VISUAL FIXATIONS ABOUT AN IMAGINARY LETTER MATRIX

By

FREDERICK VINCENT MALMSTROM

Bachelor of Science
United States Air Force Academy
Colorado
1964

Master of Aerospace Operations Management
University of Southern California
Los Angeles, California
1970

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1973

VISUAL FIXATIONS ABOUT AN IMAGINARY LETTER MATRIX

Thesis Approved:

Robert J. Weber
Thesis Adviser

Robert F. Stanners

[illegible]

N. Durham
Dean of the Graduate College

PREFACE

For nearly the past century, there has been much speculation but little measurement applied to the question of whether eye movements are associated with visual imagery. This thesis concerns itself with determining the rates at which information about a certain spatial image, the imaginary letter matrix, can be extracted. Equally important is the precise measurement of the amount of reliance a person places on eye movements in reconstructing or scanning a visual image.

I wish to express my appreciation to my major adviser, Dr. Robert J. Weber, for his continuous and valuable time and advice in the design and analysis of this thesis, and to Drs. Robert F. Stanners and Elliot A. Weiner for timely encouragement. Appreciation is also expressed to Dr. P. Larry Claypool for his assistance in the setting up and analysis of the experimental design. Finally, a note of thanks to Major (Dr.) Hal W. Hendrick for his help in the setting up of the BMD08V ALGOL computer translation in the reduction of a large amount of data, and for his introducing me to computers.

This entire study was funded by the United States Air Force's Institue of Technology graduate school education program.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

Figure | Page

NOMENCLATURE

AOV	analysis of variance
C	control blink rate interval
DV	dependent variable
E	experimenter
M	message blink rate interval
RA	rotational angle
R_e	recovery blink rate interval
RT	response time
R_t	response blink rate interval
S	subject
VA	visual angle

CHAPTER I

INTRODUCTION

The possibility that eye movements may be associated with visual imagery has been a source of some theorizing and speculation over the past 70 years. The inevitable preliminary observation by most scholars is that very little concrete experimentation has been done in this area. This observation is at least partially justified because, until the late 1950's, there were few inexpensive methods which could determine eye movements to less than one degree of accuracy. Additionally, the idea that eye movements could be closely associated with imagery attained a certain amount of relevancy and respectibility when Dement and Wolpert (1958) reported a strong correlation between the directional components of sleeping subjects' eye movements and the actual dream content. The even more recent resurrection of eidetic imagery by Haber and Haber (1964) revealed that those subjects with eidetic imagery tended to scan their images with their eyes.

These studies inevitably beg further questions. Is visual imagery common to all persons, or merely to a gifted few? What is the time required to arrive at a solution to a visual imagery problem? Is the visual imagery process primarily serial or parallel? And finally, is the eye movement required (if any) to solve a visual imagery problem identical to, similar to, or different from the eye movement required to solve the same perceptual problem?

Defining Visual Imagery

There are, of course, many workable definitions of imagery. After-images, the vogue of the late 1800's, are one possibility of an approach. However, Neisser (1967) regards after-images as "the dregs of single 'snapshots'" and, as they are primarily retinal images, they contain little "visual synthesis". Therefore, what is sought for by way of a definition, is an item which is internally generated, and if visual imagery can be analyzed and defined by some sort of psychophysical measurement, so much the better. Therefore, it is the purpose of this thesis to determine how much one relies on eye movement to solve a visual imagery problem, and whether this process is similar to the identical perceptual problem solution.

Review of the Literature

One of the earliest reports on eye movements associated with visual imagery was that of C. S. Moore (1903). Under the rules of his experiment, subjects were instructued to form certain visual images under closed eyelids. As might be expected, the subjects reported experiencing appropriate eye movements associated with the shape of the object;

however, it must be remembered that the data of this experiment were based on subjective reports. Totten (1935) devised a technique of using reflected light off the cornea to record eye movements on a photographic plate. Instructing her subjects to imagine such scenes as a moving train, the Washington Monument in varying positions, or a flaming cross, she found that in about 75% of the cases there was a positive degree of correlation between direction of eye movement and the object being imagined. One interesting speculation was that the amount of eye movement under imagery conditions would be "no doubt less" than the same object viewed under perceptual conditions. Hebb's (1949) speculation is that eye movements have a sort of "organizing function" in the synthesis of visual images; he makes the point that he personally finds it "very difficult to have a clear image of a triangle, square, or circle without imagining or actually making a series of eye movements." His thesis is that motor activity is an essential, although not sufficient component of visual integration. Of course, this implies that such "motor activity" might lie entirely within the cerebrum itself. There is support for this theory in the report by Berger, Olley, and Oswald (1966) who reported that congenitally blind persons do not experience eye movements during dreams; rather, they tend to have olfactory or tactual dreams. Hebb (1968) goes even further in his later proposition that "higher order assemblies" (presumably cortical) are the basis of a less specific imagery. In other words, this would be support for Totten's proposal that eye movements of imagined objects are "no doubt less" than those of the perceptual object. Dement and Wolpert (1958), after a rigorous analysis of dream content of sleeping subjects found a definite positive correlation between the direction of the subjects' eye movements and their dream content. For instance, when one subject was experiencing a series of vertical eye movements, he was awakened to report that he was dreaming he had climbed a flight of stairs. Deckert (1964) reported that subjects could project pursuit eye movements (as opposed to saccadic) while imagining a swinging pendulum. However, this finding must be taken with caution. Yarbus (1967) clearly denies this possibility. He is quoted as saying, "The system of pursuit of the eyes cannot be put into action voluntarily, in the absence of an object moving in the field of vision." Recently, more research has been done on these diametrically opposed proposals. Lenox, Lange, and Graham (1970), using refined measurement techniques, found that subjects imagining a swinging pendulum only tended to approximate pursuit eye movements, but that their eye movements were still definitely saccadic. Additionally, it was discovered that under open eye imagined pursuit conditions, the magnitude of eye movement was somewhat less than under perceptual conditions, and under closed eye imagined pursuit conditions, the amplitude of eye movement exceeded the perceptual conditions by as much as 250%.

Neisser (1967) furthers Hebb's "organizing influence" theory by stating that under imagery conditions there is merely a tendency to look in the appropriate direction, and that there is no such thing as a perfect correlation when comparing imagery to perceptual conditions.

This sort of speculation, of course, does not preclude the possibility that both imagery and perception use the same basic internal mechanisms. Indeed, Brooks (1967) found a definite hinderance in subjects' performance when they tried to both perceive and imagine spatial objects simultaneously.

Certainly, the quality of the material imagined must have something to do with the amount of eye movement experienced. Antrobus, Antrobus, and Siner (1964) reported that subjects instructed to imagine an active scene (such as a tennis game) experienced a great many more eye movements than those subjects instructed to imagine a static scene (such as an orange sitting on a table). This difference in the amount of eye movements may have something to do with the size of the object imagined. Noton and Stark (1971) propose that as an object becomes smaller, the more the subject can "internalize" his perception, and the more parallel his perceptual processes become. Noton and Stark also found that eye movement scanpaths are extremely specific to the subject; it is entirely possible, therefore, that many persons do not have the <u>need</u> to rely on eye movements as much as others do. Richards and Kaufman (1969) determined that the smaller the object perceived, the more was the tendency for the subject to view it as its "center of gravity". The larger the object viewed, the more was the tendency for the subject to view the object at an edge or a prominent feature. The usual dividing line of viewing an edge as a visual angle which exceeded five degrees of subtention. This process of "internalizing" visual images may be a matter of learning. In a rather rigorous observation of the eye movements of three variously skilled Russian chess players, Tikhomirov (1969) found that the more skilled players tended to rely less and less on eye movements when planning their moves; conversely, he found that the inexperienced player tended to rely extensively on eye movements, both while imagining his own and his opponent's anticipated moves. This is to say that the less experienced player (as determined by his eye scanpaths) attempted a great many more trial playthroughs than did his more experienced opponent.

The question of whether visual imagery is spatially parallel or serial in nature is yet another one to be answered. The rates at which parallel and serial information can be processed may provide a clue to the answer. As regards pure imagery time, Weber and Bach (1969), and later Weber and Castleman (1970), determined that the time required for a subject to visually imagine a particular letter of the alphabet was approximately 0.58 seconds. This time is surprisingly slow when compared to speech imagery, which was clocked at a rate of 0.19 seconds per character.

Tikhomirov (1969) determined that the average fixation times by players on chess squares occupied by pieces was 2.8 seconds, whereas the visual fixation times on unoccupied squares averaged 0.8 seconds -- none of these times is less than the 0.58 seconds supposedly required to conjure up a visual image. Neisser's (1963) series of experiments in decision times requiring subjects to scan word lists indicated that, up to a certain limit, parallel processing (after several practice trials) was just as efficient as serial processing. Supposedly, by the decision time required to locate an item or a series of items, time required for recognition is something more than just the time required for mere skimming and something less than the time required to fully analyze and reconstruct the item internally. (Specifically, Neisser arrived at a scanning process time of about 0.25 seconds per line-item scanned.) Approximately the same result in decision time was obtained by Gould and Peeples (1970) for subjects searching through a matrix of patterns rather than letters. The mean time of fixation on a particular symbol remained about the same.

Visually, therefore, it could be said that it takes a subject about 0.60 seconds to synthesize an image but only about one-half that time to analyze the percept.

If verbal imagery is, indeed, a faster process than visual imagery, there exists the possibility that visual imagery may be controlled by the verbal processes. Kelley (1971) presented evidence that in a sequential processing task that both visual and auditory imagery were under verbal control. For most tasks, it was found that, depending upon the complexity of the problem, there was some sort of minimal verbal control over imagery. Weber, Kelley, and Little (in press) proposed that the visual imagery system has a limited capacity for "chunking", and when this capacity is saturated, the verbal imagery process guides the sequencing between successive visual images.

Statement of Problems

The questions which this thesis will attempt to answer are threefold:

First, through an analysis of the eye movement data, can it be determined whether eye movements are identical to, different from, or merely similar to the perceptual conditions? In the presentation of this problem, it should be noted that there are two separate components of visual fixation material to be analyzed, the absolute distance moved and the direction in which the fixation falls.

