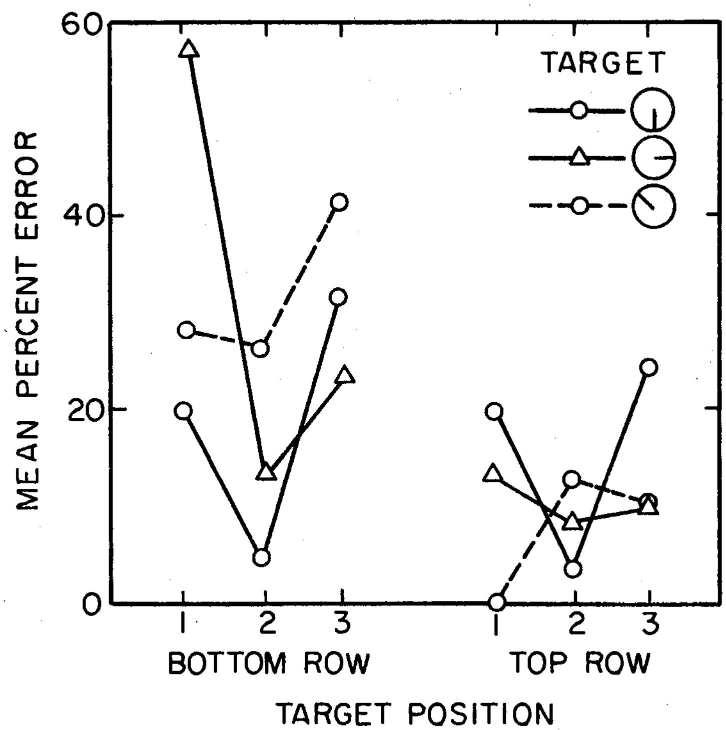


Figure 20. Missed Target Error Rates in
2 X 3 Configuration by
Target Position and Target

although the top row for the ten-thirty target did not follow this general pattern. Figure 21 shows the error pattern after combining the three targets. A summary of the ANOVA on the data of this configuration is shown in Table XIII. As revealed by the F test, the variables group (in this case, bottom and top rows) and target position were significant ($p < 0.01$) as was the variable subject ($p < 0.05$). The significance of the variable target position, according to an N-K test, was limited to the bottom row where position No. 2 was significantly lower than both position Nos. 1 and 3 ($p < 0.05$). Group-target and target position-target were the only significant interactions, both at the 0.01 level. These interactions are depicted graphically in Figures 22 and 23.

The 3 X 2 Configuration. Figures 24 and 25 show the Type I error rates by target position for the 3 X 2 configuration, the first by target and the second with all targets combined. The general pattern was bow-shaped or an inverted V, with the first and last rows having low error rates and the middle row relatively high. This pattern compared favorably to the 4 X 2 configuration pattern of Experiment I. Table XIV summarizes the ANOVA of this data. The F test showed that the variables subject, target position, and target were all significant at the 0.01 level. It is interesting to note that in this analysis no significant difference existed between the left- and right-hand columns (as evidenced by the variable group), whereas in Experiment I the right-hand column had significantly less errors ($p < 0.01$) than the left-hand column. The significant first order interactions in this study were subject-group ($p < 0.01$) and group-target ($p < 0.05$). This latter interaction is shown graphically in Figure 26.

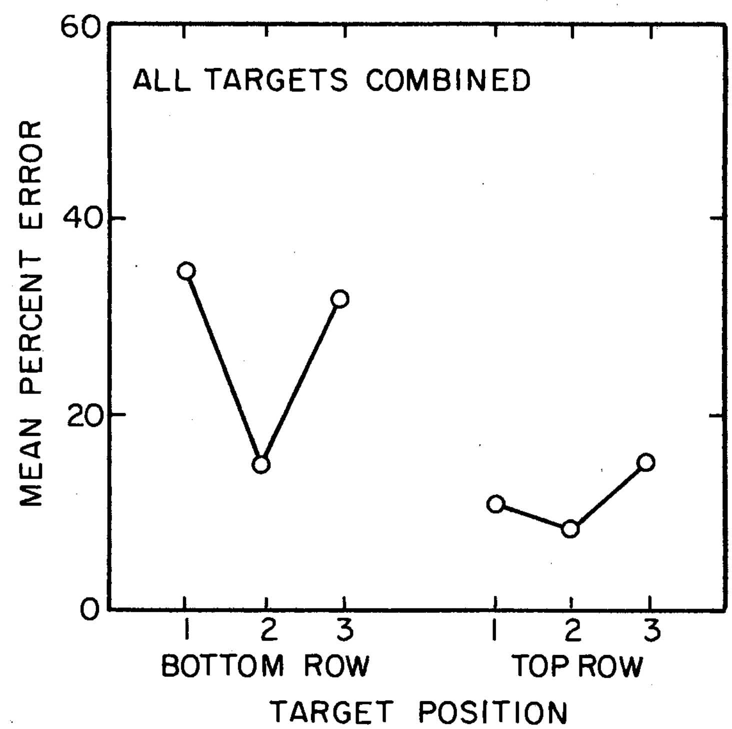


Figure 21. Missed Target Error Rates in 2 X 3 Configuration by Target Position

TABLE XIII

ANOVA FOR MISSED TARGET ERRORS -- 2 X 3 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	1.734	0.193	2.15*
Group (G)***	1	2.398	2.398	26.72**
Target Position (P)	2	1.444	0.722	8.05**
Target (T)	2	0.041	0.020	0.23
G X T	2	1.128	0.564	6.28**
P X T	4	1.865	0.466	5.20**
Residual	159	14.274	0.090	
TOTAL	179	22.884		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Bottom row and top row.

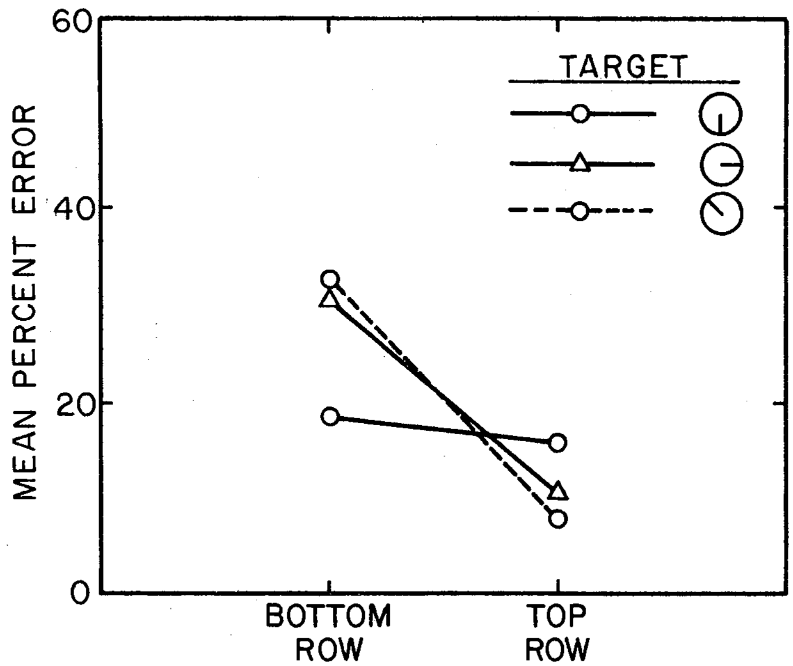


Figure 22. Missed Target Error Rates in 2 X 3 Configuration Showing Group-Target Interaction

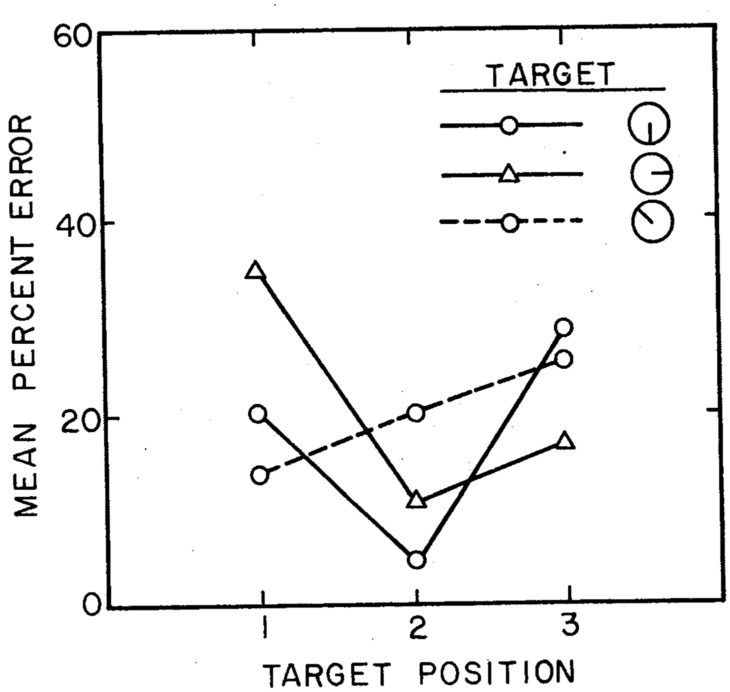


Figure 23. Missed Target Error Rates in 2 X 3 Configuration Showing Target Position-Target Interaction

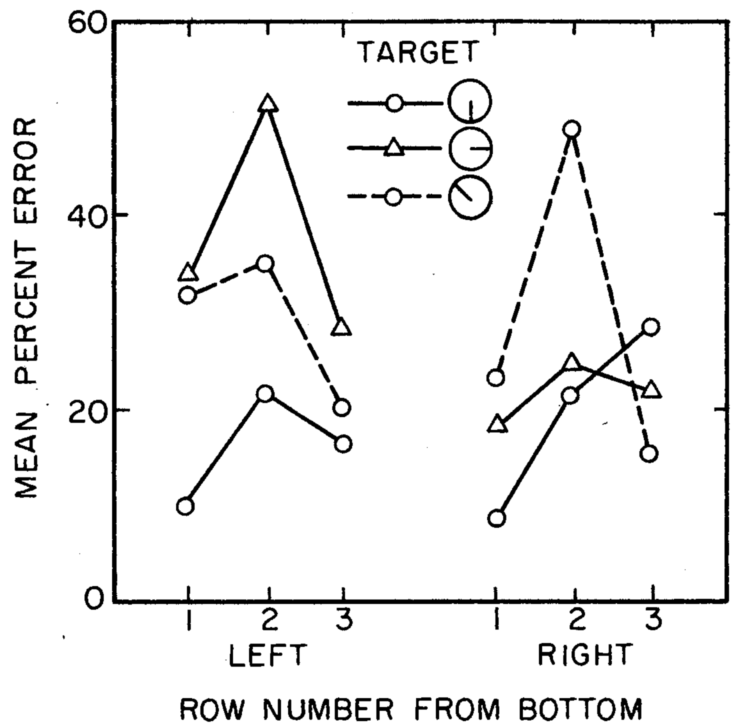


Figure 24. Missed Target Error Rates in 3 X 2 Configuration by Target Position and Target

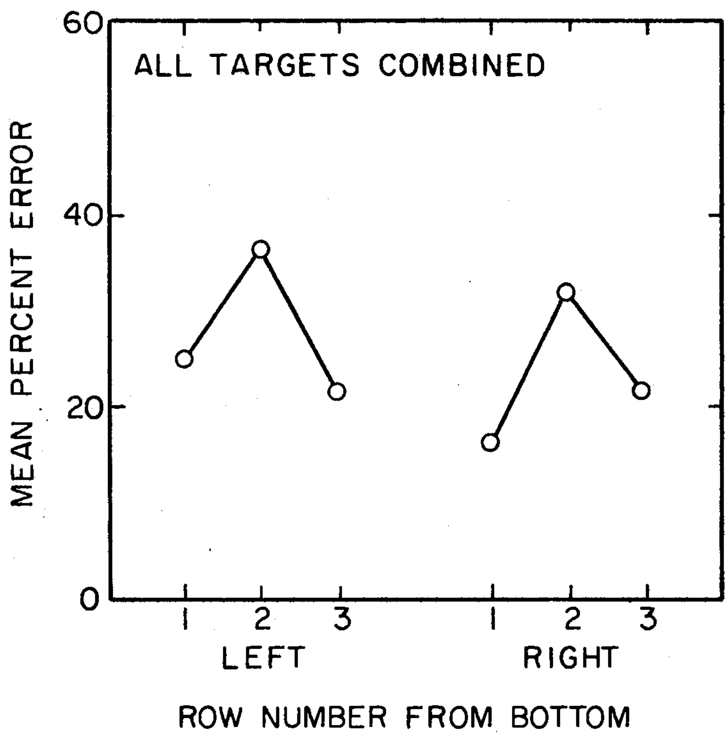


Figure 25. Missed Target Error Rates in 3 X 2 Configuration by Target Position

TABLE XIV

ANOVA FOR MISSED TARGET ERRORS -- 3 X 2 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	8.454	0.939	11.82**
Group (G)***	1	0.127	0.127	1.61
Target Position (P)	2	1.583	0.791	9.96**
Target	2	0.929	0.465	5.85**
S X G	9	2.034	0.226	2.85**
G X T	2	0.599	0.300	3.78*
Residual	154	12.218	0.079	
TOTAL	179	25.945		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Left column and right column.

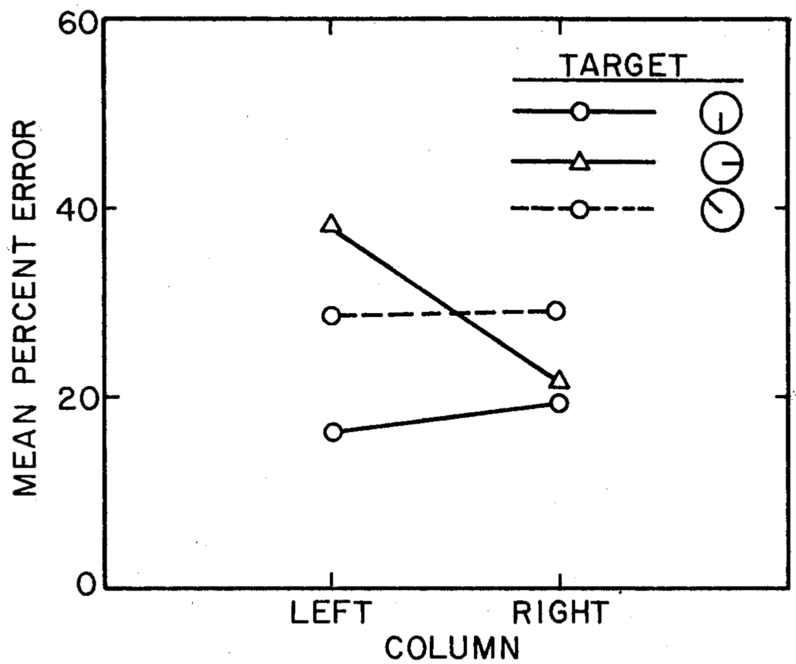


Figure 26. Missed Target Error Rates in 3 X 2 Configuration Showing Group-Target Interaction

False Alarm Errors

Interconfiguration Comparison. Figure 27 shows the false alarm error rates by configuration for each of the three targets. A summary of the ANOVA is found in Table XV. The variable target was found to be significant at the 0.01 level, due to the fact that the error rate with the six o'clock target averaged only 8.3% whereas with each of the other two targets the rates averaged over 15%. As with the results of the Type I errors, the variable configuration on Type II errors was not significant; however, with the shapes of the curves shown and with the relatively small sample size used, confirmation of the null hypothesis is rather weak (Snedecor and Cochran, page 28).

Intraconfiguration Analyses. Figures 28, 29, and 30 depict the Type II error rates by reported target position with all targets combined for the 1 X 6, 2 X 3, and 3 X 2 configurations, respectively. ANOVA summaries of these error rates have not been included in this paper.

The 1 X 6 Configuration. In the 1 X 6 configuration, reported target position was found to be significant at the 0.01 level and an N-K test showed the means of position Nos. 1 and 2 to be significantly higher than those of position Nos. 3, 4, and 5. The remaining main effects target ($p < 0.05$) and subject ($p < 0.01$) were also significant, but none of the interactions were.

The 2 X 3 Configuration. In the 2 X 3 configuration, neither group nor reported target position were significant; however, subject and target were significant at the 0.05 level. Significant interactions were subject-reported target position and group-target, both at the 0.05 level.

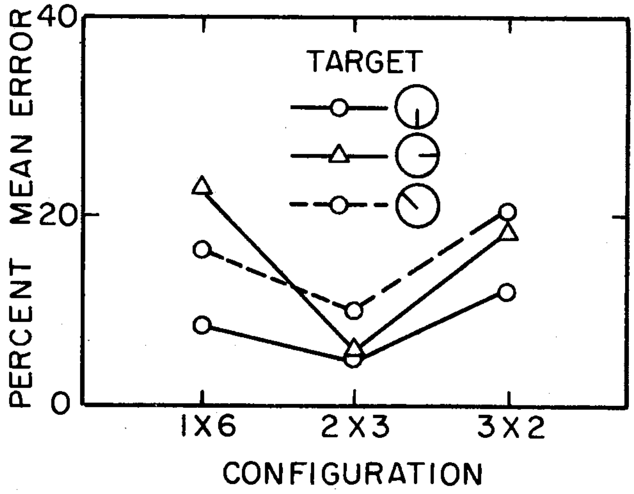


Figure 27. False Alarm Error Rates by Configuration and Target

TABLE XV

ANOVA FOR FALSE ALARM ERRORS -- ALL CONFIGURATIONS

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	0.401	0.200	1.74
Subject w. C	27	3.110	0.115	
Sub Plot				
Target (T)	2	0.421	0.210	6.28*
C × T	4	0.164	0.041	1.22
Sub-Plot Error	54	1.808	0.033	
TOTAL	89	5.903		

*Significant at 0.01 level.

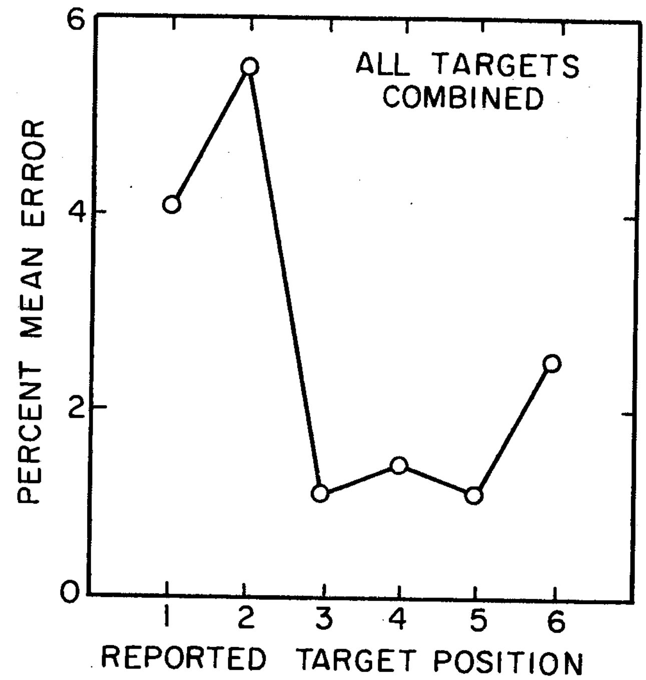


Figure 28. False Alarm Error Rates in 1 X 6 Configuration by Reported Target Position

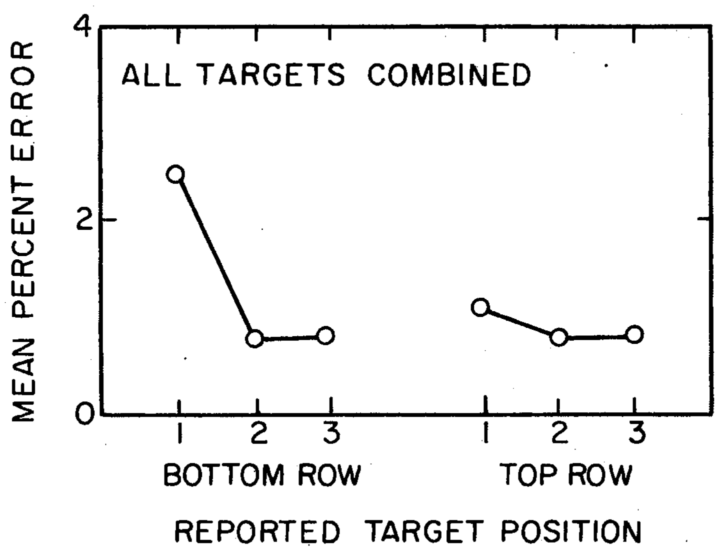


Figure 29. False Alarm Error Rates in 2 X 3 Configuration by Reported Target Position

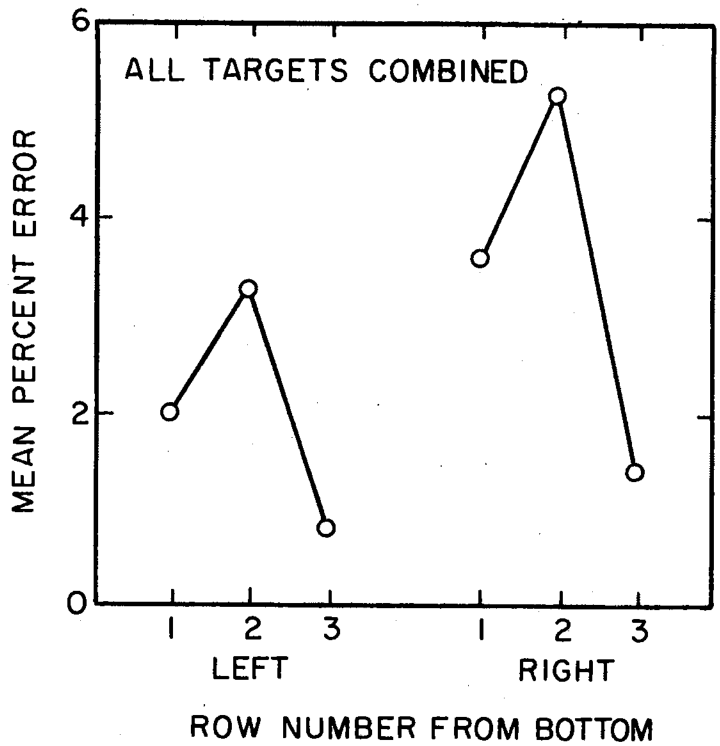


Figure 30. False Alarm Error Rates in 3 X 2 Configuration by Reported Target Position

<u>The 3 X 2 Configuration</u>. In the 3 X 2 configuration, both subject ($p < 0.05$) and reported target position ($p < 0.01$) were significant variables. An N-K test on the individual means revealed that the last row (in this case, row No. 3) had a significantly lower rate than either row Nos. 1 or 2. None of the interactions were significant. As can be seen from Figure 30, the curves are actually bow-shaped, the same general pattern that existed with the Type I error rates (see Figure 25).

<u>Analysis of Errors by Context Unit</u>. Again, as in Experiment I, it is of interest to analyze Type II errors by the context unit (in this

case, dial position) that was mistaken for the various targets. Certainly the confusability level of the context and target dial positions under the various configurations had an important role in the levels of false alarm error rates obtained. Table XVI shows the frequency that each of the context dial positions was mistaken for each of the targets by configuration.

TABLE XVI

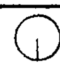
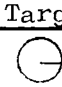
FREQUENCIES OF FALSE ALARM ERRORS BY MISTAKEN CONTEXT DIAL POSITION

		Context Dial Position							
									
Target 									
Configuration:	1 X 6	0	0	5	-	2	1	1	1
	2 X 3	0	1	3	-	0	1	1	0
	3 X 2	1	1	3	-	3	1	0	5
	All	1	2	11	-	5	3	2	6
Target 									
Configuration:	1 X 6	2	-	8	0	1	12	4	0
	2 X 3	2	-	1	0	0	3	0	1
	3 X 2	2	-	3	1	1	10	3	1
	All	6	-	12	1	2	25	7	2
Target 									
Configuration:	1 X 6	3	0	3	0	4	4	-	6
	2 X 3	2	0	5	0	0	3	-	2
	3 X 2	1	3	12	0	3	4	-	1
	All	6	3	20	0	7	11	-	9

Chi-square tests were performed on the error frequencies for each of the targets with all configurations combined. Results show that the hypothesis that each context dial position had an equal likelihood of being mistaken for the target can be rejected. With the 6 o'clock and 10:30 targets, the 4:30 dial position was the one mistaken most frequently. With the 3 o'clock target, the 9:00 dial position was the position mistaken most frequently. As with Experiment I, this variability in the confusion level between the target and the various context dial positions tends to eliminate the possibility of a high level of random guessing. Table XVII summarizes the results of the chi-square tests.

TABLE XVII

RESULTS OF CHI-SQUARE TESTS ON CONTEXT DIAL POSITIONS MISTAKEN FOR TARGET

	Target		
			
Total No. Errors	30	55	56
Chi-Squared	17	55	31
Probability of Greater No.	< 0.01	< 0.005	< 0.005

Discussion

The Primary Purpose

The results of this experiment support, but not strongly, the first hypothesis favorably tested in Experiment I; namely, that the optimum trade-off between width of stimulus material and the speed of the visual field is that combination of width and speed that just provides the subject with effective perception without the need for saccadic eye movement. Eight of the ten subjects confronted with the 1 X 6 configurations stated that they scanned across the display; the remaining two claimed to have focused centrally. This gives some indication of the need for saccadic eye movement in the perception of displays such as utilized here. On the 2 X 3 and 3 X 2 configurations, all subjects focused centrally. Thus, it is the 2 X 3 configuration that first provided the subject with effective perception without the need of saccadic eye movement. True, the variable configuration was not statistically significant in this experiment when configurations were compared as to either Type I or Type II error rates. However, the general shapes of both these sets of curves indicate a strong tendency for the 2 X 3 configuration to have lower error rates than either of the other two configurations analyzed.

Three targets were used in this experiment, one with a vertical dial reading (6 o'clock), one with a horizontal dial reading (3 o'clock), and one with a diagonal dial reading (10:30), to study their relative levels of confusability by configuration. The experimenter had hypothesized that the 6 o'clock target would have the lowest error rates under both the 1 X 6 and 3 X 2 configurations. The thinking under the 1 X 6 configuration was that for the 6 o'clock target the subject had the ability to limit his perceptual concentration to the lower half of the dial. This hypothesis can be rejected for Type I errors but cannot be rejected for Type II errors. The thinking under the 3 X 2 configuration was that at this relatively high speed, the target for which the pointer was in the direction of display movement (6 o'clock target) would be the most readily identified, despite probable high confusion with the opposite dial position (12 o'clock). This hypothesis cannot be rejected for either Type I or Type II errors.

The Secondary Purpose

The secondary purpose of the experiment was the analysis of error patterns by target position within each configuration. Results of the 1 X 6 configuration revealed the typical tunnel effect for both Type I and Type II errors. The masking effect that was so evident in Experiment I by the drop in error rates at the two extreme letter positions was not in evidence with the row of dials. Whereas closely spaced letters tend to run into one another when quickly scanned, each dial face is framed by the circular outline of the dial. This "frame-effect" of the dial face and the greater space between the stimulus units doubtlessly account for the lack of a masking effect.

The Type I error pattern of the 2 X 3 configuration did not compare favorably with those of the 2 X 4 configuration of Experiment I. No correlation existed in Experiment I between error rate and target position, whereas in this experiment a V-shape error pattern emerged in both top and bottom rows. Only the bottom row had statistical significance, however.

A favorable comparison existed between error patterns of the 3 X 2 configuration of this experiment and the Type I error pattern of the 4 X 2 configuration of Experiment I. In both cases the bottom and top rows had error rates significantly lower than any other row. Thus, results of this phase of the experiment support the contention previously made that a strong masking effect of adjacent stimulus material exists in the direction of the visual field movement at the relatively high rates of speed.

Summary

The stimulus material of this experiment differed from that of Experiment I in the following ways:

a) Dial settings were used for target and context rather than alphabetic letters.

b) Each display consisted of six rather than eight stimulus units.

c) The display widths were wider; for example, the width of the one-row configuration was two inches compared to 1 1/8 inches in Experiment I.

Despite these differences in the stimulus material between the two experiments, the results are quite similar. Experiment II supports, but not strongly, the same contention that is supported by Experiment I, namely that in a visual search task through an aperture, perception is more accurate at the slowest display speed, and thus at the greatest display width, that requires no saccadic eye movement.

In the one-row configuration, the similarity in the results of the two experiments is in the tunnel effect, or U-shape, that was found in the analysis of Type II error rates of Experiment II as well as in that of Type I error rates of both experiments. A major difference in the results is the absence of any masking effect in the case of the dial settings (Experiment II) versus the distinct masking effect in the case of the letters (Experiment I).

Although little similarity exists in the results of the two-row configurations of the two experiments, the results of the two-column configurations show a marked similarity. The results of both experiments show a strong masking effect of adjacent stimulus material in the direction of visual field movement.

CHAPTER V

THE ADDITIONAL EFFECT OF STIMULUS SPACING ON PERCEPTION

General

A masking effect of adjacent stimulus material was evidenced in the one-row configuration of Experiment I by the extremely low missed target error rates at the extreme target positions, Nos. 1 and 8. The effect of masking was less significant in the two-row configuration. Results of both Experiments I and II showed that at the relatively high visual field speeds of the two-column configurations, masking was apparent in the direction of visual field movement. This was evidenced by the low missed target error rates in the first and last rows.

These findings led to the following question:

Would changes in the spacing patterns alter the masking effects or otherwise significantly influence the error rates?

The experimenter hypothesized that lateral spacing (or subgrouping) of the stimulus material is a factor that influences error rates in one- and two-row configurations (Hypothesis No. 2). Both Experiments III and IV were designed to test this hypothesis. It was further hypothesized that vertical separation between rows of multi-row configurations is an influencing factor in error rates (Hypothesis No. 3). Experiment IV tests this hypothesis as well as exploring further the effect of stimulus configuration on error rates.

Experiment III Method

Stimulus Material

The same 8-letter groups of stimulus material, randomly developed, were used in this experiment that were used in Experiment I, with the following exceptions:

a) Lateral spacing of the stimulus was treated as a variable.

b) Single spaced letters were more compact.

c) Only the 1 X 8 and the 2 X 4 configurations were used.

Four spacing patterns were used for the 1 X 8 configuration, described as single, 2 groups of 4, 4 groups of 2, and double. In the 2 groups of 4 and 4 groups of 2 spacing patterns, each group of letters was single spaced with a double space between groups. For the 2 X 4 configuration, only the last three spacing patterns were used, since the single pattern was not applicable. Table XVIII illustrates these spacing patterns.

The same randomized letter groupings were used for each of the spacing patterns; however, the order of presentation of the groupings was randomized.

The widths of the stimuli in the 1 X 8 configuration varied from 7/8 inch for the single spaced letters to 1 5/8 inches for the double spaced letters. The target (letter K), the ratio of displays containing a target to the total number presented, and the restriction of no letter duplications in any one display were all the same as in Experiment I. Likewise, the blank space of 5/16 inch between rows of each display in the 2 X 4 configuration was the same as in that experiment.

TABLE XVIII

SPACING PATTERNS USED IN EXPERIMENT III

Spacing Pattern	Configuration 1 x 8	2 x 4
Single	NXYKLVRF	***
2 groups of 4	NXYK LVRF	LVRF NXYK
4 groups of 2	NX YK LV RF	LV RF NX YK
Double	N X Y K L V R F	L V R F N X Y K

Equipment

The same equipment was used for this experiment that was used for Experiment I. The height of the viewing aperture remained at 1/4 inch; however, the aperture widths were modified in direct relation to the widths of the stimuli.

Velocities and Exposure Time

In this experiment, the exposure time (0.625 seconds), the linear velocities (0.60 and 1.30 inches per second for the 1 X 8 and 2 X 4 configurations, respectively), and the maximum angular velocities

(2.3 and 5.0 degrees per second for the 1 X 8 and 2 X 4 configurations, respectively) are the same as those of Experiment I under "short exposure time."

Experimental Design

This experiment was a comparison of configurations and of spacing patterns within each of the two configurations. Inasmuch as the experiment was not fully balanced, as evidenced by four spacing patterns in the 1 X 8 configuration and only three in the 2 X 4, analysis of each type of error included a pair of factorial designs in addition to a completely randomized experiment with a split plot. The factorial designs included a 4 X 10 for the 1 X 8 configuration and a 3 X 10 for the 2 X 4. The variables in both these factorials were spacing pattern and subject. Configuration was the main plot treatment of the completely randomized design and spacing pattern the split plot treatment.

Subjects

Twenty volunteer subjects participated in this experiment, ten in each of the two parts according to configuration. Pretesting was the same as for Experiment I.

Procedure

A trial run, similar to that of the previous experiments, was administered to each subject prior to his starting the test. For each configuration, 48 letter-group stimuli were presented to each of the ten subjects under each of the spacing patterns. The sequence of spacing-pattern presentations was randomized.

Experiment III Results

This experiment was confined to an interconfiguration analysis and a comparison of spacing patterns within each of the configurations. Unlike the previous two experiments, this experiment did not include an analysis of error pattern by target position within each configuration.

Missed Target Errors

Fibure 31 shows the Type I error rates by spacing pattern for both configurations tested. Spacing pattern as a variable showed significant variation ($p < 0.05$) only in the F test of the 3 X 10 factorial design, which covered the 2 X 4 configuration. ANOVA summaries and further discussion of the statistical analyses of Experiment III are presented in Appendix C.

Similarities between portions of this experiment and Experiment I are worthy of special mention. Only two differences existed between the short exposure time test on the 1 X 8 configuration of Experiment I and the test on the single spaced stimuli of this experiment. The stimulus width of the former was 1 1/8 inches while that of the latter was only 7/8 inch, and different random letter strings were used in the two experiments. These differences also apply in the 2 X 4 configurations to the short exposure time test of Experiment I and the test on the 2 groups of 4 spacing pattern of this experiment. A comparison of the missed target error rates of the comparable tests of the two experiments is shown in Table XIX.

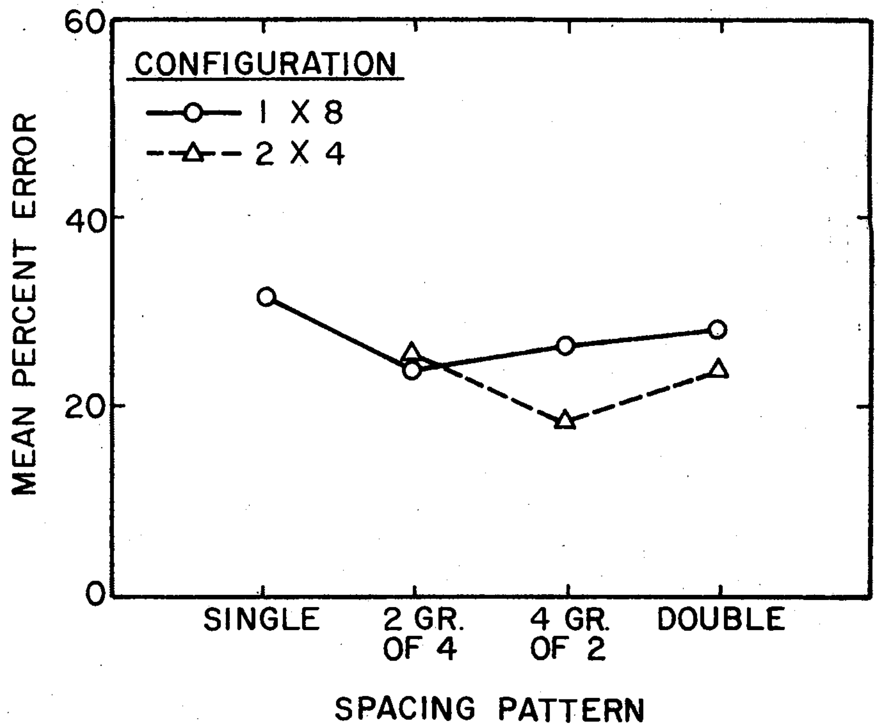


Figure 31. Missed Target Error Rates by Spacing Pattern and Configuration

TABLE XIX

TYPE I ERROR RATES OF COMPARABLE TESTS OF EXPERIMENTS I AND III

	Configuration	
Experiment	1 X 8	2 X 4
I, Short Exposure Time	34.7%	22.2%
III	31.3%*	25.3%**

*Single spacing pattern.

**2 groups of 4 spacing pattern.

<u>False Alarm Errors</u>

The Type II error rates by spacing pattern and configuration are shown in Figure 32. Spacing pattern was a significant variable as evidenced by F tests of (1) the completely randomized experiment with a split plot ($p < 0.01$), and (2) the 3 X 10 factorial design covering only the 2 X 4 configuration ($p < 0.05$).