Second, by comparing reaction-time data between solutions to both the identical perceptual and imagery problems, it ought to be determined whether the visual imagery process is similar to the parallel information processing that, it is assumed, occurs for visual perception.

Third, there is good reason for studying the possibility of practice effects on both the eye movement and the reaction-time to the correct solutions to the problems presented to the subjects. As suggested by both Tikhomirov (1969) and Noton and Stark (1971), the visual imagery process would tend to become "internalized", and measurable eye movements could drop out altogether.

It is, of course, understood that the kinds of results obtained could possibly depend on the type of problem presented to the subject. Asking a subject to imagine a static item (such as an orange sitting on a table) is not likely to yield the same results as asking him to imagine a dynamic situation (such as a ping-pong game). Likewise, an eyes-open situation may not yield the same results as an eyes-closed situation (Lenox, Lange, and Graham, 1970). Therefore, this thesis will be limited to an investigation of an eyes-open static situation. The dynamic and eyes-closed situation will be left for others to investigate.

CHAPTER II

METHOD

Subjects

The subjects (*S*s) used in this experiment were 60 male undergraduate volunteers who were enrolled in an introductory psychology course at the United States Air Force Academy, Colorado. Prior to the experiment, all *S*s were informed that this was to be a pupillary dilation experiment. Previous experience with the eye movement monitor equipment had shown that female *S*s' eye makeup and false eyelashes tended to get caught on the equipment photocells. *S*s were not selected on any predetermined basis for visual imagery ability. Each *S* was tested individually in a session that averaged about twenty-five minutes.

Experimental Design

This experiment employed two main response variables, response time (RT) and visual fixation position. There were four treatments employed. Treatment one, mode of task, had two levels, percept versus image representation of a letter matrix. Treatment two, problem type, had three levels, directional letter position, ordinal letter position, and a non-spatial backwards counting problem. (The analysis of variance [AOV] for the eye movement data did not include the third level, the non-spatial backwards counting problem. The reasons for doing this will be discussed in Chapter IV.) Treatment three had four levels of problem difficulty, step sizes two, four, six, and eight. Treatment four, trials, had three levels, trial one, trial two, and trial three.

Under the percept conditions, the S was presented with an alphabetically sequential block of letters (the letter matrix), while under the imagery conditions, the S was presented with an empty tic-tac-toe grid of the same size as the letter matrix. (See Figures 1 and 2.) For the directional letter position problems, the S was asked which letter was above, below, to the right of, or to the left of the center letter. In the ordinal letter position problems, the S was asked which letter was second, fourth, sixth, or eighth. For the non-spatial backwards counting problem, the S was asked to count backwards by three's, beginning at a predetermined point, for instance, "99-96-93 ..." etc. The level of problem difficulty, as measured in step sizes, was either the number of steps the S counted backwards, or else the serial position in the letter matrix from the central letter.

The experimental design involved two modes of presentation x three problem types x four step sizes. For the eye movement analysis, two modes of representation x two problem types x four step sizes x three trials were considered.

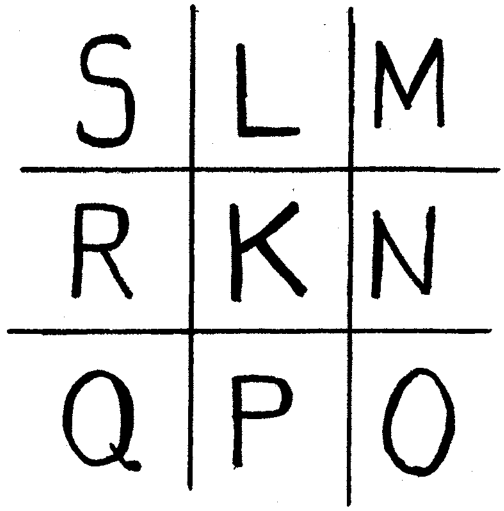


Figure 1. The Letter Matrix

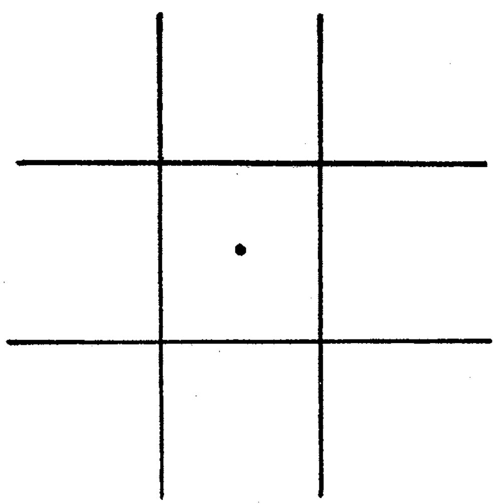


Figure 2. The Imaginary Letter Matrix or The Empty Grid

Mode of task and problem type were between-Ss variables, and difficulty level and learning trials were within-Ss variables. Each S was randomly assigned to one of the six between-Ss modes of problem combinations as he arrived to participate in the experiment.

Stimuli

The stimuli consisted either of an alphabetically sequential letter matrix arranged on a tic-tac-toe grid, or an empty grid presented alone. The first letter, K, was placed in the center of the grid, and the rest of the letters followed alphabetically, unwinding outward in a clockwise direction until the sequence terminated in the upper left-hand corner with the letter S. The letter matrix is shown in Figure 1. The empty grid, also referred to as the imaginary letter matrix, is shown in Figure 2.

The dimensions of the grid were 8.5 inches (215.9 mm.) horizontal by 9.0 inches (228.6 mm.) vertical, drawn in black. The letters were printed in upper case Roman capitals, centered in each square, covering an area of approximately 1.5 by 1.5 inches (38.1 by 38.1 mm.). Each letter was printed in bright red, thus being readily recognizable to foveal vision. The entire matrix was presented on an 8.5 by 11.0 inch (215.9 by 279.4 mm.) white card. The empty grid contained a small one-eighth inch (3.3 mm.) diamater black spot in the middle of the center cell, which was used for calibration purposes to permit the subject to "look center" when instructed to do so. The grid was placed 13.9 inches (352.5 mm.) from the subject's eyes to insure that the visual angle subtended from the center of one letter to the center of any adjacent letter measured 12.0 degrees. The actual distance from the center of one letter to the center of any adjacent letter was 3.0 inches (75.0 mm.).

The three types of stimulus probe questions, along with their step sizes, are shown in Table I. Each question is worded so that the subject could not receive the key word of the question until the last word of the sentence. The question wording, however, did allow the S to get a "running start" on processing the question information, that is, to prepare himself to count backwards, to prepare to solve a serial position problem, or to distinguish between left and right or up and down.

The dependent variables (DV) were the RT's to the correct responses and the S's visual fixation position on the matrix either at the time of the response or at any time up to two seconds prior to the response. It was evident that if visual imagery were a rather slow process, most Ss would be found looking in the "correct" position on the grid at some time prior to the time before they could verbalize their responses; hence, the two second interval before responding. The Ss' responses consisted of verbalizing the correct answer concurrent with pressing a reaction-time key.

A visual fixation is defined as the maximum deflection of the S's eyes from the center of the grid in which there

TABLE I

DIRECTIONAL PROBLEMS

"What is the letter above K?" (2-step)	(Answer: L)
"What is the letter to the right of K?" (4-step)	(Answer: N)
"What is the letter below K?" (6-step)	(Answer: P)
"What is the letter to the left of K?" (8-step)	(Answer: R)
ORDINAL POSITION PROBLEMS	
"Of the letter series, what letter is second?" (2-step)	(Answer: L)
"Of the letter series, what letter is fourth?" (4-step)	(Answer: N)
"Of the Letter series, what letter is sixth?" (6-step)	(Answer: P)
"Of the letter series, what letter is eighth?" (8-step)	(Answer: R)
NON-SPATIAL PROBLEMS	
"Count backwards by 3's; start at 91." (2-step)	(Answer: 91-88)
"Count backwards by 3's; start at 95." (4-step)	(Answer: 95-92-89-86)
"Count backwards by 3's; start at 97." (6-step)	(Answer: 97-94-91-88-85-82)
"Count backwards by 3's; start at 99." (8-step)	(Answer: 99-96-93-90-87-84-81-78)

was a noticeable pause of 0.18 seconds or more (Yarbus, 1967).

Apparatus

The apparatus used in this experiment consisted of three pieces of electrical equipment. The S's eye position was monitored by a modulated infrared eye movement monitor, Model SGH/V-2 (Biometrics, Inc.). The infrared photocells were mounted on special glasses frames which were fitted and calibrated to each S. Input from the left eye was set up to measure horizontal eye movement, while the input from the right eye was set up to measure vertical eye movement. All measurements were taken with the filter switch in the "on" position so as to smooth out minor saccades from the monitor output. Output from the eye movement monitor was fed into a 320 Dual Channel DC Amplifier-Recorder (Sanborn Company). Horizontal movement data was fed into the right channel; vertical movement data was fed into the left channel. All movement data was recorded on two channels of heat-sensitive paper moving at 2.0 mm/second. Finally, the S had control of one key of a 6302C Visual Choice reaction time discrimination timer (Lafayette Instrument Company) fitted with a 1/100th second clock (Standard). The S was then seated on a stool and helped to assume as comfortable as possible a position while placing his head in a padded cheekbone rest, so as to permit him to respond verbally to the questions without having to move the upper part of his head.