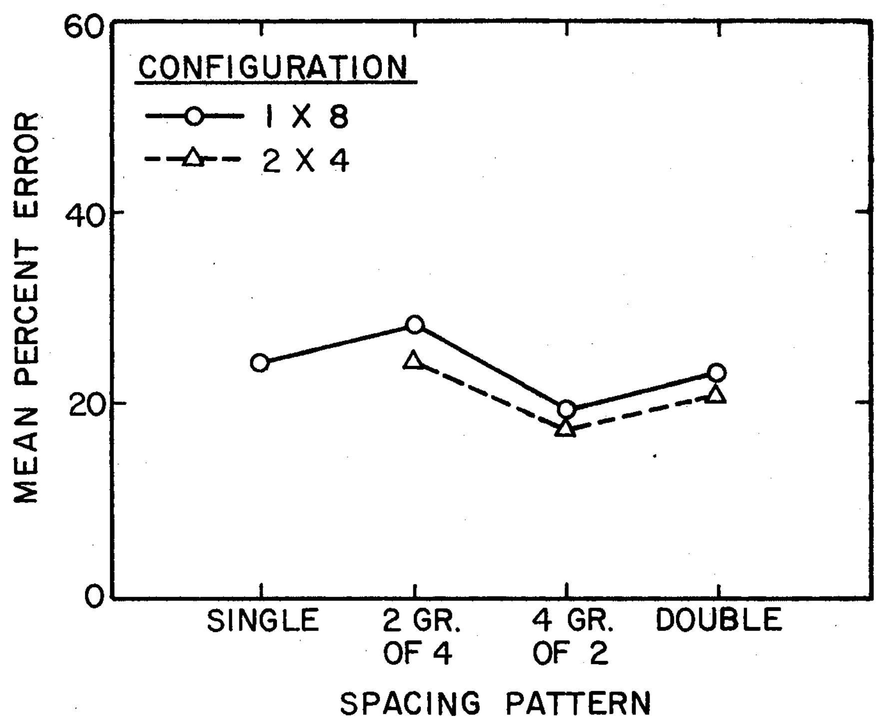


Figure 32. False Alarm Error Rates by Spacing Pattern and Configuration

Experiment III Discussion

The purpose of this experiment was to test the hypothesis that lateral spacing of the stimulus material is a factor that influences error rates in one- and two-row configurations. Results support this hypothesis but not strongly.

Spreading the stimulus from single to double spacing has no significant effect in reducing the confusability level or the masking effect of adjacent stimulus material. However, grouping of the stimulus units into a spacing pattern of 4 groups of 2 has some statistically significant advantage over the other spacing patterns considered. In the 2 X 4 configuration, that pattern has significantly lower rates of both Type I and Type II errors. In the 1 X 8 configuration, only the Type II error rate of the 4 groups of 2 spacing pattern shows a statistically significant advantage. Although not statistically significant, both grouping patterns, the 2 groups of 4 and the 4 groups of 2, appear to be advantageous over the single and double spacing patterns of the 1 X 8 configuration with respect to missed target errors.

This experiment also gives nominal support to the first hypothesis tested in Experiments I and II. This hypothesis states that the optimum trade-off between width of stimulus material and the speed of the visual field is that combination of width and speed that just provides the subject with effective perception without the need for saccadic eye movement. The perceptual advantage of the two-row configuration over the one-row configuration was not statistically significant, however.

In summary, the results of this experiment show that lateral spacing is more of an influencing factor on error rates in two-row configurations than in one-row configurations. The spacing pattern of 4 groups of 2 results in lower error rates than any of the other spacing patterns considered. As did the first two experiments, this experiment shows that the two-row configuration results in lower error rates than the single-row configuration.

Experiment IV Method

This experiment compared four different configurations of stimuli, each containing 16 stimulus units and each at the field speed that provided equal exposure time for all configurations of stimuli. In addition, the experiment explored further the effect of lateral spacing as well as the effect of the vertical separation between rows of the multi-row configurations.

Stimulus Material

Each display consisted of 16 capital letters. As before, the target was the letter K, which was found no more than once in any display. The context letters, randomly presented, were the same eight letters used in Experiments I and III. None of the context letters was found more than twice in any display, and the restriction existed that no letter was ever adjacent to itself. The same 1/8-inch-high letters in an executive type that were used in Experiment I were also used in this experiment. The ratio of displays containing a target to the total number of displays presented in each configuration was 2/3, so that for every 24 displays, the target was randomly found in each of the 16 letter positions once.

The 1 X 16 and the 2 X 8 configuration stimuli had letters grouped in fours, with the letters in each group single spaced. The lateral spacing between groups varied between a single and a double space. The blank space, or vertical separation, between rows of the multi-row configurations was of two sizes: 1/4 inch and 7/16 inch. The widths of the stimuli in the 1 X 16 configuration were 2 1/8 and 2 1/2 inches; in the 2 X 8 configuration, 1 and 1 1/8 inches; in the 4 X 4 configuration, 7/16 inch; and in the 8 X 2 configuration, 7/32 inch.

Equipment

The same equipment was used in this experiment that was used in the other three experiments. The modifications for this experiment were limited to the sizes of apertures used. The aperture widths for the 1 X 16 single-spaced and double-spaced displays were 3 and 3 3/8 inches, respectively. The width for each of the other displays was such that the blank space on either side of the display was approximately the same throughout the experiment. The height of the viewing aperture in this experiment was 3/8 inch, an increase of 1/8 inch over that used in the three earlier experiments. As in the other experiments, a tape was drawn across the work station at forehead level to restrict the subject either to a minimum of 15 inches from the aperture or to a maximum angular velocity of eight degrees per second, whichever was the greater distance.

Velocities and Exposure Times

For the 1 X 16 configuration, the linear velocity of the visual field was 0.435 inches per second. This provided an exposure time, defined as the time from start of appearance of the stimulus material in the aperture until its final disappearance, of 1.15 seconds. Table XX shows the linear velocities and the maximum angular velocities of the displays by configuration. Sample computations are included in Appendix C.

TABLE XX

LINEAR AND MAXIMUM ANGULAR VELOCITIES BY CONFIGURATION

Exposure Time in Seconds	1.15		
	Vertical Row Separation		
	1/4 Inch	7/16 Inch	N.A.*
Linear Velocity in inches/second:			
Configuration			
1 X 16			0.435
2 X 8	0.76	0.93	
4 X 4	1.41	1.90	
8 X 2	2.72	3.85	
Maximum Angular Velocity in degrees/second:			
Configuration			
1 X 16			1.7
2 X 8	2.9	3.5	
4 X 4	5.4	7.3	
8 X 2	8.0**	8.0***	

*Not Applicable.

**Restriction tape 19 1/2 inches from aperture.

***Restriction tape 27 1/2 inches from aperture.

Experimental Design

As did Experiments I and II, this experiment had two aspects. The first was a comparison of the four configurations of stimulus material and the effects of spacing, both lateral and vertical, on performance by each of the configurations. The second was the intraconfiguration analysis of error patterns. Similarly to Experiment III, this experiment was not fully balanced. It analyzed lateral spacing between letter groups, which analysis applied only to the 1 X 16 and the 2 X 8 configurations. It also analyzed the vertical separation between rows, which analysis excluded the single-row configuration. Because of this lack of balance, a more complicated experimental design was found necessary.

Two completely randomized designs with split plots were used to compare the 1 X 16 and the 2 X 8 configurations and also the lateral spacing variables, single and double. The first utilized the small vertical separation between the rows of the 2 X 8 configuration, the second utilized the large vertical separation. In each of these, configuration was the main plot treatment, it being a between-subject variable. Lateral spacing was the split plot treatment and was within subjects.

Another two completely randomized designs with split plots were used to compare the 2 X 8, the 4 X 4, and the 8 X 2 configurations and the vertical separation variables, small and large. The first utilized the single lateral spacing of the 2 X 8 configuration, the second utilized the double lateral spacing. In each of these, configuration (a between-subject variable) was the main plot treatment and vertical separation (a within-subject variable) was the split plot treatment.

For the intraconfiguration analysis of error patterns, various factorial designs were used. For instance, in the 1 X 16 configuration one analysis was a 2 X 10 X 16 factorial, the variables being lateral spacing, subject, and target position. A second analysis in the same configuration was a 2 X 4 X 4 X 10, in which the variables were lateral spacing, group, letter position, and subject.

Subjects

Forty volunteer subjects, male and female, between the ages of 18 and 46 took part in this experiment. Twenty of these subjects also participated in Experiment III, which was run intermittently with parts of this experiment on a randomized basis. An attempt was made to group the subjects, one for each of the four configurations, so that the number of females and the number of subjects over 30 years of age were well dispersed between groups. An explanation of the pretest given the subjects can be found under Method of Experiment I.

Procedure

The trial run consisted of a total of 48 displays presented with the various spacing patterns and in the appropriate configuration. Each subject displayed a reasonable ability to perform the task (less than 50% misses) before the test began. As in the previous experiments, a ready signal prepared the subject for the appearance of the stimulus, and the experimenter stopped the conveyor after the disappearance of each stimulus to allow the subject time to record his response.

For each configuration, 48 letter-group stimuli were presented to each of the ten subjects in each of the appropriate variations in lateral spacing and/or vertical row separation. The sequence of presentation of these variations was randomized. As in the previous experiments, the data compiled and analyzed were Type I and Type II error rates.

Experiment IV Results

Missed Target Errors

Interconfiguration Comparison. Figure 33 shows the rates of missed target errors by configuration; and by lateral spacing, in the case of the 1 X 16 and the 2 X 8 configurations, and by vertical row separation, in the case of the multi-row configurations. Configuration as a variable produced statistically significant variation (F test at the 0.01 level), the 2 X 8 and 4 X 4 configurations having significantly lower error rates than both the 1 X 16 and the 8 X 2 configurations (N-K test at the 0.05 level). Neither lateral spacing nor vertical row separation were statistically significant variables. The statistical details of this experiment are covered in Appendix E.

Repeated Measures Analysis. Similar to the analysis in Experiment I, repeated measures analyses were performed on the data of this experiment to determine the significance of any sequence effect. The rationale of performing these analyses yet limiting them to only two of four experiments has been presented in the results of Experiment I. The test results of each subject were divided into trials 1 and 2. The data for trial 1 were the results of the first 24 stimulus presentations in each of the lateral spacing or vertical row separation variations; those for trial 2, the results of the last 24. Figure 34 shows graphically the

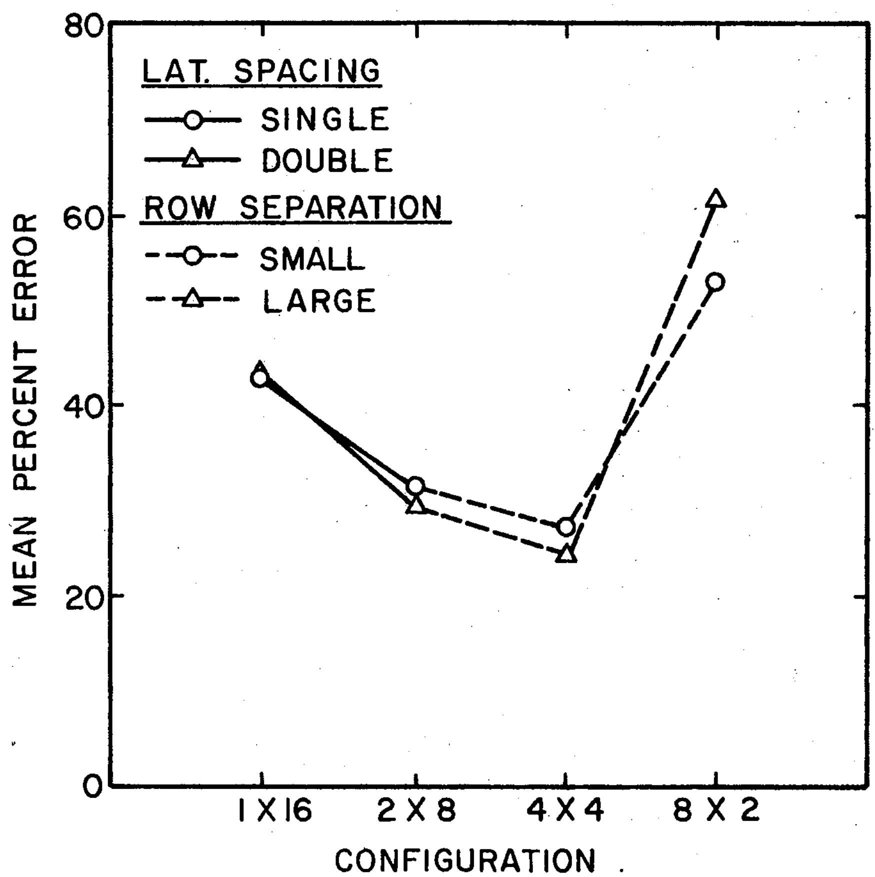


Figure 33. Missed Target Error Rates by Configuration, by Lateral Spacing (Configurations 1 X 16 and 2 X 8), and by Vertical Row Separation (Configurations 2 X 8, 4 X 4, and 8 X 2)

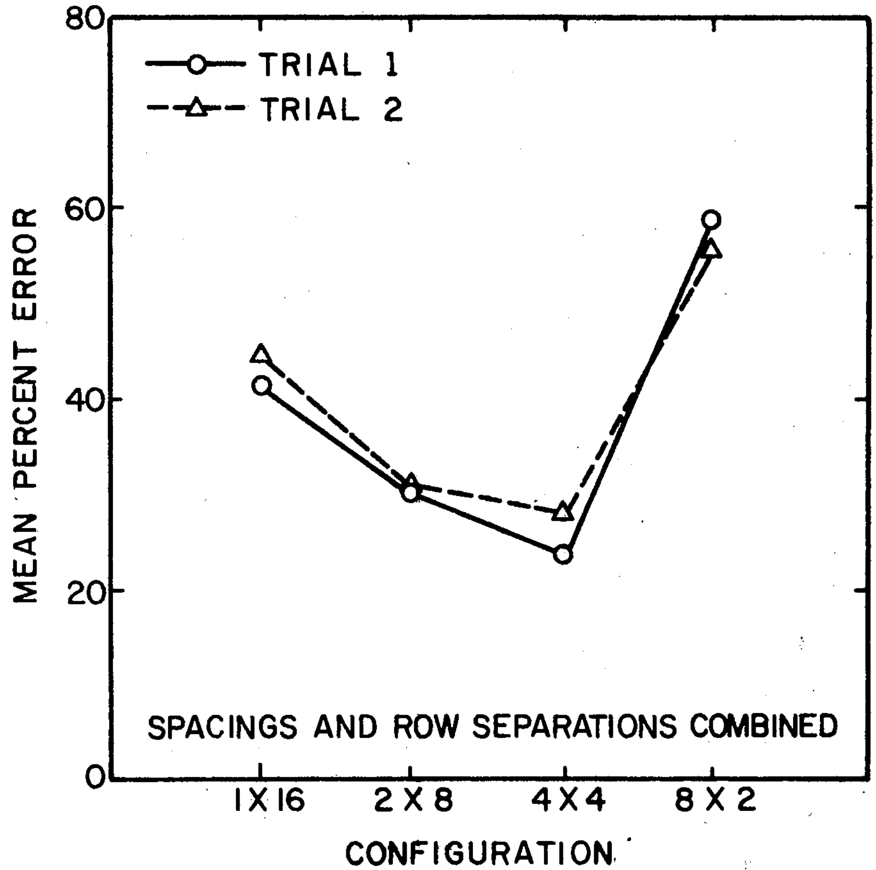


Figure 34. Repeated Measures Analysis of Missed Target Error Rates by Configuration

results of these analyses. For clarity of presentation, the variations in lateral spacing and row separation have been combined in this graph.

Results of the F test on the completely randomized experiments with split plots show that the variable trial (with one degree of freedom) did not have statistically significant variations. Thus, a sequence effect apparently presents no problem throughout this experiment in confounding the treatment effects.

The 1 X 16 Configuration. Figure 35 shows the rates of missed target errors by letter position in the 1 X 16 configuration. Because of the lack of significance in the variable lateral spacing, the single and double spacings have been combined in the graph. Target position as a variable showed significant variation by the F test (at the 0.05 level) but no significant differences by the N-K test. As mentioned in Experiment I, the lack of normality of data was the main reason for the inconsistency of results between these tests.

Also of interest in the analysis of missed target errors of the one-row configuration, were the patterns of error rates by 4-letter group and by letter position within groups. Figures 36 and 37 portray these error patterns graphically. In the error pattern by 4-letter group, each group starting from the left has been designated by a letter "a" through "d". In like fashion, in the pattern by letter position within groups, the letter positions have been numbered consecutively from the left.