Proceudre

Each S was informed that this was a pupillary dilation experiment, and the involuntary dilations and constrictions of the pupil could give valuable indications of his attitude toward the questions he would be asked. Without yet fitting the infrared frames to the S, the E showed the S a practice letter matrix similar to the one described in Figure 1, but which began with the letter C. The S was informed that the letter matrix proceeded outwards in a clockwise direction. The S was then given three sample questions similar to the ones he was to be asked, but all the sample questions were "filler" questions, that is, three, five, or seven step questions. The S was further instructed to press the key stopping the timer, and to concurrently verbalize the answer. For example, when the S was asked, "What is the letter below F?", the experimenter (E) pressed a switch to start the clock and the event recorder, simultaneously with the saying of the letter "F". The S stopped the clock by pressing his key simultaneously as he responded verbally with the correct answer, "G". If the S was required to do a non-spatial backwards counting problem, he was instructed to press the key concurrently with every successive backwards counting step. Early in the pilot study, it was discovered that to instruct, for example, "Without going beyond 83, count backwards by 3's; start at 97." was hopelessly confusing to the S. Therefore, the instructions were modified to permit the S to press the key on every backwards counting step, and the S's key was activated by the E's rotating a selector switch as the S approached the desired final step. At no time during the practice trials was the S shown the empty letter grid, nor was he informed that he would be required to answer any questions without the letters actually present. At this point, the S was fitted with the infrared photocell frames and taken step-by-step through a five to ten minute calibration sequence. The calibration chart consisted of a matrix of nine dots in the exact positions of the centers of the letters in the matrices. The S was informed that there would be numerous calibration checks throughout the course of the experiment, and if he felt his eyes getting fatigued at any time, he should inform the E, and the experiment would be halted while the S closed his eyes and rested.

At this time, the S was shown the letter matrix which began with the letter "K", along with the information that it was also constructed in an outward spiral pattern and could be memorized in that manner. After the S had examined the new letter matrix for approximately 10 seconds, the E asked the S whether he thought he had the matrix memorized. When the S replied in the affirmative, the E either left the matrix in place (if the S was to answer the questions under perceptual conditions) or removed the matrix and replaced it with the tic-tac-toe grid (if the S was to answer the questions under the imagery conditions.) Then, the E started the dual channel recorder running, and once again reminded the S to press the key on the timer simultaneously with every verbal response to a question. A very few S's had a tendency to "jump the gun" on the first few responses to the stimulus probe questions. That is, they were pressing the key in advance of verbalizing their answers. However, this anticipatory action was audibly obvious to the E, and after one or two admonishments by the E, the S was able to coordinate his key press and verbal response quite well. Prior to each stimulus probe question, the S was instructed, "Look center", but the instruction applied only for the instant of the instruction, and at any other time the S was free to look wherever he pleased. As each stimulus probe question was presented, the E checked for the accuracy of the response. If the S gave an incorrect response or forgot to press the reaction time key, the S was informed of the correct answer. Then, the question was removed from the deck and the S was asked it again at the end of the question block. Hence, a correction procedure was used. Errors in verbal response to all questions constituted less than 3% of the total, so they did not present a serious problem. One interesting footnote to the Procedures is the case of a S who, contrary to the instructions by the E, kept his eyes focused in the center of the grid and relied on head movements in lieu of eye movements. This S will be discussed in greater detail in Chapter IV.

Calibration checks were conducted at both the beginning and end of the experiment. In addition, the S was requested to relax and look center for 30 seconds at both the beginning and at the end of the experiment under the guise that the equipment was "stabilizing", when, in fact, the E was merely checking the S's eye blink rate. After the experiment was over, all Ss were informed of the true nature of the experiment, which was, of course, eye movement and visual fixations, but they were requested not to discuss the experiment with anyone else who had not yet participated. The instructions to the Ss can be found in Appendix A.

CHAPTER III

RESULTS

The results of this experiment are measured both in terms of the visual angle subtended (VA) from the center of the matrix, and in response time (RT), which was the actual time taken for the Ss to solve correctly the problem presented. In addition, there was also a third parameter, rotational angle (RA), which was considered along with the visual angle parameter; however, for the analysis of variance (AOV), the rotational angle was not used. The reasons for discounting the rotational angle are enumerated later in this chapter.

From any given reference point, any other point can be described by an angle (RA) and a distance (VA) from the reference point. Therefore, all points of visual fixations in this experiment are described first by the VA (12.0 degrees VA = 304.8 mm = 3.0 inches), and second by the RA (the actual clock position measured from the expected or "correct" value in degrees on a compass rose -- clockwise degrees are defined as plus and counterclockwise degrees are minus values). Also, if any S were found looking at the exact reciprocal of the expected rotational angle, he was recorded as looking in a +180 degrees, since it was assumed that he was always solving his problem in a clockwise direction. A typical visual fixation might be recorded as 10.5/-15, or 7.0/0. This type of notation for the former example would mean that the S was looking at a point which was at a VA of 10.5 from the center reference point at a counterclockwise RA of minus 15 degrees from the centerline of the correct answer. Then, for each of the experimental conditions, a mean geometric centroid, or center of gravity was calculated. The centroid could have been determined through methods using vector analysis, but for purposes of simplicity and convenience, the graphical method of determination was used. No noticeable amount of accuracy was sacrificed by using the graphical method.

The graphical method is identical to the system a navigator would use when determining an average wind along a given flight path. For purposes of explanation, an example problem in plotting a visual fixation from the recorder tracings and the determination of a centroid from several fixations are shown in Appendix D.

Rotational Angle

For all spatial problems, whether perceptual or imaginary, it was determined that only 5.2% of the visual fixations could be classified as falling in an inappropriate direction. An inappropriate direction is defined as any visual fixation which did not fall either in the direct center of the matrix or within a cone of plus or minus forty-five degrees RA of the expected centerline. By contrast, it was determined that at least 37.1% of the visual fixations for the non-spatial problems did not fall within an appropriate direction.

Similarly, the mean geometric rotational angle for all spatial problems was found to be very near the expected centerline. The very largest mean deviation from the expected centerline was +12.0 degrees RA, and this value was twice recorded under perceptual conditions, making the letter next to the expected centerline fixation point certainly recognizable to foveal vision. However, as regards the non-spatial problems, the mean geometric RA appeared much different from the actual values.

The actual number of visual fixation falling within an inappropriate direction are found in Table II.

TABLE II

NUMBERS OF VISUAL FIXATIONS FALLING WITHIN AN INAPPROPRIATE DIRECTION, 120 POSSIBLE FOR EACH CELL

	Directional	Ordinal	Non-Spatial
Perceptual Conditions	3	11	46
Imagery Conditions	6	5	43

The mean rotational angles, along with the mean geometric visual angles are presented in Table VI of Appendix B. Also, the actual raw data from which the centroids were computed are shown in this table.

Figures 3, 4, and 5 show the virtual indistinguishability of the RA from the expected value for all spatial problems.

Rotational angle has already established itself as an excellent dependent variable; it distinguishes between spatial and non-spatial problems, and it increases linearly with step size. However, for the following reasons, it was decided not to use the RA in any further data analysis. First, it was not possible to define an appropriate RA for any of the non-spatial problems. That is, if the visual fixations were assumed to be randomly distributed about the center reference point of the tic-tac-toe grid, then the centerline of <u>any</u> RA would always be zero, regardless of any arbitrary direction considered. As is the case with undefined values, the value is anything the observer wants it to be. Second, and most important, is the almost visually indistinguishable difference in the RA found in the solutions to the spatial problems presented (Figures 3 and 4). In the remainder of this experiment, <u>all</u> visual fixations will be considered as falling in the appropriate direction.

Visual Angle (VA)

The AOV for visual angles shows significant main

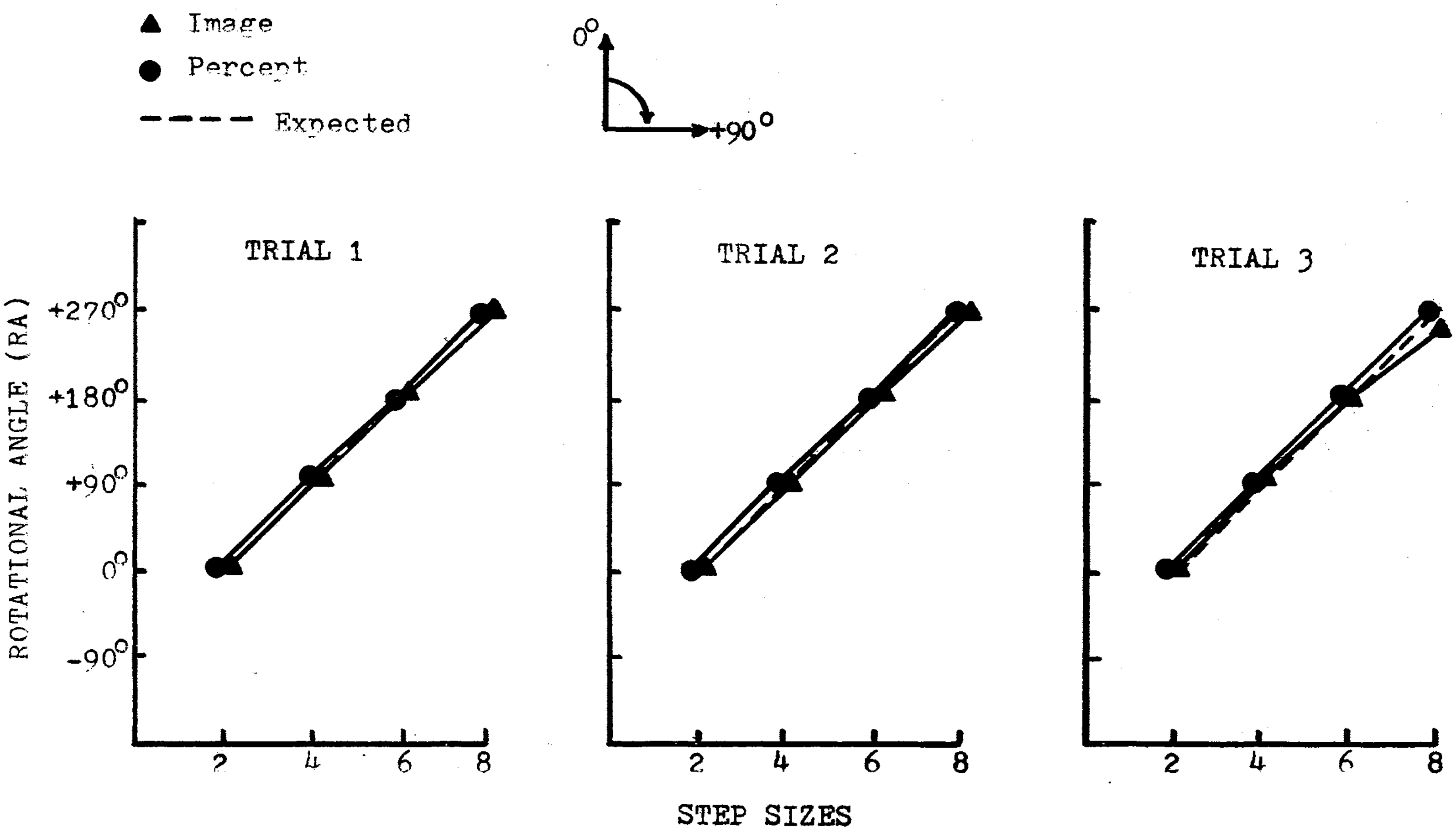


Figure 3. Directional Problems. Rotational Angle or Clock Position of Visual Fixations (Degrees) as a Function of Step Size. Values Represented Are Mean Geometric Angles Over Consecutive Trials