Despite some lack of significance, it is worthy of note that the error pattern within most of the 4-letter groups was somewhat bow shaped, especially that of groups b and c (Figure 35). By the same token, the inter-group error levels formed a similar shallow bow

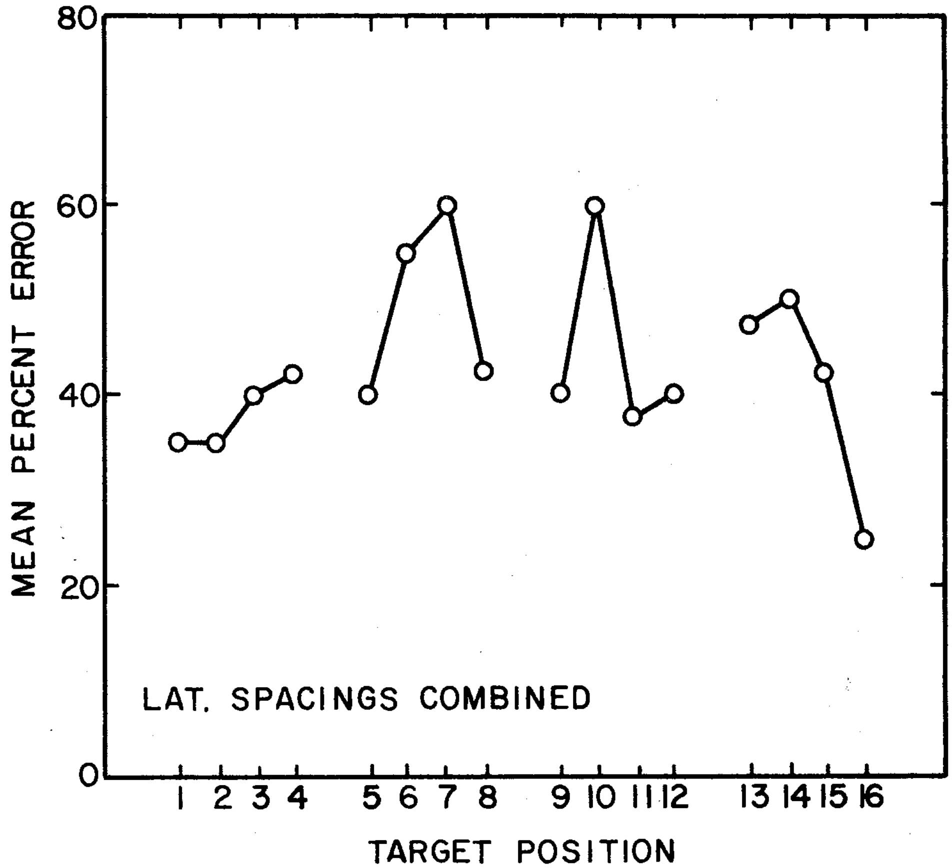


Figure 35. Missed Target Error Rates in 1 X 16 Configuration by Target Position

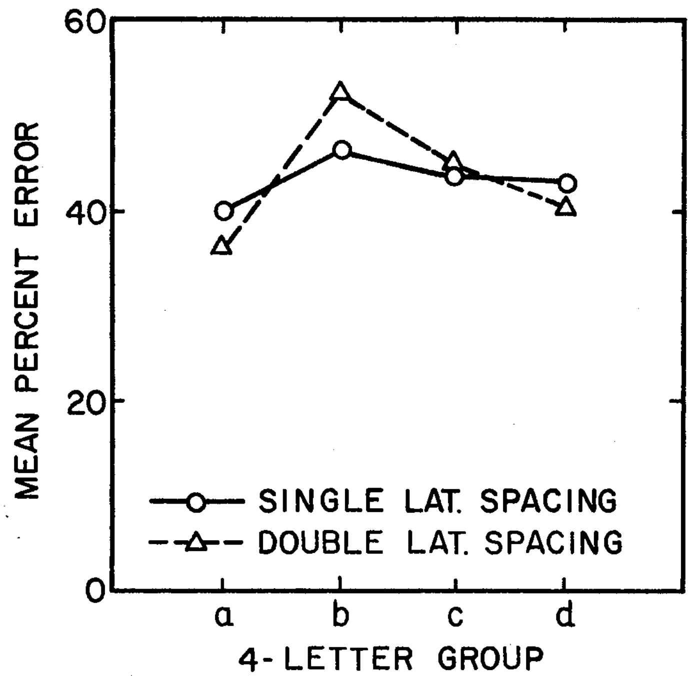


Figure 36. Missed Target Error Rates in 1 X 16 Configuration by 4-Letter Group

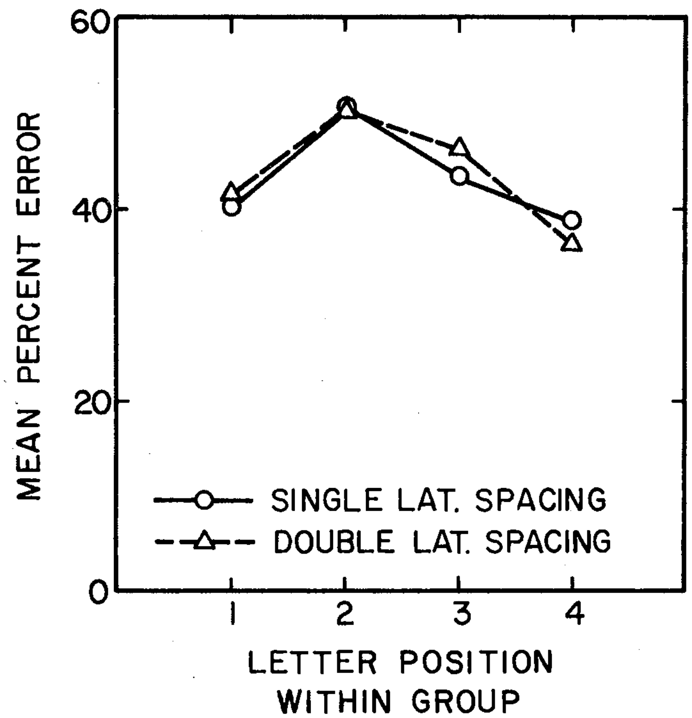


Figure 37. Missed Target Error Rates in 1 X 16 Configuration by Letter Position Within Group

($p < 0.05$, F test). These patterns indicate the prominence of a masking effect in this configuration, evidenced not only by the relatively low error rates at target position Nos. 1 and 16, but by drop in rates at the within-group letter position Nos. 1 and 4.

The 2 X 8 Configuration. Figure 38 shows the rates of missed target errors by letter position for the 2 X 8 configuration. Again, the lateral spacing variables and the row separation variables have been combined because of their lack of significance. Two distinctive features of this error pattern were apparent. One was the prominence of a masking effect in each of the rows, as evidenced by the drastic drop in error rates at target position Nos. 1 and 8. The second was the remarkable similarity between rows. Also of interest was the fact that the lateral spacing, either single or double, between the 4-letter groups within each row, had little effect in reducing the problem of masking.

As with the analysis of data in the single-row configuration, the analysis in the 2 X 8 configuration included error patterns by 4-letter group and by letter position within groups. Figures 39 and 40 are the graphs of these error patterns. Although the 4-letter group as a variable showed no statistical significance, the within-group letter position Nos. 1 and 4 were significantly lower than the two interior positions.

The 4 X 4 Configuration. In the 4 X 4 configuration, a bow-shaped error pattern was present in each of the 4-letter rows. This is shown graphically in Figure 41. Group (in this case, row) and target position were statistically significant variables (F test, 0.01 level). Once again, row separation was found to be an insignificant variable.

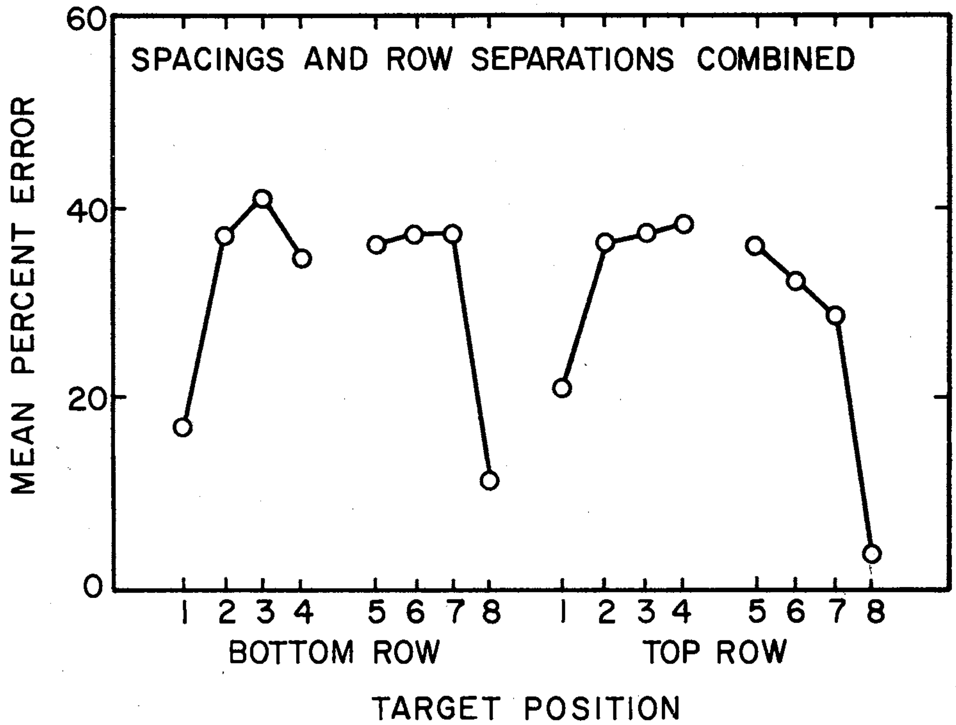


Figure 38. Missed Target Error Rates in 2 X 8 Configuration by Target Position

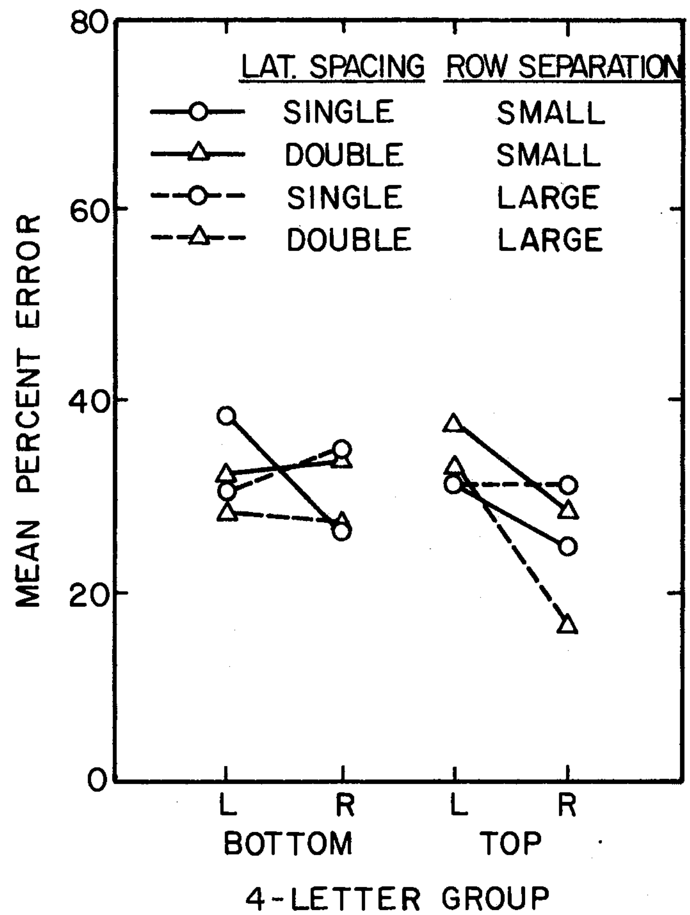


Figure 39. Missed Target Error Rates in 2 X 8 Configuration by 4-Letter Group

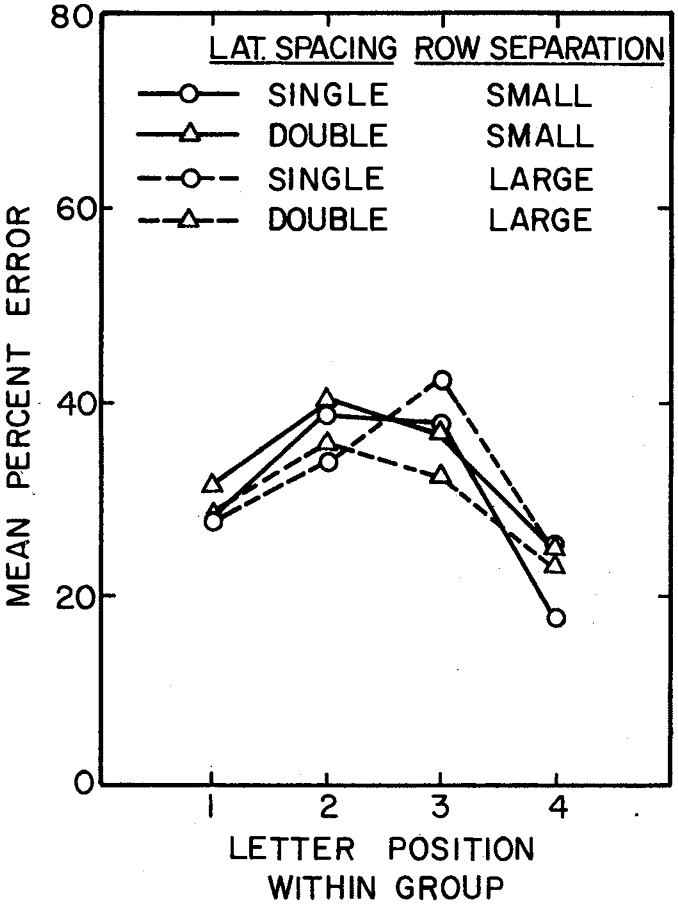


Figure 40. Missed Target Error Rates in 2 X 8 Configuration by Letter Position Within Group

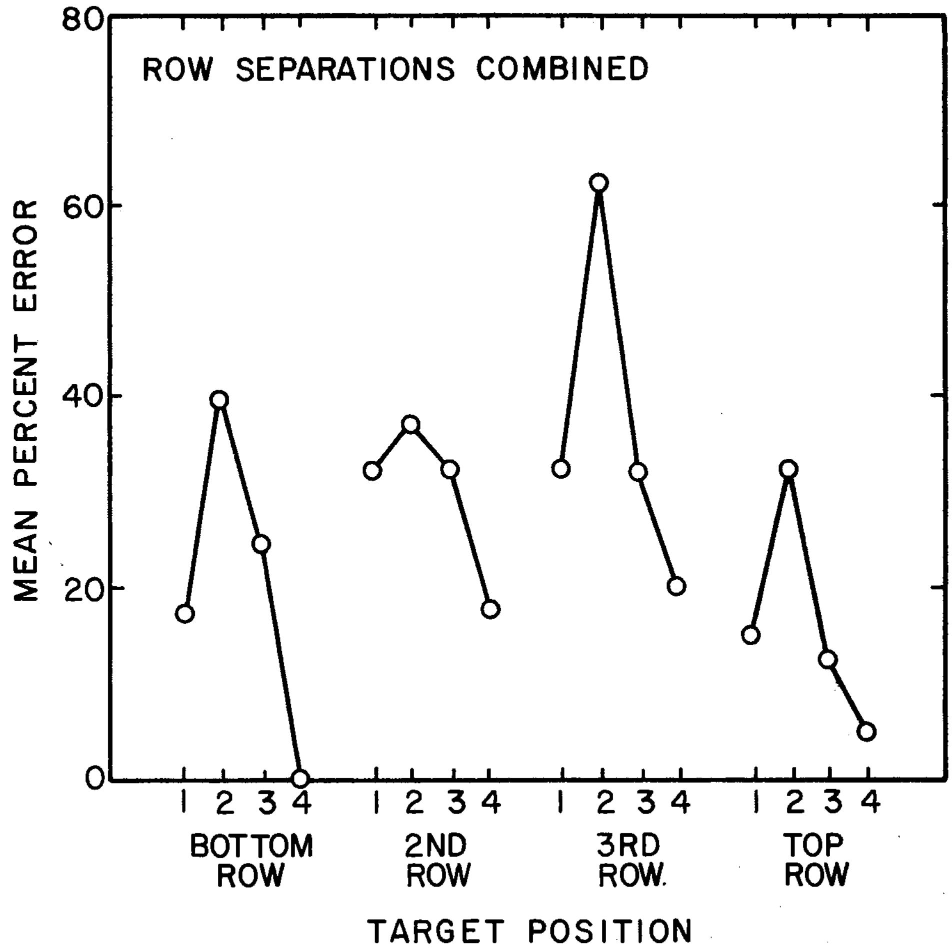


Figure 41. Missed Target Error Rates in 4 X 4 Configuration by Target Position

Error rates by group, or row, are shown in Figure 42. The bottom and top rows had significantly lower rates than the middle rows, revealing a definite masking effect in the direction of conveyor movement. Figure 43 shows the error rates by letter position within each row. The prevalence of the effect of masking within each row is apparent.

The 8 X 2 Configuration. Figure 44 shows the error pattern by target position for the 8 X 2 configuration. The pattern of each column was bow shaped, the pattern typical of the 2-column configurations throughout this experimentation. Target position was a highly significant variable and, for the first time, row separation showed statistical significance (F test, 0.05 level). The mean error rate of the small row separation was 52.9% and that of the large row separation was 61.6%. Whereas in Experiment I the right-hand column had a significantly lower error rate than the left-hand column, no significant difference between columns materialized in this experiment.

False Alarm Errors

Interconfiguration Comparison. Figure 45 shows the false alarm error rates by configuration and by lateral spacing, in the case of the one- and two-row configurations, and by row separation, in the case of the multi-row configurations. The terminals of the solid lines at the 2 X 8 configuration are values with row separations combined. Likewise, the terminals of the dashed lines at the same configuration are values with lateral spacings combined.

Row separation was the only significant variable; both configuration and lateral spacing as variables were statistically insignificant.

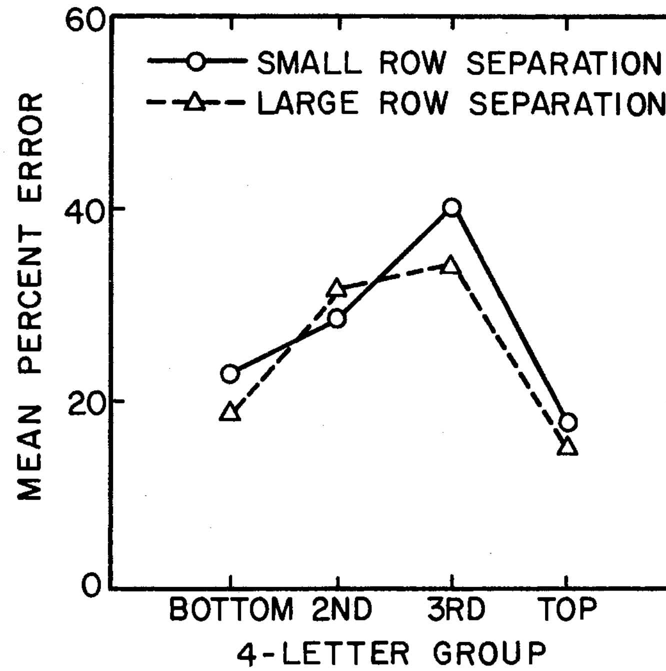


Figure 42. Missed Target Error Rates in 4 X 4 Configuration by 4-Letter Group

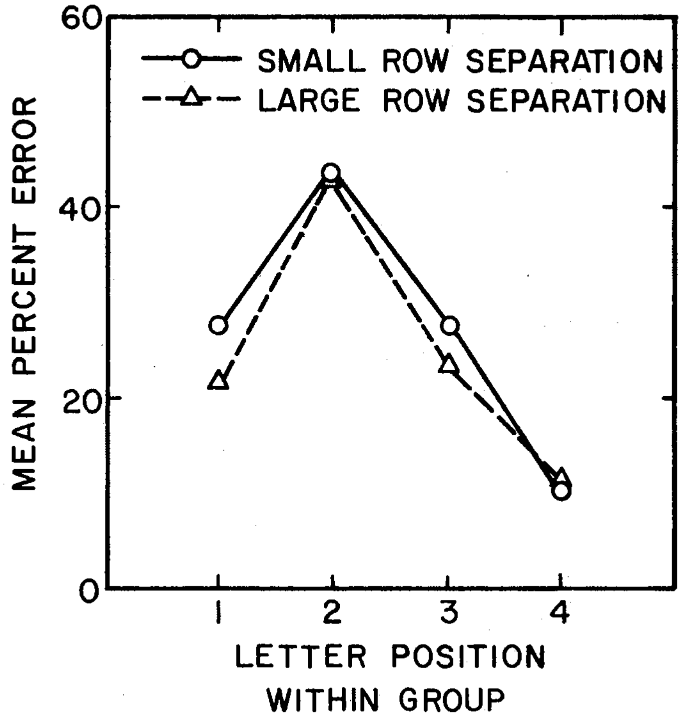


Figure 43. Missed Target Error Rates in 4 X 4 Configuration by Letter Position Within Group

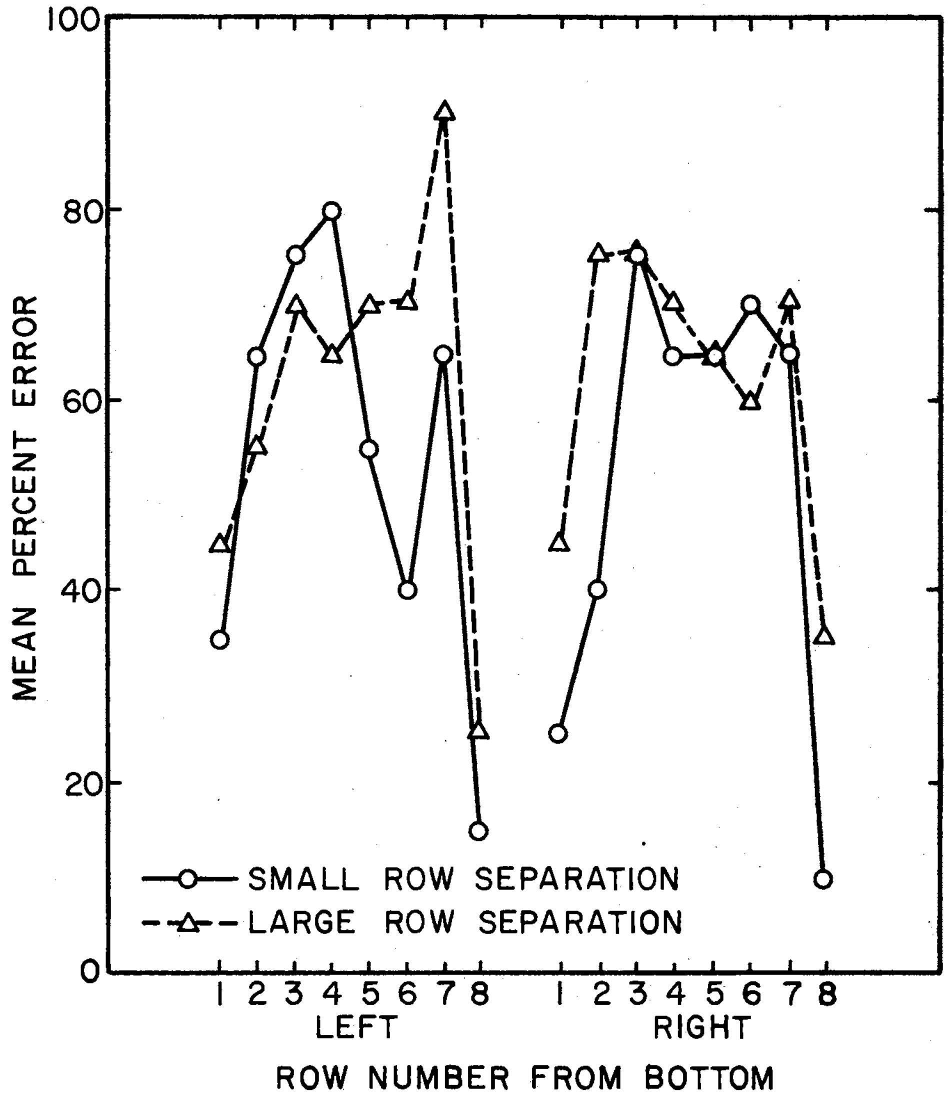


Figure 44. Missed Target Error Rates in 8 X 2 Configuration by Target Position

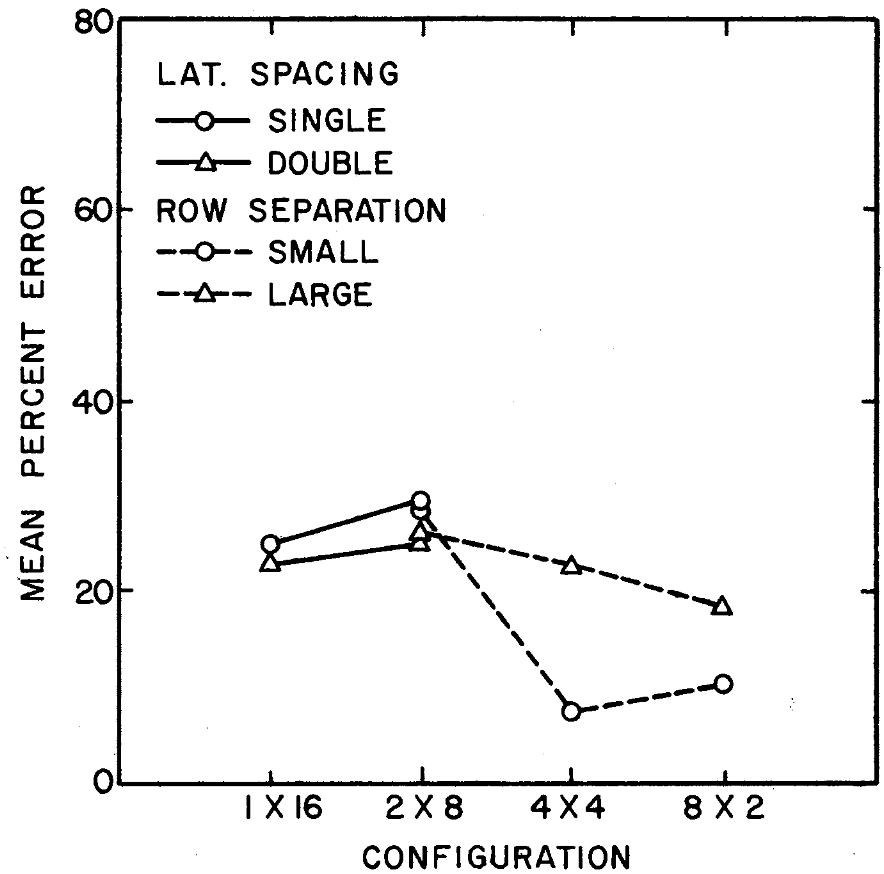


Figure 45. False Alarm Error Rates by Configuration, by Lateral Spacing (Configurations 1 X 16 and 2 X 8), and by Vertical Row Separation (Configurations 2 X 8, 4 X 4, and 8 X 2)

The 1 X 16 Configuration. The false alarm error rates in the 1 X 16 configuration are shown graphically in Figure 46. The single and double lateral spacing variables were combined because of their lack of significance. A semblance of a bow-shaped error pattern existed within each of the four-letter groups, more prominent in the first and last groups than in the middle two.

The Type II error rates by the reported 4-letter group and by the reported letter position within each group are shown in Figures 47 and 48, respectively. Unlike the pattern of Type I errors by group, Figure 47 reveals an increasing error rate across the 4-letter groups. However, the pattern by reported position within each group (Figure 48) was the familiar bow shape, similar to that on Type I errors. Both group and letter position within group were statistically significant variables.

The 2 X 8 Configuration. Figure 49 shows the rates of false alarm errors for the 2 X 8 configuration by reported target position. The error rates formed a series of distinct bow-shaped patterns by 4-letter group. Neither lateral spacing nor row separation were significant variables. Reported target position was highly significant. The variable group, in this case bottom and top rows, showed inconsistent variability throughout the factorial designs of this portion of the experiment. Table XXI summarizes the false alarm error rates showing the inconsistency in this variable. Note that with the large row separation, the variable group showed a great deal of variation when the lateral spacing was combined. Likewise, with the double lateral spacing, the same variable showed a high level of variation when row separation was combined.

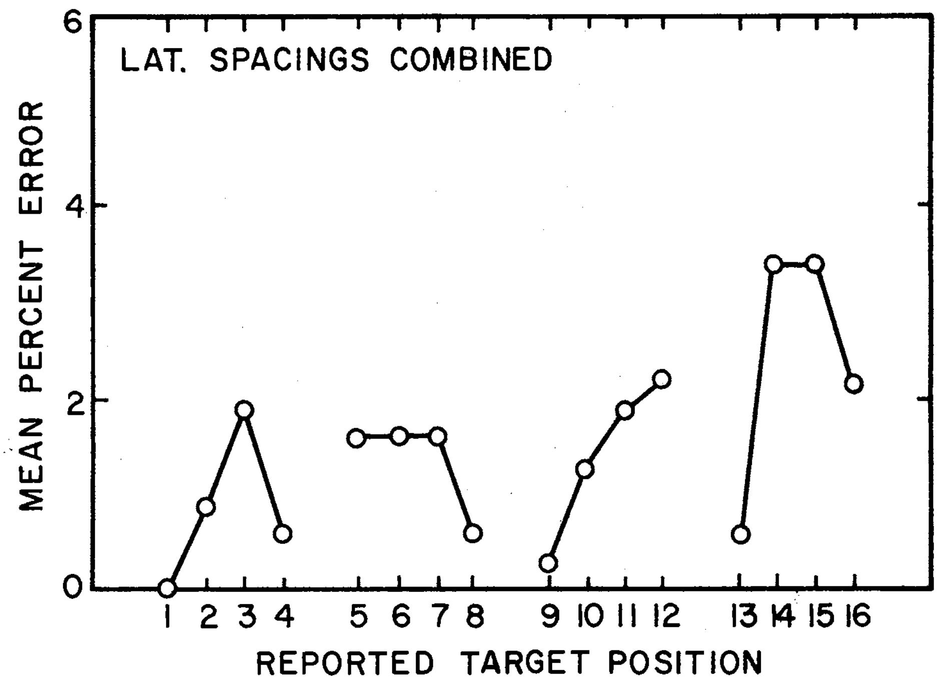


Figure 46. False Alarm Error Rates in 1 X 16 Configuration by Reported Target Position

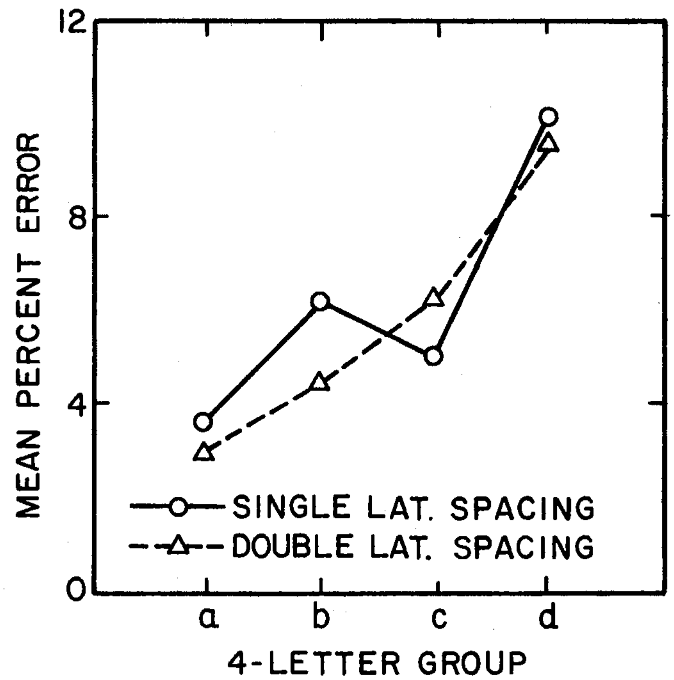


Figure 47. False Alarm Error Rates in 1 X 16 Configuration by Reported 4-Letter Group

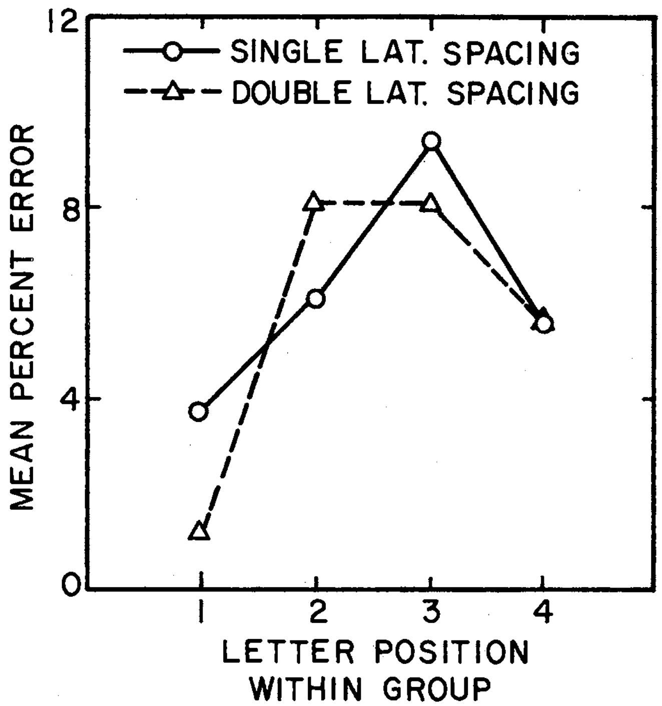


Figure 48. False Alarm Error Rates in 1 X 16 Configuration by Reported Letter Position Within Group

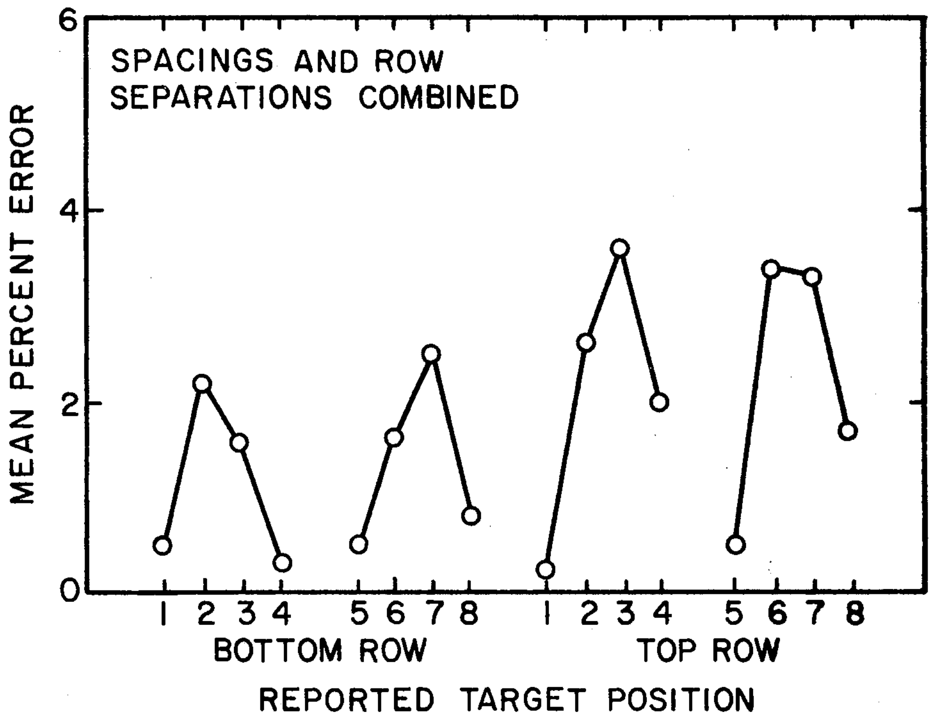


Figure 49. False Alarm Error Rates in 2 X 8 Configuration by Reported Target Position

TABLE XXI

SUMMARY OF FALSE ALARM ERROR RATES IN 2 X 8 CONFIGURATION

	Row Separation			
	Small		Large	
	Group (Row)		Group (Row)	
Lateral Spacing	Bottom	Top	Bottom	Top
Single	18.9	11.9	6.3	21.9
Double	8.3	17.5	6.3	18.2
Average	13.6	14.7	6.3	20.1
	Lateral Spacing			
	Single		Double	
	Group (Row)		Group (Row)	
Row Separation	Bottom	Top	Bottom	Top
Small	18.9	11.9	8.3	17.5
Large	6.3	21.9	6.3	18.2
Average	12.6	16.9	7.3	17.9

The Type II error patterns by the reported 4-letter group and by the reported letter position within groups are shown in Figures 50 and 51, respectively. Both of those variables were statistically significant. It can be noted from Figure 50 that the variability of the lateral spacing and row separation as variables in any one group was rather large. However, in combining groups the variability cancelled out, resulting in a lack of statistical significance of these two variables.