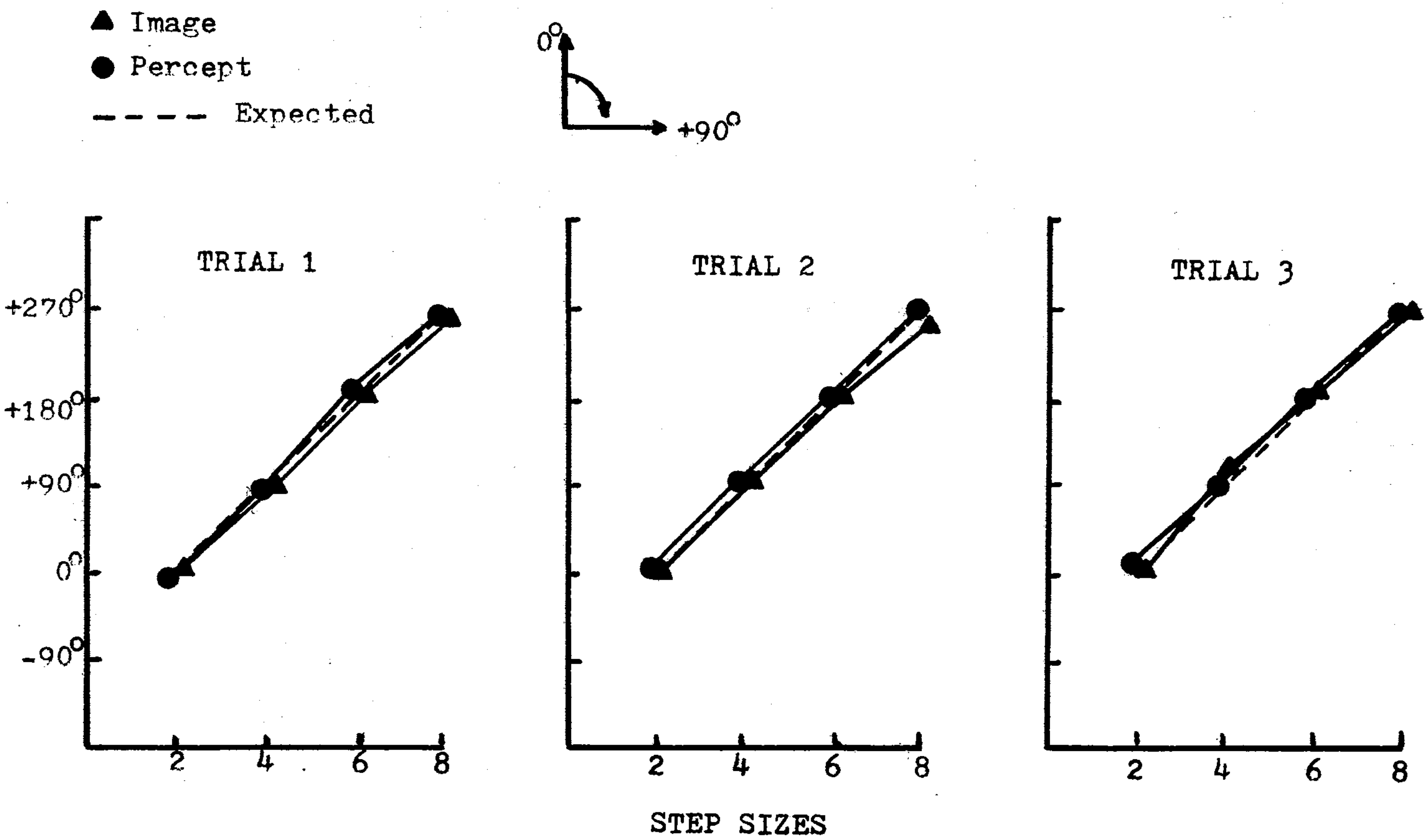


Figure 4. Ordinal Problems. Rotational Angle or Clock Position of Visual Fixations (Degrees) as a Function of Step Size. Values Represented Are Mean Geometric Angles Over Consecutive Trials

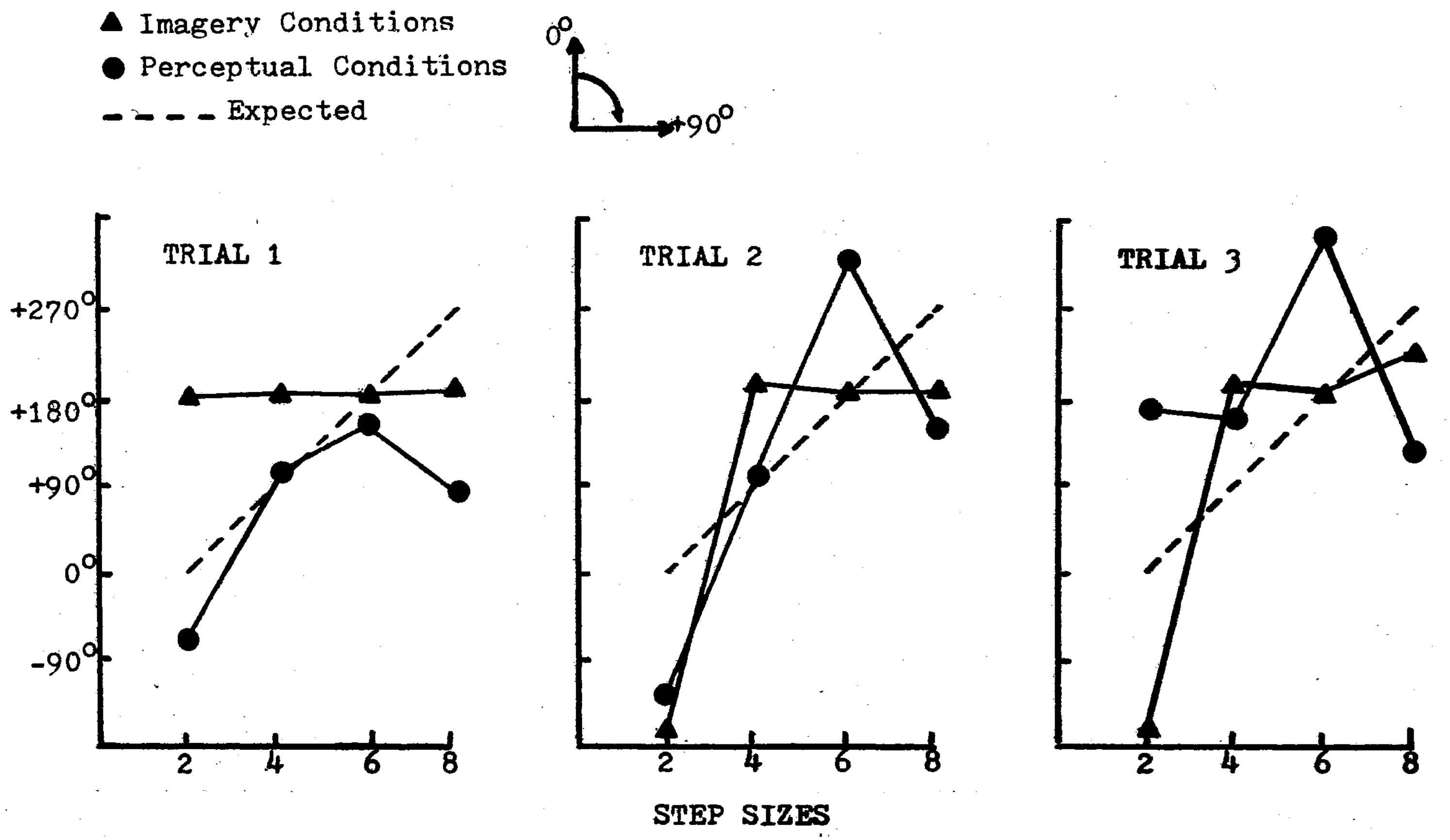


Figure 5. Non-Spatial Problems. Rotational Angle or Clock Position of Visual Fixations (Degrees) as a Function of Step Size. Values Represented Are Mean Geometric Angles Over Consecutive Trials

effects for A (percept-image), F (1,36) = 24.261, $p < .01$; and for B (step sizes 2,4,6, and 8), F (3,108) = 12.931, $p < .01$. There is also a significant four-way interaction effect of percept-image x directional-ordinal x step size x trials, F (6,216) = 2.294, $p < .05$.

Table III gives the AOV for the main and interaction effects of VA data.

Figures 6, 7, and 8, respectively, show the mean geometric VA's for the fixation points at the time of solution for all problems presented, directional, ordinal, and non-spatial. It should be noted that, as regards the non-spatial problems, although the RA appeared to fluctuate violently, the actual distance the Ss moved their fixation points while solving the problems was usually less than three degrees VA -- nowhere outside the center square, and certainly well within the original cone of foveal vision. The actual raw data, along with the geometric centroids, can be found in Table VII, Appendix B.

Response Time (RT)

Figures 9, 10, and 11 show RT as a function of trials and step sizes. As with the VA and RA, it can be seen that there is a clear distinction between the spatial and non-spatial problems. As might be expected, the RT required to determine the position of a letter actually presented on the matrix (the perceptual conditions) nearly always required somewhat less than one second, regardless of the

TABLE III

AOV OF MAIN AND INTERACTION EFFECTS FOR VISUAL ANGLES (VA) SUBTENDED

Source of Variation	D.F.	S.S.	M.S.	*F*.
Between Subjects	39	5646.641		
A (Percept-Image)	1	2272.876	2272.876	24.261**
C (Directional-Ordinal)	1	.151	.151	.002
AC	1	.962	.962	.010
S w. Groups [error (between)]	36	3372.652	93.685	
Within Subjects	440	4826.771		
B (Step Size)	3	411.427	137.142	12.931**
AB	3	44.530	14.843	1.399
BC	3	.555	.185	.017
ABC	3	45.519	15.173	1.431
B x *S* w. Groups [error (within)]	108	1145.407	10.606	
D (Trials)	2	78.907	39.355	2.576
AD	2	55.726	27.863	1.824
CD	2	8.688	4.344	.284
ACD	2	46.371	23.186	1.518
D x *S* w. Groups [error (within)]	72	1100.017	15.278	
BD	6	74.085	12.348	1.655
ABD	6	92.199	15.367	2.060
BCD	6	9.912	1.652	.221
ABCD	6	102.679	17.113	2.294*
BD x *S* w. Groups [error (within)]	216	1610.749	7.457	

*$p < .05$

**$p < .01$

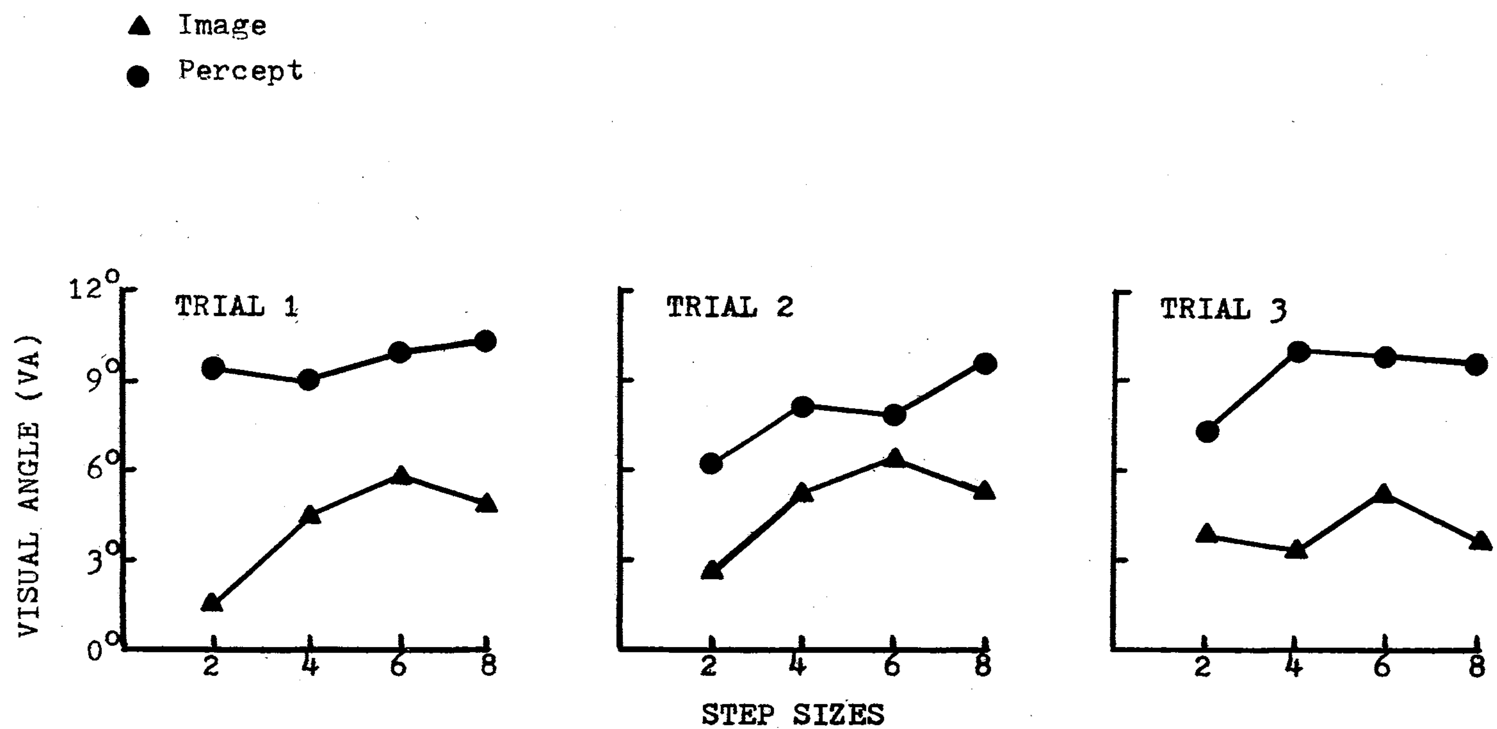


Figure 6. Directional Problems. Mean Visual Angle or Angle of Subtention (Degrees) as a Function of Step Size. Values Represented Are Mean Geometric Distances Over Consecutive Trials

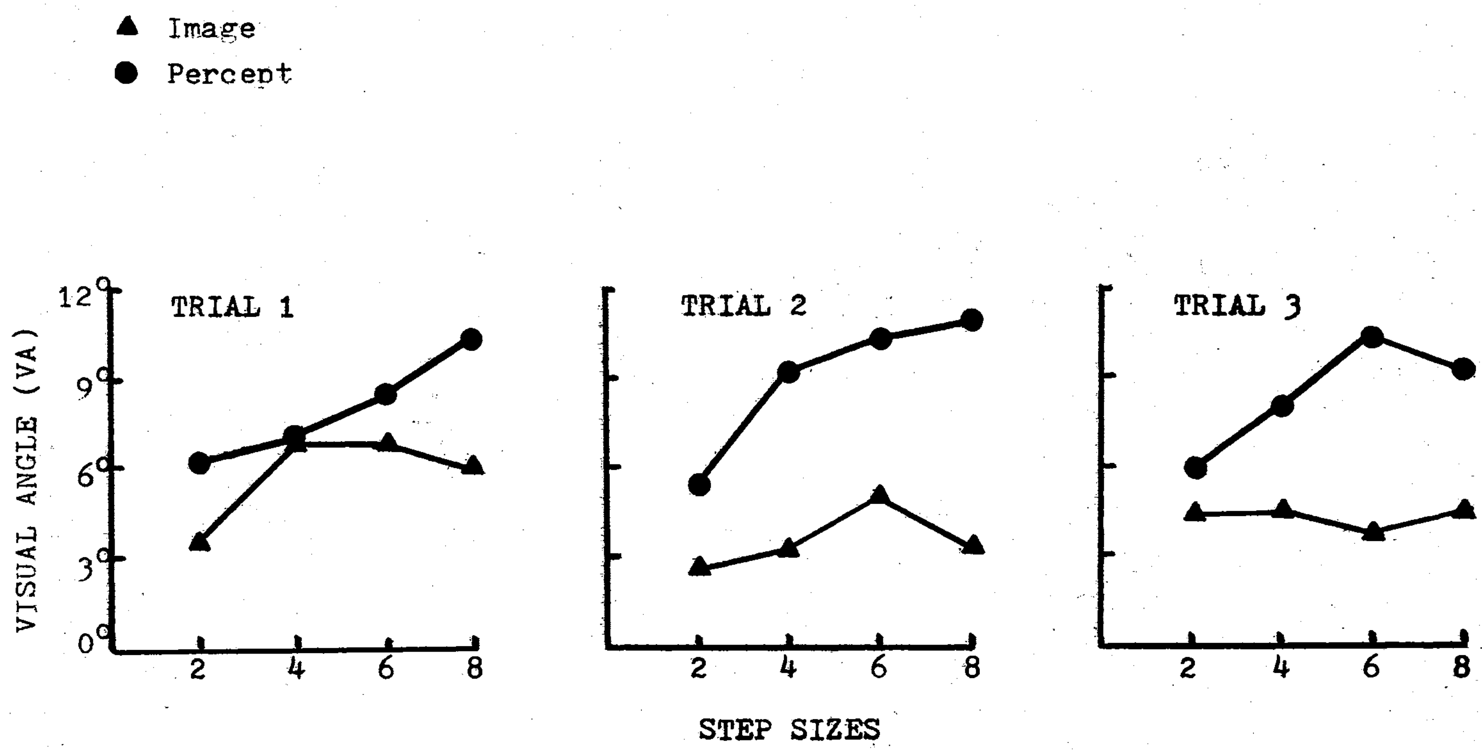


Figure 7. Ordinal Problems. Mean Visual Angle or Angle of Subtention (Degrees) As a Function of Step Size. Values Represented Are Mean Geometric Distances Over Consecutive Trials