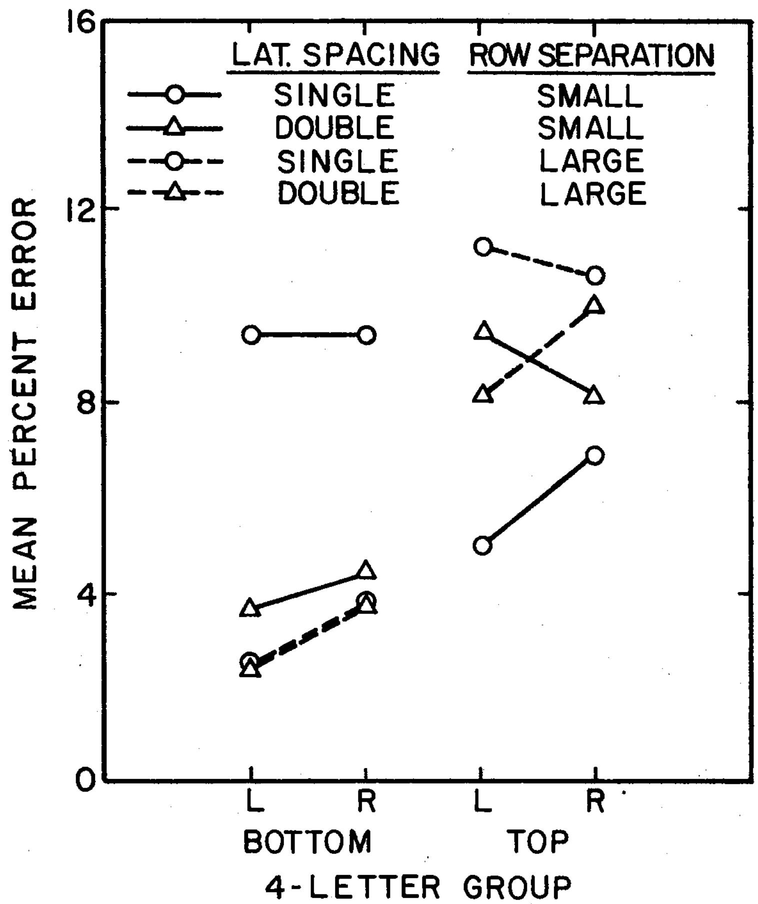


Figure 50. False Alarm Error Rates in 2 X 8 Configuration by Reported 4-Letter Group

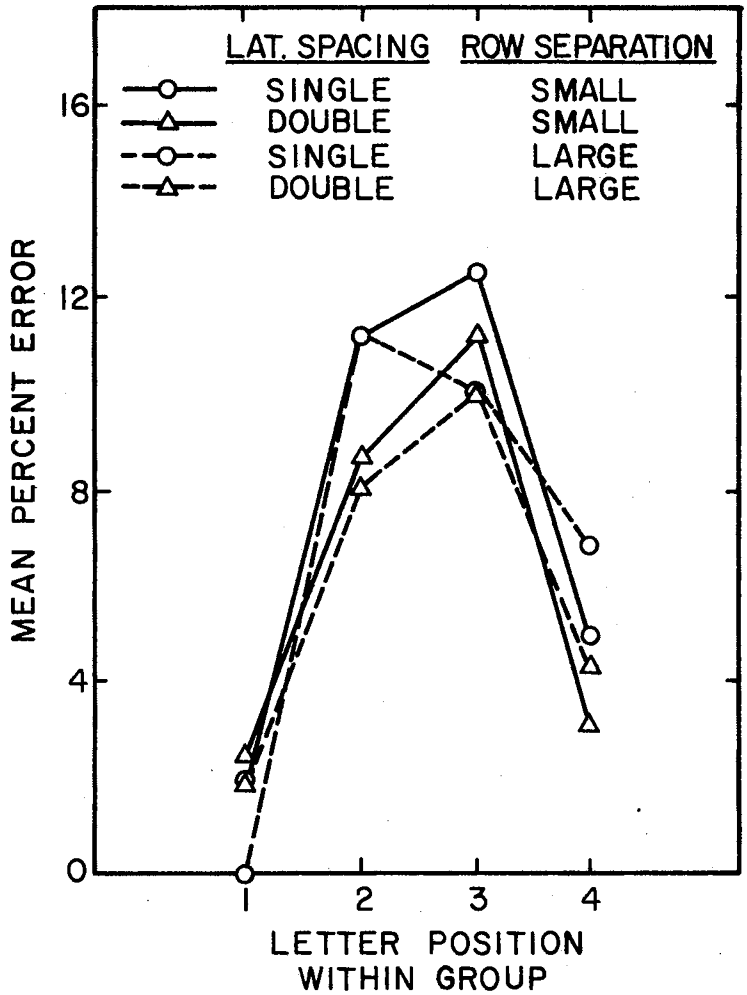


Figure 51. False Alarm Error Rates in 2 X 8 Configuration by Reported Letter Position Within Group

The 4 X 4 Configuration. As with the Type I errors in the same configuration, the false alarm errors in the 4 X 4 configuration formed a bow-shaped pattern in each of the four rows. Figure 52 shows the pattern graphically. Both reported target position and row separation were statistically significant variables (F test, at the 0.01 level). The mean false alarm error rate of the small row separation was only 7.5% compared to 22.4% for that of the large row separation. The experimenter has no explanation for this substantial difference.

The Type II error rates by reported group (in this case, by row) are shown in Figure 53. As can be seen, a substantial surge in the false alarm error rate occurred in the top two rows with the large row separation. No such surge occurred with the small row separation or in Type I errors with either row separation. The error rate patterns by reported letter position within each group are shown in Figure 54. This shows the surge in error rate with the large row separation to have been limited to the two interior positions, Nos. 2 and 3.

The 8 X 2 Configuration. Figure 55 shows the Type II error pattern by target position for the 8 X 2 configuration. The pattern was roughly bow shaped for each of the two columns. Both reported target position and row separation were variables having statistical significance. The mean Type II error rate of the small row separation in this configuration was 10.0% and that of the large row separation 18.1%. As with the Type I error pattern, no significant difference existed between the left- and right-hand columns.

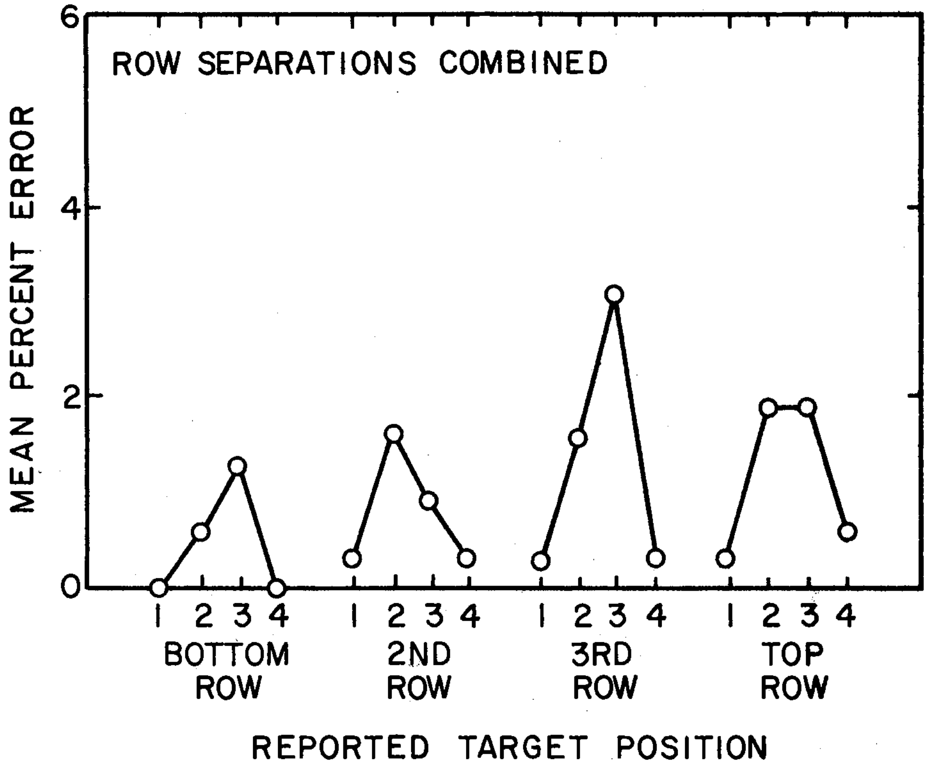


Figure 52. False Alarm Error Rates in 4 x 4 Configuration by Reported Target Position

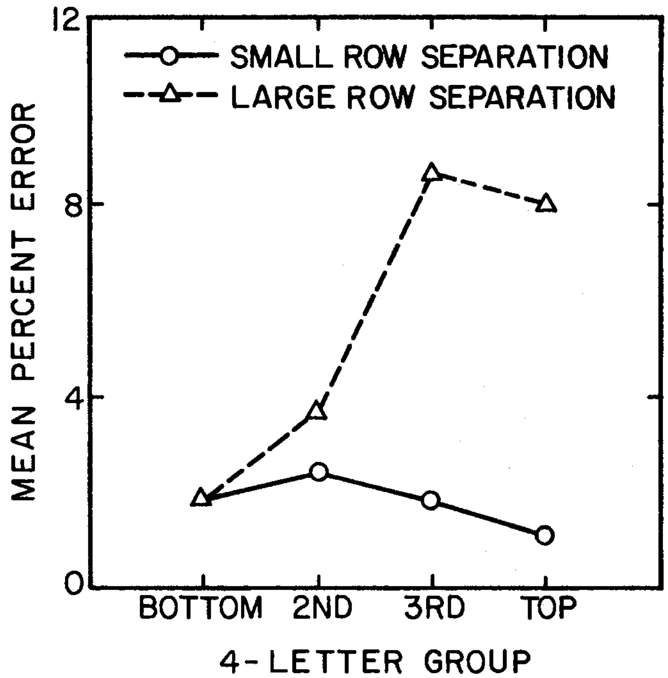


Figure 53. False Alarm Error Rates in 4 X 4 Configuration by Reported 4-Letter Group

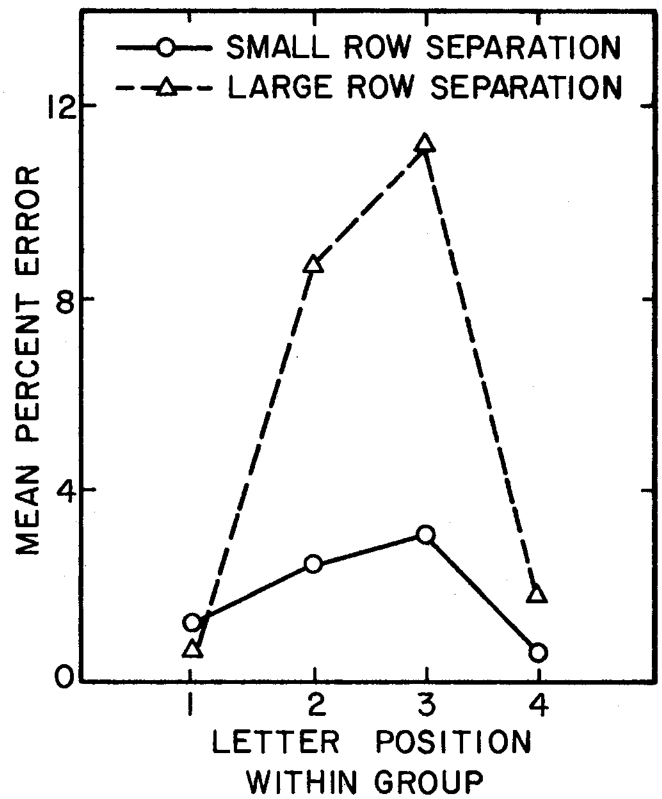


Figure 54. False Alarm Error Rates in 4 X 4 Configuration by Reported Letter Position Within Group

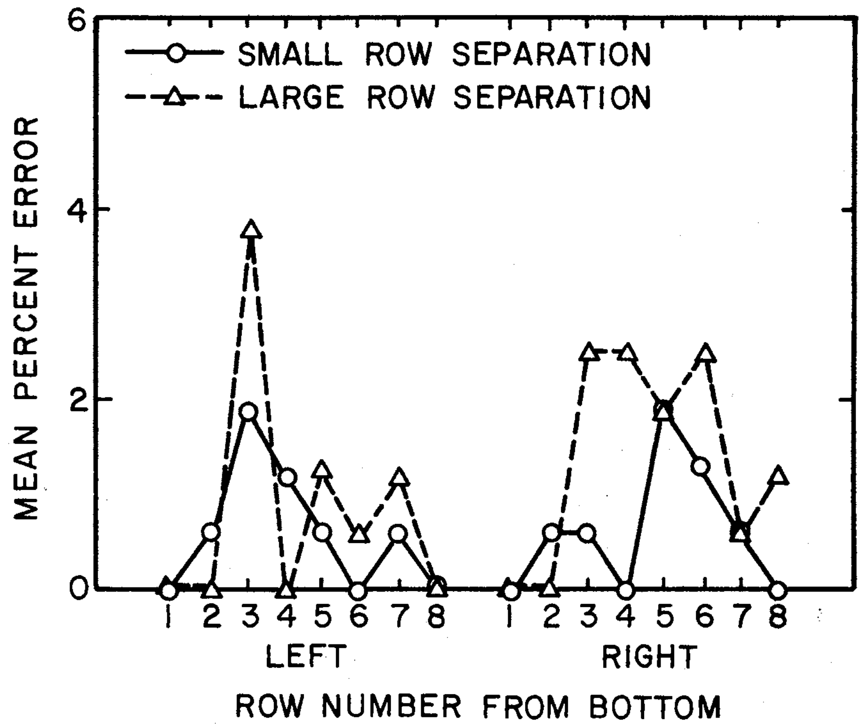


Figure 55. False Alarm Error Rates in 8 X 2 Configuration by Reported Target Position

Experiment IV Discussion

The Primary Purpose

The primary purpose of this experiment was to compare the effects of four configurations of 16-letter stimuli on visual performance. Analysis showed that the 4 X 4 configuration, the widest configuration normally perceived without lateral saccades, resulted in the lowest error level of the configurations compared. Although the advantage in Type I error rates of that configuration over the 2 X 8 configuration was not statistically significant, its advantage over the other two configurations were.

The 4 X 4 configuration also showed some advantage over the one- and two-row configurations with respect to Type II errors, especially with the small row separation, but this advantage was found to be statistically insignificant. The lack of advantage of the 4 X 4 configuration over the 8 X 2 configuration regarding Type II errors does not detract from the 4 X 4 configuration. The Type I error rates in the 8 X 2 configuration were extremely high, indicating that perception was poor at the high angular velocities used. Type II error rates under such conditions would be expected to be relatively low unless guessing prevailed.

Thus, the results of this experiment further support the first hypothesis favorably tested in Experiments I and II, namely, that the optimum trade-off between width of stimulus material and the speed of the visual field is that combination of width and speed that just provides the subject with effective perception without the need for saccadic eye movement.

<u>The Secondary Purposes</u>

One of the secondary purposes of this experiment was to test the second and third hypotheses of this research. These hypotheses read as follows:

> Hypothesis 2. Lateral spacing of the stimulus material is a factor that influences error rates in one- and two-row configurations.
>
> Hypothesis 3. Vertical separation between rows of multi-row configurations is an influencing factor on error rates.

Results show that to the extent to which this experiment tested these hypotheses, they both must be rejected. Neither the lateral spacing in the one- and two-row configurations nor the vertical separation between rows of multi-row configurations were significant variables with respect to Type I error rates.

The conclusions can be reached, then, that whereas some lateral spacing <u>patterns</u>, such as the 4 groups of 2 in an eight-unit stimulus (Experiment III), have significant perceptual advantage over other patterns, a small variation in the <u>amount</u> of spacing between groups of stimuli (Experiment IV) has no significant effect.

It also can be concluded that relatively small variations in the separation between rows, such as used in this experiment, have no significant effect on perceptual accuracy. It is readily apparent, however, that the vertical separation could be of such magnitude that the necessary angular velocities would significantly and adversely affect error rates.

Another secondary purpose of this experiment, as that of Experiments I and II, was the analysis of error patterns by target position within each configuration. Results of analysis of the Type I error rates in the 1 X 16 configuration revealed the typical masking effect, which causes increased error rates at all target positions except the extreme positions. The bow-shaped error pattern within each 4-letter group showed that grouping the stimulus material partially reduces the masking effect.

Results of the 2 X 8 and the 4 X 4 configurations also showed the masking effect within each row of stimulus material to be very prominent; however, in the 2 X 8 configuration, the 4-letter grouping did not reduce the masking effect as it did in the 1 X 16 configuration.

Analysis of Type I error rates in the 8 X 2 configuration confirmed the findings of Experiments I and II, namely that a strong masking effect of adjacent stimulus material exists in the direction of visual field movement at relatively high speeds. Evidence of this effect was also found in the 4 X 4 configuration (see Figure 42) but to a lesser degree.

Type II error rates in the 2 X 8 and 4 X 4 configurations show an effect equivalent to that of masking; that is, the extreme positions within each 4-letter group are reported erroneously less frequently than the interior positions. Type II error patterns in the other two configurations, the 1 X 16 and the 8 X 2, are basically random.

CHAPTER VI

SUMMARY AND CONCLUSION

Summary

In any visual search task in a dynamic field there exists an interaction between viewer's perceptual ability and the display width-display speed combination. The primary purpose of this research is to investigate this interaction by evaluating task performance under various configurations of stimulus material.

The task throughout this experimentation was for each subject to determine the existence and location of a predetermined target within an array of background stimulus material. Performance was evaluated on the basis of missed target and false alarm error rates committed.

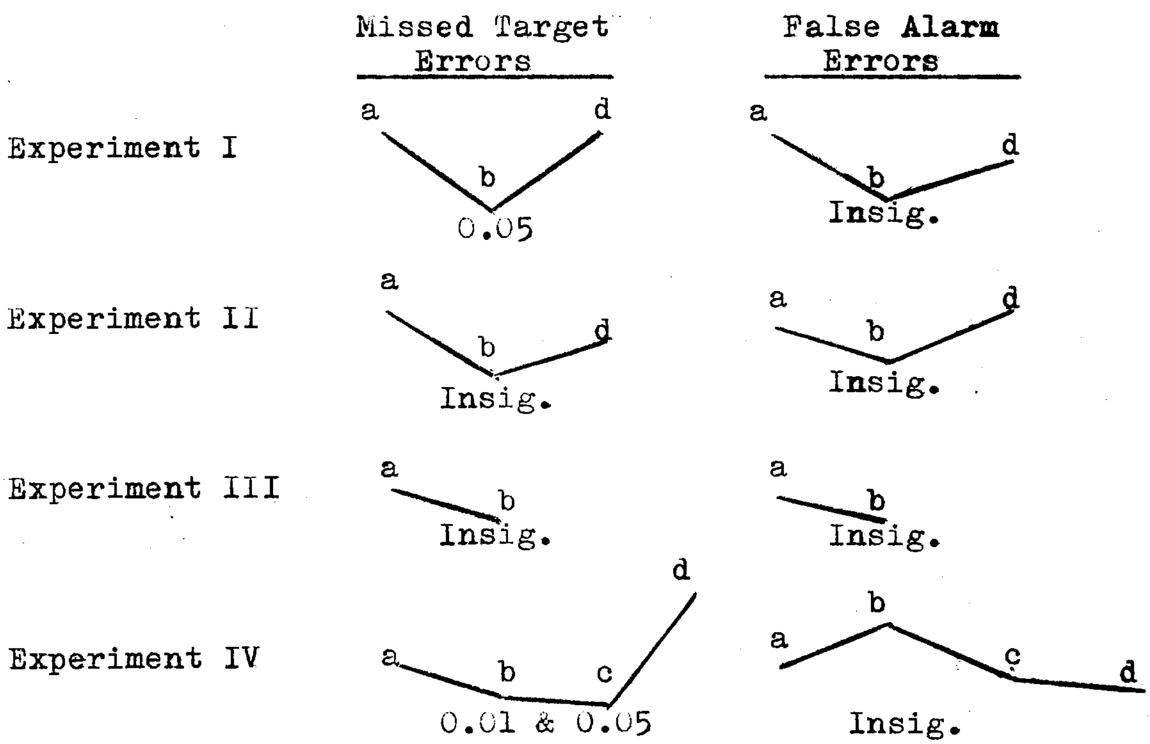
Secondary purposes of this investigation include the analysis of error patterns within each stimulus configuration and the effect of relatively small spacing variations in the arrays of stimulus material on perceptual accuracy.