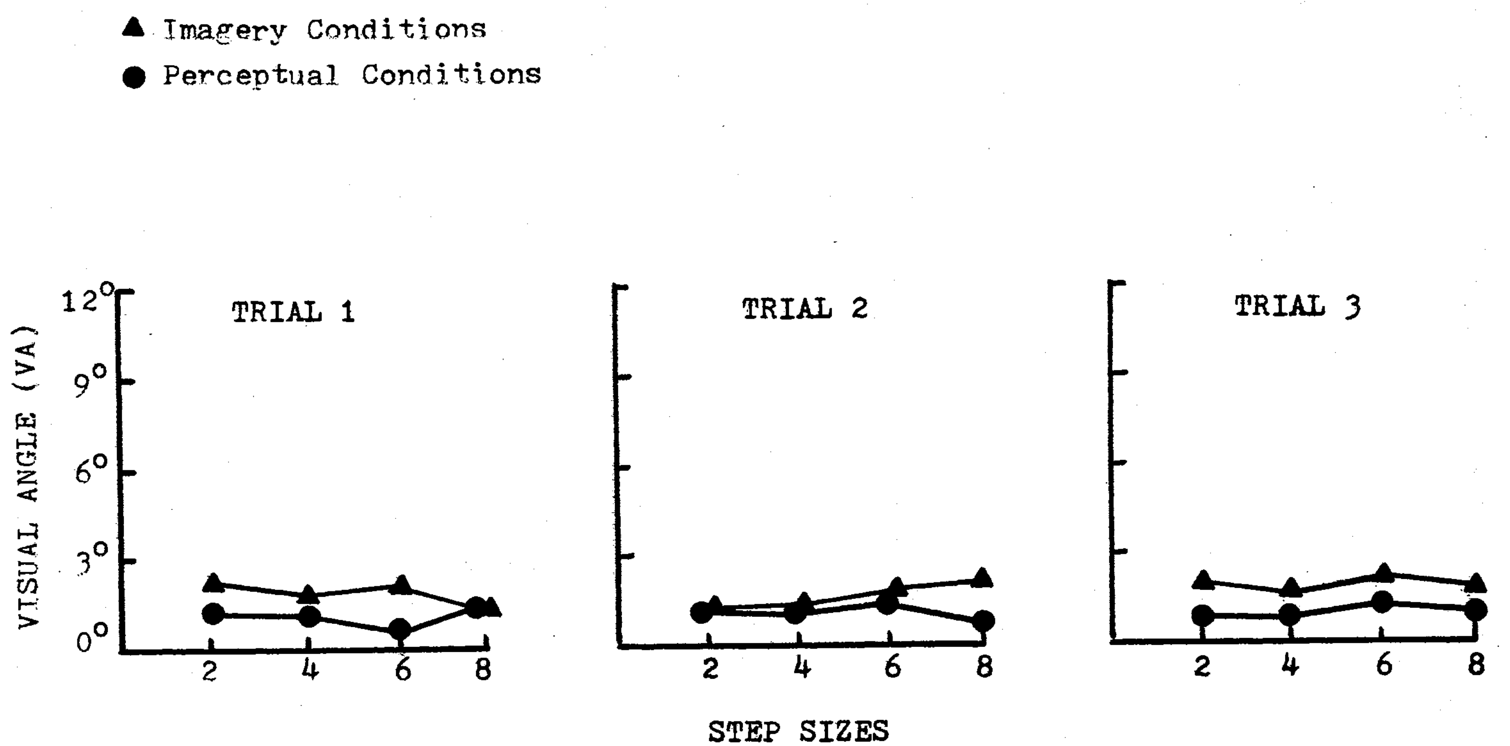


Figure 8. Non-Spatial Problems. Mean Visual Angle or Angle of Subtention (Degrees) as a Function of Step Size. Values Represented Are Mean Geometric Distances Over Consecutive Trials

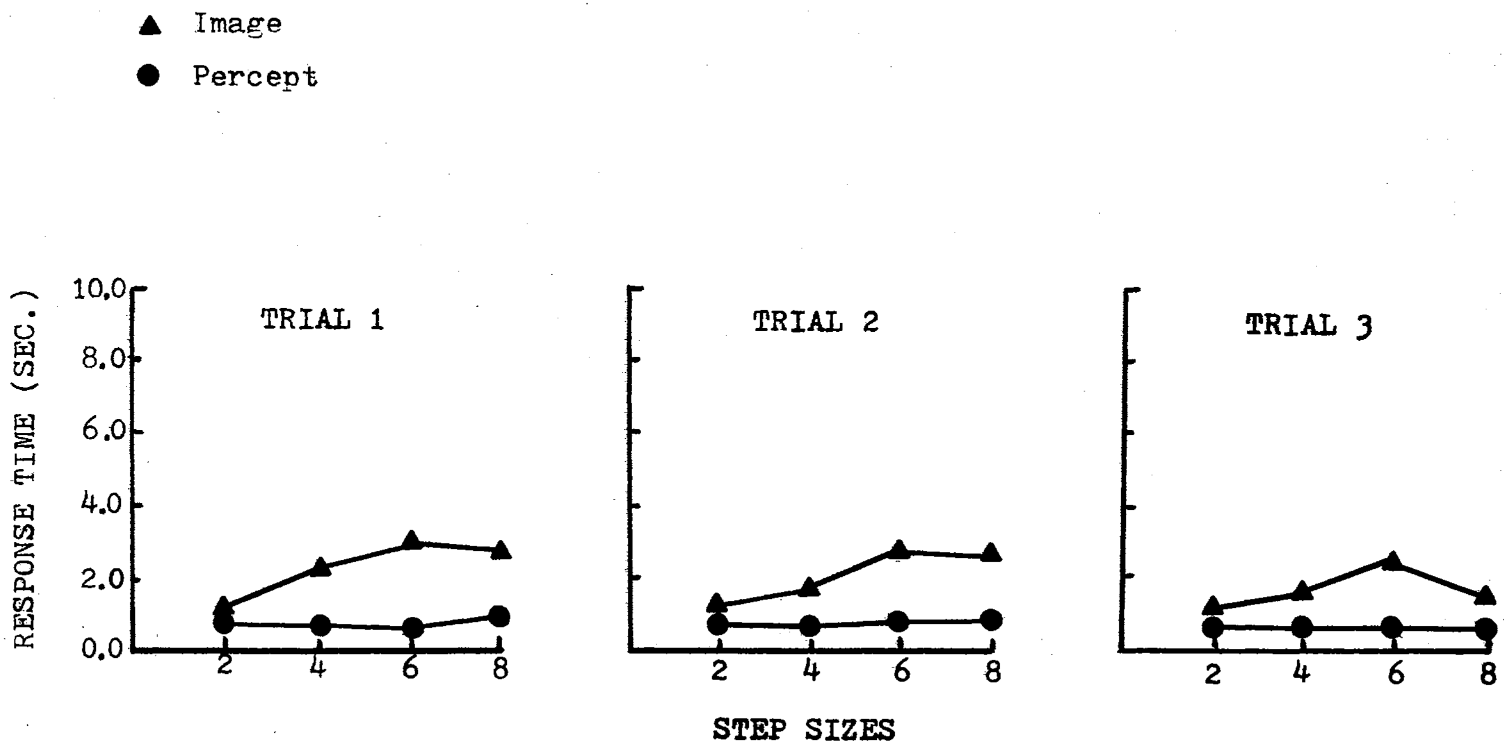


Figure 9. Directional Problems. Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

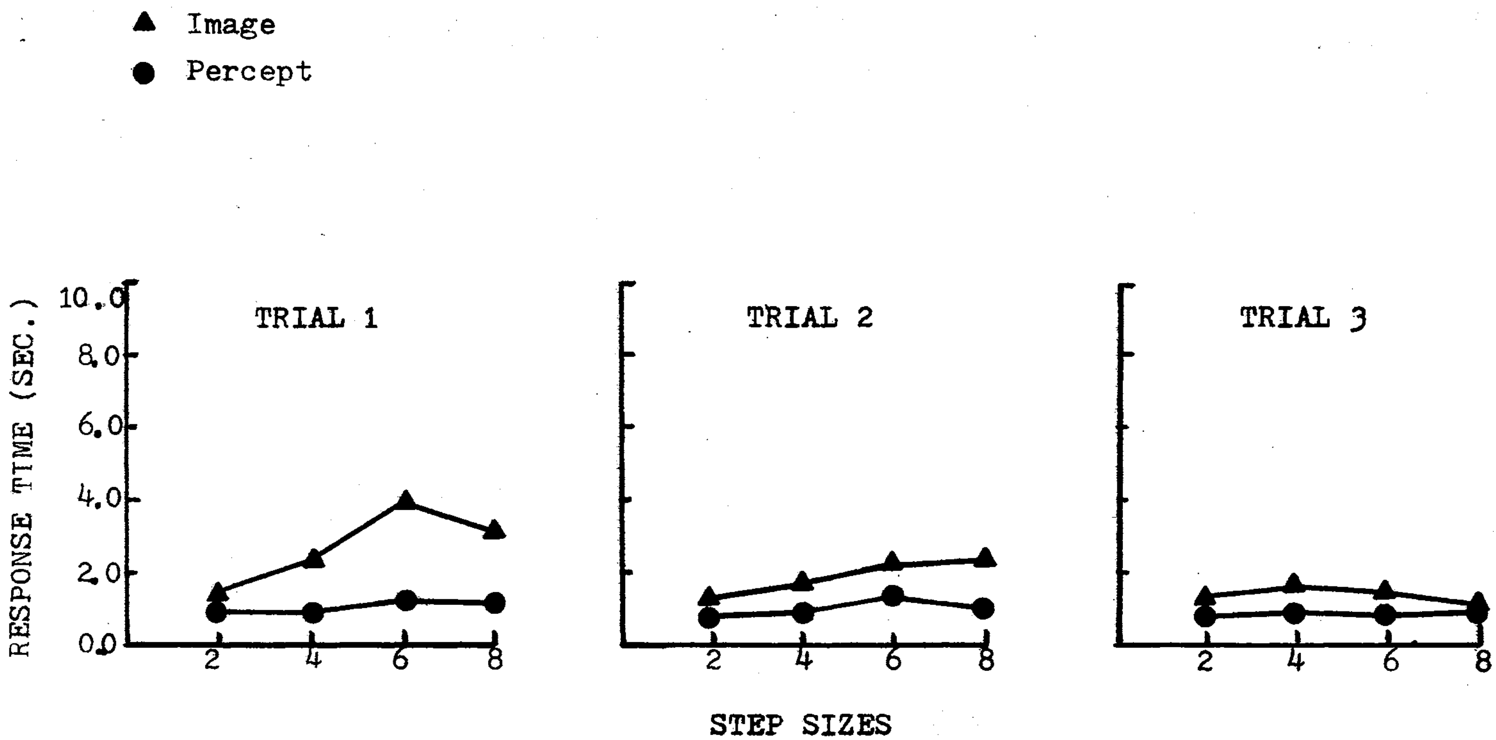


Figure 10. Ordinal Problems. Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

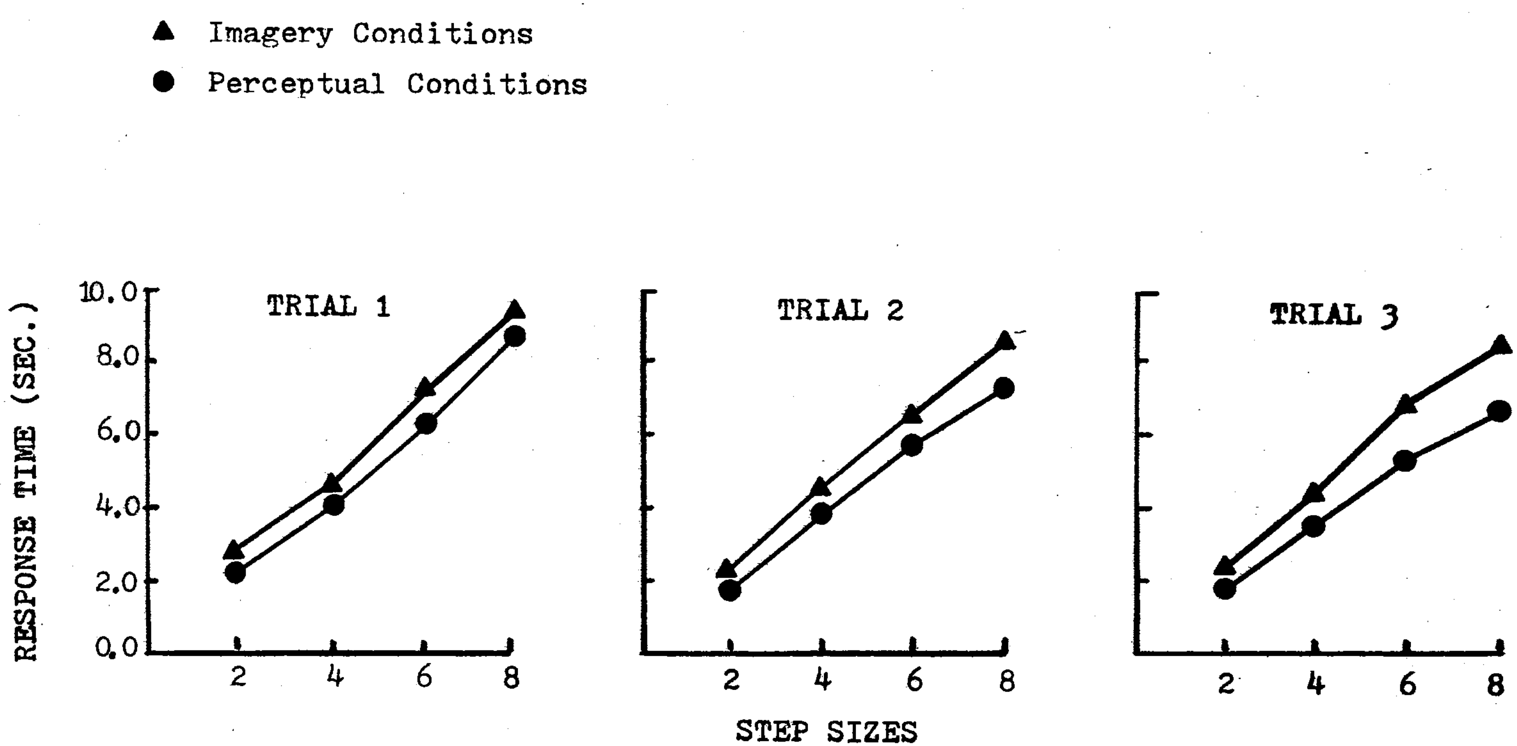


Figure 11. Non-Spatial Problems. Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

position of the letter sought. In distinct contrast, for the non-spatial problem there is no such uniform response. Indeed, one could hardly expect a S to perform two mathematical calculations in less time than it would take him to perform just one. However, for imagery problems, there appears to be a distinct linear rise in the RT required to solve the matrix, at least up to and including the 6-step problem. If one uses the following formula to determine the time-per-step imagery process:

$$\text{Time-per-Step (Imagery)} = \frac{\text{Response Time}}{\text{Step Size}} \qquad (1)$$

for the first trial data, it can be seen that the actual RT's per letter are in good agreement with Weber and Castleman's (1970) finding of 0.58 seconds per letter imagery time, at least through the 6-step problem. Beyond the 6-step problem, there is good evidence that a serial-position effect comes into play significantly, and this evidence will be discussed in Chapter IV.

Table IV shows the time-per-step solutions for the first trial on all imagery problems. The mean times-per-step are computed using the formula (1) shown above.

TABLE IV

MEAN TIMES PER STEP (SECONDS) REQUIRED FOR SOLUTIONS TO IMAGERY PROBLEMS

Step Size	2-Step	4-Step	6-Step	8-Step
Directional	0.51	0.54	0.48	0.34
Ordinal	0.63	0.52	0.65	0.38
Non-Spatial	1.29	1.10	1.17	1.56

The non-spatial times-per-item are about twice the value of the spatial times-per-letter for the imagery problems.

The analysis of variance for RT's reveals significant main effects for all conditions. For the between subjects conditions, there are significant effects for A (percept-image), F (1,59) = 16.816, $p < .01$; and for C (directional-ordinal-non-spatial), F (2,59) = 110.458, $p < .01$. For the within subjects conditions, there are significant effects for B (step sizes), F (3,162) = 173.072, $p < .01$; and for D (trials), F (2,108) = 30.258, $p < .01$.

There are also several interesting two-way interaction effects, AB (percept-image x step size), F (3,162) = 9.343, $p < .01$; CB (directional-ordinal-non-spatial x step size), F (6,162) = 95.361, $p < .01$; and BD (step size x trials), F (6,324) = 5.277, $p < .01$.

Table V presents the analysis of variance for the main

TABLE V

AOV OF MAIN AND INTERACTION EFFECTS FOR RESPONSE TIMES (RT)

Source of Variation	D.F.	S.S.	M.S.	F.
Between Subjects	59	3028.938		
A (Percept-Image)	1	174.257	174.257	16.816**
C (Directional-Ordinal-Non-Spatial)	2	2289.200	1144.600	110.458**
AC	2	5.916	2.958	.285
S w. Groups /error (between)/	54	559.565	10.362	
Within Subjects	660	1576.336		
B (Step Size)	3	636.713	212.238	173.072**
AB	3	34.373	11.458	9.343**
BC	6	701.647	95.361	95.361**
ABC	6	4.946	.824	.672
B x S w. Groups /error (within)/	162	198.657	1.226	
D (Trials)	2	46.798	23.398	30.258**
AD	2	2.894	1.447	1.871
CD	4	5.378	1.345	1.739
ACD	4	17.548	4.387	5.637**
D x S w. Groups	108	83.514	.773	
BD	6	14.707	2.451	5.277**
ABD	6	3.610	.602	1.295
BCD	12	9.555	.796	1.714
ABCD	12	12.278	1.023	2.203*
BD x S w. Groups /error (within)/	324	150.494	.465	

*$p < .05$

**$p < .01$

and interaction effects for all RT's.

Because there was some doubt as to whether the non-spatial RT's belonged in the AOV, it was decided to recompute the AOV without the non-spatial conditions, similar to the original AOV in Table III. The recomputed AOV can be found in Appendix B as Table IX.

CHAPTER IV

DISCUSSION

Serial Position Effect

As determined by the response times (RT's), it was apparent that the Ss were able to extract information about the 8-step visual imagery problem more rapidly than information about the 6-step problem. A serial position effect has previously been described in terms of RT's (Postman and Rau, 1957), but not in terms of eye scanpaths. In a search for another descriptive measure of a serial position effect, therefore, it was decided to trace out the scanpaths of a single trial of the Ss' visual imagery problems in order to determine whether there was any concurrent "short-circuiting" of the Ss' scanpaths along with the decrease in RT's for solution to the 8-step problem.

Because of the limited accuracy of the recording equipment, there are certain cautions against any attempt to trace scanpaths. First, neither the eye movement monitor nor the recorder was calibrated to distinguish whether the S was following a curved or a straight scanpath, or some combination of the two. Yarbus (1967) found that the usual scanpath followed by a S looking towards a diagonal position (for example, from a clock center to the 4:30 position) is predominantly a curved or bowed path. Furthermore, tracings of scanpaths by Noton and Stark (1971) have shown scanpaths not to be clean, direct movements, but rather like the path traced out by a drunken insect attempting to walk a straight line. Therefore, it should be noted that the scanpaths represented in Figure 12 do not represent the exact scanpaths, but merely the trend of the sequence of fixations. What is seen in Figure 12 is an idealized connection of the visual fixations with straight lines, not necessarily the actual scanpaths. The actual scanpaths could possibly have varied one to two degrees either side of the connecting lines at any instant between fixations.

Trial 1 of the image-directional problem was chosen for the following reasons. First, the image-directional problem is the primary condition being studied for this experiment; second, the method by which the S arrived at his solution was not confounded by prior learning effects.