In three of the four experiments comprising this research, the displays consisted of capital letters. In each of these experiments the context-target combination was of a high confusability level (Kaplan et al., 1966). The remaining experiment (Experiment II) used displays consisting of six dials. Experiment I compared three configurations: 1 X 8, 2 X 4, and 4 X 2, where the first digit of each pair gives the number of rows in the display and the second digit, the number of units per row. For interconfiguration analyses throughout this research the speed of the moving field was adjusted so as to provide the same display exposure time for each configuration.

Experiment II compared the following three configurations: 1 X 6, 2 X 3, and 3 X 2. Although each display had fewer units than in the first experiment, the display widths were approximately 78% greater (two inches versus 1 1/8 inches, in the one-row configuration).

Experiment III, using 8-letter displays in the one- and two-row configurations, compared various lateral spacing patterns. In Experiment IV, 16-letter displays were used, the configurations compared being 1 X 16, 2 X 8, 4 X 4, and 8 X 2. The lateral spacing between four-letter groups in the one- and two-row configurations was treated as a variable as was the vertical separation between rows of the multi-row configurations.

In order that the major findings of the various experiments can readily be compared, summaries of error patterns are presented as Figures 56 and 57. The former summarizes error patterns by configuration and shows the statistical significance of that variable as determined by the F test. With the exception of the patterns of Experiment III, which compares only two configurations, the patterns generally form a V shape. This reveals that the one-row and two-column configurations, presented respectively at relatively slow and fast visual field speeds, have higher error rates than the configurations presented at the moderate visual field speeds. The missed target error patterns of Experiments I and IV are the only patterns of those investigated in which configuration is a statistically significant variable.



Key:
a = One-row confgn. c = Four-row confgn.
b = Two-row confgn. d = Two-column confgn.

Figure 56. A Summary of Error Patterns by Configuration Showing Statistical Significance by the F Test

	Configuration			
	One-Row	Two-Row	Four-Row	Two-Column
Experiment I				
	8 Letters	4 Letters each	---	4 Letters each
Missed Target Errors	0.01	Random Insig.		0.01
False Alarm Errors	Random Insig.	0.01		Random 0.01
Experiment II				
	6 Dials	3 Dials each	---	3 Dials each
Missed Target Errors	0.01	0.01		0.01
False Alarm Errors	0.01	Insig.		0.01
Experiment IV				
	16 Letters	8 Letters each	4 Letters each	8 Letters each
Missed Target Errors	0.05	0.01	0.01	0.01
False Alarm Errors	0.01	0.01	0.01	Random 0.01
Groups of 4 Letters Each:				
Missed Target Errors	Insig.	Insig.	0.01	N.A.
False Alarm Errors	0.05	0.01	Insig.	N.A.
Letter Position Within Group:				
Missed Target Errors	0.05	0.01 & 0.05	0.01	N.A.
False Alarm Errors	0.01	0.01	0.01	N.A.

Figure 57. A Summary of Error Patterns Within Configuration Showing Statistical Significance by the F Test

Figure 57 summarizes the error patterns within each configuration. Experiment III is not included in the chart inasmuch as that experiment did not include an intraconfiguration analysis. The statistical significance of target position as a variable is also shown. The glaring differences in error pattern between experiments are found in the one-row configuration under missed target errors, and include (1) the lack of a masking effect with the dials in Experiment II, and (2) the lack of a tunnel effect, or U-shape pattern, with the 16-letter string of Experiment IV.

The outstanding similarity in the error patterns from experiment to experiment is in the masking effect in the direction of visual field movement, as evidenced by the inverted U, in the two-column configuration. Several other similarities in the patterns of Experiment IV are noteworthy: (1) the similarity between the missed target and the false alarm error patterns in each of the configurations, and (2) the similarity in the bow shape of the grouped error patterns, namely, the groups of 4 letters each, and the letter position within group.

Conclusion

Analysis of the experimental data of this research suggests the following:

1) In a visual task involving the search of a given amount of stimulus material in a given time, accuracy is greatest on the widest and slowest moving display that does not require saccadic eye movement. This statement withstands the test of variations in the size of the display area, in the size

and number of stimulus units, and in the spacing characteristics of the display. However, insufficient experimentation was performed to fully prove this first hypothesis.

2) In searching displays in which the stimulus units are relatively compact, such as rows of closely spaced letters, the effect of lateral masking is dominant. This allows the extreme target positions to be perceived more accurately than interior target positions. This effect does not prevail, however, with larger, less compact stimulus units, such as 0.22-inch-diameter dials.

3) Segregating an otherwise compact row of stimulus units into groups, such as four groups of two units each, tends to improve perceptual accuracy. On the other hand, small variations in the amount of lateral spacing between units or groups of units have no appreciable effect.

4) The effect of masking from adjacent stimulus material is strong in the direction of visual field movement at the higher rates of speed. This masking effect is a function of the field speed, the greater the speed the more prominent the effect.

5) Small variations in the amount of spacing between rows of stimulus material have no appreciable effect on perceptual accuracy.

6) The missed target error pattern of one-row configurations having six or eight stimulus units uniformly spaced (Experiments I and II) has a distinct U-shape or tunnel effect. This conclusion agrees with the findings of Averbach-Coriell

and Crovitz-Shiffman, who conducted studies with tachistoscopic projections and also of Green, whose studies were with both tachistoscopic and dynamic field perception. No such tunnel effect occurs, however, in the patterns of missed target errors of configurations in which the stimulus units are grouped (Experiment IV). Rather, the effect of masking dominates.

Results of these experiments suggest the following areas for future investigation of visual search behavior:

1) The study of perceptual accuracy under large variations of stimulus widths and aperture heights.

2) Analysis of the trade-off between the amount of stimulus material to be scanned in a given time and the target-context confusion level.

3) The effects of changes in frequency of target appearance.

It is for future research in areas such as suggested here to develop more fully the optimum conditions under which visual inspection tasks should be undertaken. Hopefully, the findings of this research will be a worthwhile contribution to this endeavor.

A SELECTED BIBLIOGRAPHY

Adams, S. Keith.

1970 "Dynamic Perceptual Factors in the Visual Inspection of Linear Displays." (Unpub. paper presented at the Fourteenth Annual Meeting of the Human Factors Society, San Francisco.)

Adler, F. H.

1950 _Physiology of the Eye_. St. Louis, Missouri: C. V. Mosby Co., 392-394.

Averbach, E., and A. S. Coriell.

1961 "Short-Term Memory in Vision." _The Bell System Technical Journal_, Vol. 40, Pt. 1 (January), 309-328.

Baker, Charles A., D. F. Morris, and W. C. Steedman.

1960 "Target Recognition on Complex Displays." _Human Factors_, Vol. 2 (May), 51-61.

Brown, R., and K. Strongman.

1966 "Visual Search and Stimulus Orientation." _Perceptual and Motor Skills_, Vol. 23, 539-542.

Burg, A., and S. F. Hulbert.

1961 "Dynamic Visual Acuity as Related to Age, Sex, and Static Acuity." _Journal of Applied Psychology_, Vol. 45, 111-116.

Crovitz, H. F., and H. R. Schiffman.

1965 "Visual Field and the Letter Span." _Journal of Experimental Psychology_, Vol. 70, No. 2, 218-223.

Erickson, Donald A.

1964a "Relation Between Visual Search Time and Peripheral Visual Acuity." _Human Factors_, Vol. 6 (April), 165-177.

1964b "Visual Search Performance in a Moving Structural Field." _The Optical Society of America_, Vol. 54, No. 3, 399-405.

Gibson, E. J., and A. Yonas.

1966 "A Developmental Study of the Effects of Visual and Auditory Interference on a Visual Scanning Task." Psychonomic Science, Vol. 5 (4), 163-164.

Green, Jesse L.

1970 "Visual Search in a Dynamic Field." (Unpub. Ph.D. Dissertation, Oklahoma State University.)

Harcum, E. Rae.

1957 "Parallel Functions of Serial Learning and Tachistoscopic Pattern Perception." Psychological Review, Vol. 74, No. 1, 51-62.

1964 "Interactive Effects Within Visual Patterns on the Discriminability of Individual Elements." Journal of Experimental Psychology, Vol. 64, No. 4, 351-356.

Kaplan, G. A., A. Yonas, and A. Shurcliff.

1966 "Visual and Acoustic Confusability in a Visual Search Task." Perception and Psychophysics, Vol. 1, 172-174.

Lippert, S.

1963 "Dynamic Vision - The Legibility of Equally Spaced Alphanumeric Symbols." Human Factors, Vol. 5, No. 2 (April), 129-138.

Lippert, S., and D. M. Lee.

1965 "Dynamic Vision - The Legibility of Moderately Spaced Alphanumeric Symbols." Human Factors, Vol. 7, No. 6 (December), 555-560.

Ludvigh, Elek, and James W. Miller.

1958 "Study of Visual Acuity During the Ocular Pursuit of Moving Test Objects. I. Introduction." The Optical Society of America, 48 (11), 799-802.

Mackworth, N.

1965 "Visual Noise Causes Tunnel Vision." Psychonomic Science, Vol. 3, 67-68.

Miller, James W.

1958 "Study of Visual Acuity During the Ocular Pursuit of Moving Test Objects. II. Effects of Direction of Movement, Relative Movement, and Illumination." _The Optical Society of America_, 48 (11), 803-808.

Neisser, Ulric.

1963 "Decision-time Without Reaction-time: Experiments in Visual Scanning." _American Journal of Psychology_, Vol. 76, 376-385.

1964 "Visual Search." _Scientific American_, Vol. 210, 94-102.

Nelson, J. B.

1969 "A Dynamic Visual-Recognition Test for Paced Inspection Tasks." (Unpub. Ph.D. Dissertation, Purdue University.)

Ostle, Bernard.

1963 "Analysis of a Completely Randomized Design Involving Factorial Treatment Combinations." _Statistics in Research_, 2nd. ed. Ames, Iowa: The Iowa State University Press.

Snedecor, George W., and W. G. Cochran.

1967 "Non-normality. Variance-stabilizing Transformations." _Statistical Methods_, 6th ed. Ames, Iowa: The Iowa State University Press.

Steedman, W. C., and C. A. Baker.

1960 "Target Size and Visual Recognition." _Human Factors_, Vol. 2 (August), 120-127.

Underwood, B. J.

1966 _Experimental Psychology_. New York: Appleton-Century-Crofts, 113-278.

Weissman, Seymour, and C. M. Freeburne.

1965 "Relationship Between Static and Dynamic Visual Acuity." _Journal of Experimental Psychology_, Vol. 70 (2), 141-146.

Williams, Leon G., and M. S. Borow.

1963 "The Effect of Rate and Direction of Display Movement Upon Visual Search." _Human Factors_, Vol. 5, No. 2 (April), 139-146.

Winer, B. J.

1962 *Statistical Principles in Experimental Design.* New York: McGraw-Hill.

Woodworth, R. S.

1938 *Experimental Psychology.* New York: Henry Holt and Co., 746-749.

APPENDIXES

APPENDIX A

SAMPLE VELOCITY COMPUTATIONS FOR EXPERIMENT I

Linear Distance Travelled During Exposure Time

General Formula:

Distance = Aperture Ht. + (Letter Ht. × No. Rows) + (Row Septn. × No. Septns.)

Example for 4 × 2 Configuration:

$$\text{Distance} = 1/4'' + (1/8'' \times 4) + (5/16'' \times 3) = \underline{\underline{1\ 11/16}}''$$

Linear Velocity in Inches Per Second

General Formula:

$$\text{Velocity} = \frac{\text{Distance Travelled During Exposure Time}}{\text{Exposure Time in Sec.}}$$

Example for 4 × 2 Configuration, Long Exposure Time:

$$\text{Velocity} = \frac{1\ 11/16''}{0.833\ \text{sec.}} = \underline{\underline{2.03''/\text{sec.}}}$$

Maximum Angular Velocity in Degrees Per Second

General Formula:

$$\text{Max. Ang. Vel.} = \frac{\text{Linear Velocity} \times 57.3^\circ/\text{rad.}}{\text{Min. Distance in Inches}}$$

Example for 4 × 2 Configuration, Long Exposure Time:

$$\text{Max. Ang. Vel.} = \frac{2.03''/\text{sec.} \times 57.3^\circ/\text{rad.}}{15''} = \underline{\underline{7.7^\circ/\text{sec.}}}$$

APPENDIX B

INSTRUCTIONS FOR FIRST CONFIGURATION OF EXPERIMENT I

This experiment deals with visual perception in a moving field. Your task is to identify and locate a given target within a horizontal string of similar characters.

The string of characters in this experiment is composed of eight alphabetic letters and the target is always the letter K. The string of letters will always pass in front of the viewing slot from top to bottom. A horizontal line will appear in the viewing slot as a "get ready" signal approximately one second prior to the presentation of each string. A string of letters will contain no more than one target and may contain no target at all.

If you perceive the target in a presented string, you are to check on the tally sheet its perceived position in the string of eight positions, from position one through position eight. If you do not perceive the target, draw a line through the trial number. Ample time will be provided between string presentations for you to record your answer.

Keep in mind, not every string contains the target. In the strings that do contain a target, the target position is located on a random basis. Remember, the target is always the letter K. Please try to be as accurate as you can.

Are there any questions?

APPENDIX C

STATISTICAL ANALYSIS OF EXPERIMENT III

Missed Target Errors

The completely randomized experiment with a split plot included the three spacing patterns that were used in both configurations; namely, the 2 groups of 4, and 4 groups of 2, and double spacing. Single spacing was eliminated from this analysis because it did not apply to both configurations. None of the variables in this design were found from the F test to be significant at the 0.05 level, not the main plot variable configuration, nor either of the sub-plot variables spacing pattern or the configuration-spacing pattern interaction. Because of this lack of significance the summary of the ANOVA has not been included in this paper.

The F test on the 4 X 10 factorial design covering the 1 X 8 configuration showed the variable spacing pattern to be statistically insignificant. A similar test on the 3 X 10 factorial covering the 2 X 4 configuration showed spacing pattern to be significant at the 0.05 level. The variable subject was significant ($p < 0.01$) in both these tests. A summary of the ANOVA of the 3 X 10 factorial design is given, as illustration, in Table XXII; that of the 4 X 10 factorial has not been included.

TABLE XXII

ANOVA FOR MISSED TARGET ERRORS BY SPACING PATTERN -- 2 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Subject (S)	9	0.749	0.083	16.72**
Spacing Pattern (L)	2	0.040	0.020	3.98*
Error	18	0.090	0.005	
TOTAL	29	0.879		

*Significant at 0.05 level.

**Significant at 0.01 level.

False Alarm Errors

Table XXIII shows a summary of the ANOVA of the completely randomized experiment with a split plot. As has been mentioned earlier, this analysis included only those three spacing patterns that were used in both configurations; thus the single spacing pattern of the 1 X 8 configuration was excluded. The F test showed that spacing pattern was the only significant variable ($p < 0.01$), the 4 groups of 2 spacing pattern having a lower error rate than either the 2 groups of 4 or the double spacing patterns.

The F test on the 4 X 10 factorial design covering the 1 X 8 configuration indicated that the variable spacing pattern was statistically insignificant. However, the 3 X 10 factorial covering the 2 X 4 configuration showed the variable spacing pattern to be barely significant at the 0.05 level. The variable subject was significant in both these tests at the 0.01 level. The ANOVA of the 3 X 10 factorial for the 2 X 4 configuration is shown in Table XXIV; that of the 4 X 10 factorial has not been included.

TABLE XXIII

ANOVA FOR FALSE ALARM ERRORS -- BOTH CONFIGURATIONS

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	1	0.192	0.192	0.64
Subject w. C	18	5.443	0.302	
Sub Plot				
Spacing Pattern (L)	2	0.187	0.094	6.49*
C X L	2	0.007	0.004	0.24
Sub-Plot Error	36	0.519	0.014	
TOTAL	59	6.348		

*Significant at 0.01 level.

TABLE XXIV

ANOVA FOR FALSE ALARM ERRORS BY SPACING PATTERN -- 2 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Subject (S)	9	1.710	0.190	10.15**
Spacing Pattern (L)	2	0.133	0.067	3.56*
Error	18	0.337	0.019	
TOTAL	29	2.180		

*Significant at 0.05 level.

**Significant at 0.01 level.

APPENDIX D

SAMPLE VELOCITY COMPUTATIONS FOR EXPERIMENT IV

<u>Linear Distance Travelled During Exposure Time</u>

General Formula:

Distance = Aperture Ht. + (Letter Ht. X No. Rows) +
(Row Septn. X No. Septns.)

Example for 4 X 4 Configuration, 7/16" Row Septn:

Distance = 3/8" + (1/8" X 4) + (7/16" X 3) = <u>2 3/16"</u>

<u>Linear Velocity in Inches Per Second</u>

General Formula:

$$\text{Velocity} = \frac{\text{Distance Travelled During Exposure Time}}{\text{Exposure Time in Sec.}}$$

Example for 4 X 4 Configuration, 7/16" Row Septn:

$$\text{Velocity} = \frac{2\ 3/16''}{1.15\text{ sec.}} = \underline{\underline{1.90''/\text{sec.}}}$$

<u>Maximum Angular Velocity in Degrees Per Second</u>

General Formula:

$$\text{Max. Ang. Vel.} = \frac{\text{Linear Velocity} \times 57.3^{\circ}/\text{rad.}}{\text{Min. Distance in Inches}}$$

Example for 4 X 4 Configuration, 7/16" Row Septn:

$$\text{Max. Ang. Vel.} = \frac{1.90''/\text{sec.} \times 57.3^{\circ}/\text{rad.}}{15''} = \underline{\underline{7.3^{\circ}/\text{sec.}}}$$

Minimum Distance to Limit Angular Velocity

General Formula:

$$\text{Min. Distance} = \frac{\text{Linear Velocity} \times 57.3^{\circ}/\text{rad.}}{\text{Max. Angular Velocity}}$$

Example for 8 X 2 Configuration, 7/16" Row Septn:

$$\text{Min. Distance} = \frac{3.85''/\text{sec.} \times 57.3^{\circ}/\text{rad.}}{8^{\circ}/\text{sec.}} = \underline{\underline{27.5''}}$$

APPENDIX E

STATISTICAL ANALYSIS OF EXPERIMENT IV

Missed Target Errors

Interconfiguration Comparison. The first completely randomized experiment with a split plot was an analysis of lateral spacing and the one- and two-row configurations. Only the data from the small row separation were used for the 2 X 8 configuration. A second analysis of the same design was used to make the same comparison using the data from the large row separation of the 2 X 8 configuration. The F test as applied to both these designs showed the main plot variable configuration to be significant, in the former at the 0.05 level, and in the latter at the 0.01 level. Neither the variable lateral spacing nor the configuration-lateral spacing interaction were significant in either design.

Another pair of completely randomized experiments with split plots were utilized to analyze vertical row separation and the multi-row configurations. In the first, only the data from the single lateral spacing were used for the 2 X 8 configuration. In the second, data from the double spacing for the 2 X 8 configuration were utilized. As before, the main plot variable configuration was the only significant variable, and this at the 0.01 level in both designs.

Because of the similarity in the ANOVA's of these four completely randomized experiments, only one is presented as example. The ANOVA of the third experiment mentioned (analysis of multi-row configurations, single spacing used for the 2 X 8) is summarized in Table XXV.

TABLE XXV

ANOVA FOR MISSED TARGET ERRORS -- MULTI-ROW CONFIGURATIONS-SINGLE SPACING IN 2 X 8 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	1.411	0.706	12.96*
Subject w. C	27	1.470	0.054	
Sub Plot				
Row Separation (V)	1	0.003	0.003	0.31
C X V	2	0.058	0.029	2.98
Sub-Plot Error	27	0.263	0.010	
TOTAL	59	3.205		

*Significant at 0.01 level.

A Newman-Keuls (N-K) test was run on the individual means of each of the latter two completely randomized experiments. Results of these showed that with vertical row separations combined, the mean percent error rate of the 8 X 2 configuration was significantly greater than that of either the 2 X 8 or the 4 X 4 configurations. Since mention has already been made that the error rates of the 1 X 16 and 2 X 8 configurations were significantly different, it can be concluded that the 2 X 8 and the 4 X 4 configurations had significantly lower error rates than those of the other two configurations. However, the N-K test revealed that the mean error rate of the 4 X 4 configuration was not significantly lower than that of the 2 X 8 configuration.

Repeated Measures Analysis. An ANOVA was developed for each of four different repeated measures analyses corresponding to the four completely randomized experiments with split plots described earlier. As expected from the results of the earlier analyses, the variable configuration was found significant in each of the repeated measures analyses but neither lateral spacing nor row separation was found significant in any of the analyses. Likewise, the sequence effect, as evidenced by the variable trial in the ANOVA, was found insignificant throughout the repeated measures analyses. A summary of the ANOVA of one of these analyses is shown, as example, in Table XXVI.

TABLE XXVI

ANOVA FOR MISSED TARGET ERRORS USING REPEATED MEASURES -- MULTI-ROW CONFIGURATIONS-SINGLE SPACING IN 2 X 8 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Between Subjects:				
Configuration (C)	2	2.977	1.488	12.28*
Error	27	3.273	0.121	
Within Subjects:				
Row Separation (V)	1	0.008	0.008	0.39
Trial (T)	1	0.001	0.001	0.03
V X T	1	0.010	0.010	0.48
V X C	2	0.107	0.054	2.62
T X C	2	0.025	0.013	0.62
V X T X C	2	0.027	0.013	0.65
Error	81	1.656	0.020	
TOTAL	119	8.084		

*Significant at 0.01 level.

<u>The 1 X 16 Configuration</u>. Two factorials were designed to analyze error rates in this configuration. In the first, a 2 X 10 X 16 factorial, target position as a variable had 15 degrees of freedom. In the second, a 2 X 4 X 4 X 10 factorial, the target positions were placed in four groups of four letter positions each. A summary of the ANOVA of the first factorial is shown in Table XXVII. The F test revealed that the variable subject was significant at the 0.01 level and the variable target position at the 0.05 level (see Figure 35). The subject-target position interaction was also found to be significant ($p < 0.01$). As mentioned earlier, the statistical significance of subject as a variable and of the first-order interactions involving subject points up the lack of homogeneity in the cognitive processes of people. This is evidenced throughout this experimentation. An N-K test revealed no significant differences in the mean error rates of the individual target positions. As mentioned in Experiment I, the lack of normality of data was the main reason for the inconsistency of results between the F test and the N-K test.

Table XXVIII shows the summary of the ANOVA of the 2 X 4 X 4 X 10 factorial design. Neither lateral spacing nor group was found to be significant. The significant main effect variables were subject ($p < 0.01$) and letter position ($p < 0.05$) (see Figures 36 and 37). Subject-group and subject-letter position were significant first-order interactions, both at the 0.01 level, while group-letter position-lateral spacing was the sole significant second-order interaction ($p < 0.05$). Although the F test showed letter position to be a significant variable, an N-K test revealed no significant differences between any of the means of the four-letter positions.

TABLE XXVII

ANOVA FOR MISSED TARGET ERRORS BY TARGET POSITION -- 1 X 16 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	10.054	1.117	5.10**
Target Position (P)	15	6.455	0.430	1.97*
Lat. Spacing (L)	1	0.002	0.002	0.01
S X P	135	49.265	0.365	1.67**
Residual	159	34.818	0.219	
TOTAL	319	100.594		

*Significant at 0.05 level.

**Significant at 0.01 level.

TABLE XXVIII

ANOVA FOR MISSED TARGET ERRORS BY GROUP AND LETTER POSITION WITHIN GROUP -- 1 X 16 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	10.054	1.117	5.19**
Group (G)***	3	1.362	0.454	2.11
Letter Position (P)	3	1.748	0.583	2.71*
Lat. Spacing (L)	1	0.002	0.002	0.01
S X G	27	18.686	0.692	3.22**
S X P	27	12.602	0.467	2.17**
G X P X L	9	4.471	0.497	2.31*
Residual	240	51.668	0.215	
TOTAL	319	100.594		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: 4-letter groups designated a, b, c, and d.

<u>The 2 X 8 Configuration</u>. Four factorial designs were found necessary in the analysis of this data. The reason for this was the fact that a single factorial covering the entire analysis would have had data points far in excess of the capacity of the IBM 1130 computer, the computer used in the statistical analysis throughout this investigation. Each of the four designs was a 2 X 2 X 8 X 10 factorial. The first was limited to data involving the small row separation; the second, limited to data involving the large row separation. In these analyses the variables were group (bottom and top rows), lateral spacing, target position, and subject. The third and fourth analyses were limited to single and double lateral spacing, respectively. In these analyses, row separation replaced lateral spacing as a variable.

In all four of these analyses, the variables subject and target position were found from the F test to be significant at the 0.01 level. The variables group, lateral spacing, and row separation were found insignificant in each of the appropriate analyses (see Figure 38). Only in an occasional significant interaction was there any difference in the F test results of the various analyses. A summary of the ANOVA of the first of the four analyses is shown in Table XXIX. Several N-K tests showed significance at the 0.05 level as follows:

a) In the bottom row, target position No. 8 was significantly lower than position No. 3.

b) In the top row, target position No. 8 was significantly lower than all other target positions.

c) Combining bottom and top rows, target position No. 8 was significantly lower than all other target positions and target position No. 1 was significantly lower than position No. 3.

TABLE XXIX

ANOVA FOR MISSED TARGET ERRORS BY TARGET POSITION --
2 X 8 CONFIGURATION-SMALL ROW SEPARATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	8.941	0.993	4.38*
Group (G)**	1	0.156	0.156	0.69
Target Position (P)	7	9.985	1.426	6.29*
Lat. Spacing (L)	1	0.094	0.094	0.42
S X P	63	31.290	0.497	2.19*
G X P X L	7	4.575	0.654	2.98*
Residual	231	52.342	0.227	
TOTAL	319	107.383		

*Significant at 0.01 level.

**Groups are: Bottom row and top row.

Again, four factorial designs were found necessary in the analysis of error patterns by 4-letter group and letter position within groups. Letter position as a variable was significant at the 0.01 level in the first and third factorials and at the 0.05 level in the other two (see Figures 39 and 40). The variable group (in this case, bottom left, bottom right, top left, and top right) was insignificant in each of the analyses. The other variables, subject (significant at the 0.01 level), lateral spacing (insignificant), and row separation (insignificant) showed the same results as in the previous analysis. Because of this similarity of results, another ANOVA summary has not been included. An N-K test showed that the within-group target position No. 4 was significantly lower than the other three target positions and position No. 1 was significantly lower than both position Nos. 2 and 3.

The 4 X 4 Configuration. A summary of the ANOVA of the data of this configuration is shown in Table XXX. The F test revealed that subject, group (in this case, row), and target position were variables statistically significant at the 0.01 level (see Figure 41). Also significant, as noted in the table, were several first- and second-order interactions, all interactions involving the variable subject. Once again, the main effect variable row separation was found to be insignificant.

TABLE XXX

ANOVA FOR MISSED TARGET ERRORS -- 4 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	28.359	3.151	25.38**
Group (G)***	3	5.092	1.697	13.65**
Target Position (P)	3	10.501	3.500	28.14**
Row Separation (V)	1	0.123	0.123	0.99
S X G	27	11.162	0.413	3.32**
S X P	27	14.538	0.538	4.33**
S X G X P	81	13.799	0.170	1.37*
S X P X V	27	6.087	0.225	1.81*
Residual	141	17.515	0.124	
TOTAL	319	107.175		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Bottom, 2nd, 3rd, and top rows.

An N-K test on the mean error rates by group, or row, indicated that both the top and bottom rows had significantly lower Type I error rates than that of either of the middle two rows ($p < 0.05$) (see Figure 42). Letter position No. 4 had a significantly lower error rate than any of the other positions, according to an N-K test on the means of the letter positions within group, and position No. 2 had a significantly higher rate than any of the other positions (see Figure 43).

<u>The 8 X 2 Configuration</u>. The ANOVA summary is shown in Table XXXI. As can be seen, the F test showed the variables subject and target position to be significant at the 0.01 level, and for the first time, the variable row separation showed significance ($p < 0.05$) (see Figure 44). An N-K test showed that with both row separations and both columns combined, the top row had a significantly lower error rate than all rows other than the bottom row, and the bottom row had a significantly lower rate than the third row from the bottom only.

TABLE XXXI

ANOVA FOR MISSED TARGET ERRORS -- 8 X 2 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	7.980	0.887	3.18**
Group (G)***	1	0.008	0.008	0.03
Target Position (P)	7	23.720	3.389	12.14**
Row Separation (V)	1	1.510	1.510	5.41*
Residual	301	85.943	0.285	
TOTAL	319	119.160		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Left and right columns.

False Alarm Errors

Interconfiguration Comparison. As with the analysis of Type I error rates by configuration, four completely randomized experiments with split plots were used in the analysis of Type II error rates. The first two, which compared the 1 X 16 and the 2 X 8 configurations, revealed no significant variables as determined by the F test. Both the latter two, which compared error rates in the multi-row configurations, showed the variable row separation to be the only significant variable ($p < 0.05$). The ANOVA of the last of these four analyses is presented as example in Table XXXII.

TABLE XXXII

ANOVA FOR FALSE ALARM ERRORS -- MULTI-ROW CONFIGURATIONS-
DOUBLE SPACING IN 2 X 8 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Main Plot				
Configuration (C)	2	0.388	0.194	1.54
Subject w. C	27	3.411	0.126	
Sub Plot				
Row Separation (V)	1	0.189	0.189	4.68*
C X V	2	0.221	0.111	2.74
Sub-Plot Error	27	1.091	0.040	
TOTAL	59	5.301		

*Significant at the 0.05 level.

The 1 X 16 Configuration. In the 2 X 10 X 16 factorial design, the main effects subject and reported target position were the only significant variables, and these at the 0.01 level. A summary of the ANOVA is not shown. An N-K test showed that reported target position Nos. 1 and 9 were the only positions having significantly lower Type II error rates than any other individual positions (see Figure 46). The error rate of position No. 1 was significantly lower than the ten highest positions, and that of position No. 9 was significantly lower than the two highest positions, Nos. 14 and 15.

A summary of the ANOVA of error rates by reported 4-letter group and by reported letter position within each group is shown in Table XXXIII. Results of the F test showed that the main effect variables subject and reported letter position were significant at the 0.01 level and the variable group at the 0.05 level (see Figures 47 and 48). None of the interactions were significant. An N-K test on the data of Figure 47 revealed that with the lateral spacings combined, group "a" had a significantly lower error rate than any of the other 4-letter groups and that group "d" had a significantly higher rate than any of the other groups. The same test on the data of Figure 48 showed that with the lateral spacings combined, letter position No. 1 was significantly lower than any of the other three positions. By the same test, letter position No. 4 was significantly lower than position No. 3.

The 2 X 8 Configuration. As with the analysis of Type I errors, four 2 X 2 X 8 X 10 factorial designs were found necessary in this analysis because of the complexity of the data and the limitation of the computer used. The main effect variables subject and reported target position were consistently significant at the 0.01 level in each of the factorials, while neither lateral spacing nor row separation was found to be a significant variable in any of the appropriate factorials. However, group, which consists of bottom and top rows, as a variable was not consistently significant throughout the factorials. In two of the factorial designs, including the small row separation analysis and the single lateral spacing analysis, the variable group was found to be insignificant; in the other two designs, involving the large row separation and the double lateral spacing analyses, that variable was significant at the 0.01 level (see Figure 49 and Table XXI). In those designs in which that variable was significant, the top row had a higher error rate than the bottom row. Other differences in the factorials were limited to differences in significance in some of the interactions.

TABLE XXXIII

ANOVA FOR FALSE ALARM ERRORS BY GROUP AND LETTER POSITION WITHIN GROUP -- 1 X 16 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	0.281	0.031	2.73**
Group (G)***	3	0.126	0.042	3.68*
Reported Ltr. Posn. (P)	3	0.150	0.050	4.37**
Lat. Spacing (L)	1	0.002	0.002	0.17
Residual	303	3.456	0.011	
TOTAL	319	4.014		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: 4-letter groups designated a, b, c, and d.

The statistical analysis of error patterns by 4-letter group and by reported letter position within groups required four 2 X 4 X 4 X 10 factorials. Exactly the same significance was found in each of the main effects of these factorials that was found in each of the 2 X 2 X 8 X 10 factorials, described above. A summary of the ANOVA of one of these factorial designs is presented, as example, in Table XXXIV (see Figures 50 and 51).

TABLE XXXIV

ANOVA FOR FALSE ALARM ERRORS BY GROUP AND LETTER POSITION WITHIN GROUP -- 2 X 8 CONFIGURATION-DOUBLE LATERAL SPACING

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	0.574	0.064	6.96*
Group (G)**	3	0.161	0.054	5.85*
Reported Tgt. Posn. (P)	3	0.321	0.107	11.68*
Row Separation (V)	1	0.001	0.001	0.08
S X P	27	0.556	0.021	2.25*
Residual	276	2.528	0.009	
TOTAL	319	4.141		

*Significant at 0.01 level.

**Groups are: Bottom left, bottom right, top left, and top right.

<u>The 4 X 4 Configuration</u>. A summary of the ANOVA of the Type II error data in this configuration is shown in Table XXXV. The F test showed the following main effects to be significant at the 0.01 level:

subject, reported target position, and row separation. The significant interactions were subject-reported target position and subject-row separation, both at the 0.05 level (see Figures 52, 53, and 54).

TABLE XXXV

ANOVA FOR FALSE ALARM ERRORS -- 4 X 4 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	0.326	0.036	5.36**
Group (G)***	3	0.022	0.007	1.08
Reported Tgt. Posn. (P)	3	0.159	0.053	7.85**
Row Separation (V)	1	0.052	0.052	7.65**
S X P	27	0.315	0.012	1.73*
S X V	9	0.146	0.016	2.41*
Residual	267	1.799	0.007	
TOTAL	319	2.818		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Bottom, 2nd, 3rd, and top rows.

The 8 X 2 Configuration. A summary of the ANOVA covering this configuration is shown in Table XXXVI. An F test revealed that the main effects subject and reported target position were both significant at the 0.01 level, while the variable row separation was significant at the 0.05 level (see Figure 55). Subject-reported target position was the only significant first-order interaction ($p < 0.01$) and subject-reported target position-row separation the only significant second-order interaction ($p < 0.05$).

TABLE XXXVI

ANOVA FOR FALSE ALARM ERRORS -- 8 X 2 CONFIGURATION

Source	d.f.	S.S.	M.S.	F
Final Test:				
Subject (S)	9	0.246	0.027	4.91**
Group (G)***	1	0.012	0.012	2.07
Reported Tgt. Posn. (P)	7	0.179	0.026	4.59**
Row Separation (V)	1	0.026	0.026	4.59*
S X P	63	0.578	0.009	1.65**
S X P X V	63	0.534	0.008	1.52*
Residual	175	0.974	0.006	
TOTAL	319	2.549		

*Significant at 0.05 level.

**Significant at 0.01 level.

***Groups are: Left and right columns.

VITA

Robert H. Ralston

Candidate for the Degree of

Doctor of Philosophy

Thesis: THE EFFECT OF DISPLAY CONFIGURATIONS IN VISUAL SEARCH TASKS

Major Field: Engineering

Biographical:

Personal Data: Born in Pittsburgh, Pennsylvania, October 3, 1922, the son of Mr. and Mrs. John A. Ralston.

Education: Graduated from Peabody High School, Pittsburgh, Pennsylvania, in June, 1940; received Bachelor of Science degree in Industrial Engineering from Lehigh University in 1949; received Master of Science degree in Industrial Engineering from the University of Houston in 1954; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in July, 1974.

Professional Experience: Management Engineer, 1949-52, Senior Management Engineer, 1952-56, Process Control Engineer, 1956-60, Senior Industrial Engineer, 1960-61, Supervisor of Industrial Engineering, 1961-63, Champion Papers, Incorporated; Corporate Industrial Engineer, St. Regis Corporation, 1963-64; Assistant Professor, 1964-66, Associate Professor, 1966-68 and 1970-74; graduate teaching assistant, Oklahoma State University, School of Industrial Engineering, 1968-70.

Professional Organizations: Alpha Pi Mu, American Institute of Industrial Engineers, American Society for Engineering Education.