In Figure 12, the arrowed lines represent the approximate scanpaths through which the Ss moved their eyes to arrive at the correct solution to the 8-step image-directional problem. All scanpaths start at the exact center of the grid (as the Ss were instructed to do). The triangles represent the terminal fixation points at the time of the solution or at any time two seconds prior to solution. The numbers next to the triangles identify the S who executed that particular scanpath (there were 10 Ss for the

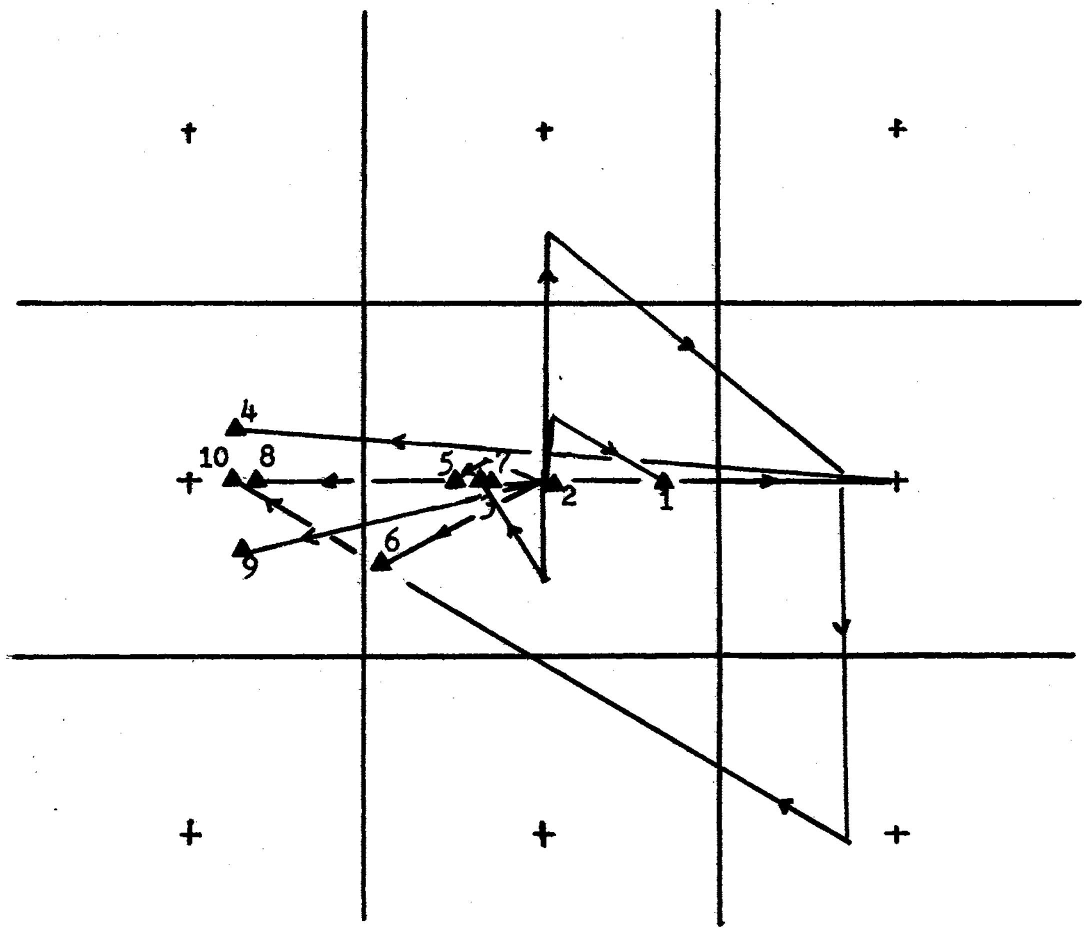


Figure 12. Approximate Scanpaths for Each Subject On Trial 1 of Image-Directional Problem ("What is the Letter to the Left of K?")

image-directional condition).

As can be seen in Figure 12, in every case the S "short-circuited" what might be the expected clockwise sequence of letters, "K-L-M-N-O-P-Q-R". In six of the ten instances, the Ss' scanpaths proceeded almost directly into the appropriate direction of the correct letter answer. In the case of S = 10, his scanpath was in the expected clockwise direction, but, even so, he had a clear tendency to skip portions of the alphabetical sequence; his actual sequence of visual fixations went from the center block containing K to L-N-O-R.

What is more interesting than the decrease in RT's for the 8-step imagery problem is the apparent short-circuiting maneuver by the eyes. The preponderance of evidence for this single trial says that there is, indeed, a visual serial position effect; it may be possible to describe a serial position effect by physical movements as well as by RT's.

Fixations at Corners and Edges

Richards and Kaufman (1969) have determined that the smaller the object perceived, the greater was the tendency for the S to view the object at its center of gravity. Because the squares of the grid measured twelve degrees across -- well above the dividing line of five degrees where the S tends to look at an edge or a prominent feature -- there exists the possibility that the S might tend to look at the grid lines, especially under the imagery conditions. The pilot studies for this experiment were run using grid squares of both three and six degrees of visual angle as well as the actual experimental value of twelve degrees, and all distributions and centroids appeared to be essentially the same. The only difference noted using the larger twelve degree grid squares was that the degree of accuracy in plotting the visual fixations was much more pronounced.

Motor Components

As stated by Paivio (1971) and others, eye movements might be considered to be nothing more than motor components of the imagery sequencing process. Certainly, there is no suggestion in this experiment whatever that eye movements could be the only sequencing mechanism, even for a visual imagery problem. One S in this experiment, by his rather fortuitous failure to heed the instructions of the E presented some unusual support for this "motor sequencing" theory. During the time that the S was answering the Image-Directional problem, it was noted that, even though the S was giving the correct verbal responses to the stimulus probe questions, his visual fixations were falling in the exact opposite direction from what might be expected. When queried after the completion of the experiment, the S admitted that he had been keeping his eyes fixed center, but he had been swinging his head in the direction of the target letter. (With the particular apparatus used, a head movement in one direction will give a false indication of an eye movement in the opposite direction.) Interestingly enough, this S's RT's compared quite favorably with the other Ss' RT data, and his visual angle movements (in this case, more properly head movements) were precisely twelve degrees, the exact distance from the center of one grid square to the next. For the purposes of data representation in plotting this S's visual fixation, the fixations were plotted in the direction of the head movements, not his apparent eye movements. This single example suggests eye movements are not necessary to solutions of a visual imagery problem, but it would seem that they are a convenient means towards solving a visual imagery problem. Saccadic eye movements are extremely quick, and Yarbus (1967) states that, for example, in a saccade of only five degrees VA, the eye reaches a maximum rotational velocity of about 200 degrees per second, whereas the rotational acceleration of the eye for this same movement approaches about 15,000 degrees per second squared. Clearly, for a person to use his head or arm movements in lieu of eye movements for the generation of spatial imagery would be a most inefficient, tiring, and acrobatic maneuver.

Weber, Kelley, and Little (in press) have discussed the strong possibility that there is verbal control over visual image sequencing, at least for alphabet strings of letters. The findings of this experiment would indicate that, at least for certain kinds of tasks, there is verbal control over motor image sequencing.

Analysis of Variance for Visual Angles

The analysis of variance (AOV) for the visual angles (VA's) suggests some rather powerful variables. The significant main effects of the between subjects condition A (percept-image), and the within subjects condition B (step size) are the only ones noted. One interesting and unexpected negative result was the lack of a main effect for condition D (trials). There are two interpretations possible for this negative finding. First, it is possible that, regardless of the practice effects, the S tends to rely just as much on eye movements for solution to a spatial imagery problem. The second possibility, which is more likely, is that eye movements tend to be "internalized" much more slowly than could be done in only three trials. As has been demonstrated by the approximate scanpaths for the first trial of the image-directional problem, there are many intermediate steps in the generation of the correct answer which are short-circuited. Herein exists the possibility that the intermediate eye movements are the first to drop out, and the final, "solution step" eye movements may be the last to drop out. When this negative result is compared to the RT analysis of variance (Table V) it can be seen that condition D (trials), $F\ (6,324) = 30.258$, $p < .01$ is, indeed, significant. The AOV computed for the spatial problems only (see Appendix B, Table IX) continues to show a significant main effect for D (trials) with regard to response times, indicating that the RT practice effects are not unique only to the solutions of non-spatial problems.

There is a word of caution regarding the use of an analysis of variance for visual angles. Richards and Kaufman (1970) suggested that the actual distribution of visual fixations for small fields of view may be bimodal rather than normal. From inspection, it would appear that the distribution of fixations for the percept-spatial problems is normal, but the large number of $0/0^{\circ}$ fixations for the image-spatial problems would indicate that the distribution for this condition is not normal. However, for the purposes of continuity in the computation of this AOV, it has been assumed that the distributions are normal for all VA's. Furthermore, the accuracy of the equipment limits any distinction of visual fixations of less than one-half degree VA, so any distribution of fixations between zero and one-half degree VA is unknown and was assumed to be zero.

Analysis of Variance for Response Times

As with the data for the VA's, there are significant main effects for the between-subjects condition A (percept-image) and the within subjects condition B (step size). In addition, as mentioned previously, there is a significant main effect for D (trials) and C (directional-ordinal-non-spatial), both of which do not show up on the visual angle AOV.

The significant two-way interaction effect for AB (percept-image x step size) would appear to be exclusively due to a serial position effect on the image-spatial problems. The accessibility of the solutions to the image-spatial problems does not proceed in a linear, predictable model beyond step size 6.

Again, in regard to the two-way interaction CB (directional-ordinal-non-spatial x step size), this finding can be attributed to the absence of a serial position effect in the solutions to the non-spatial problems. The RT's for the non-spatial problems were preponderantly larger than for the spatial problems. The heavy weight of RT's without a serial position effect might be expected to appear in such an interaction. Again, the AOV computed for the spatial problem RT's only, shows almost the complete lack of any CB (directional-ordinal x step size) interaction. (See Appendix B, Table IX.)

The two-way interaction BD (step-size x trials) can be explained by the fact that learning was faster on the ordinal position imagery problem than for the directional position imagery problem. This might be expected if one regards the ordinal position problem as primarily a verbal paired-associate learning experience. That is, if one were to associate the word "sixth" with the letter "P"; where there is one possible correct solution, learning might be expected to be faster than in the equivalent directional position problem. In the equivalent directional position problem, "What is the letter <u>below</u> K?", the <u>S</u> has, before the stimulus probe "K" is delivered, alternatives of six possible choices: R,K,N on the second line of the matrix, and Q,P, and O on the bottom line of the matrix. Therefore, it could be assumed that the image-directional problem is a more difficult one to memorize and regenerate.

CHAPTER V

SUMMARY AND CONCLUSIONS

It might have seemed apparent that the magnitude of visual deflection used for the solution to a visual imagery problem would be "no doubt less" than the deflection used for the identical percept (Totten, 1935). However, it was necessary to verify this hypothesis with the now available and more accurate equipment. By analysis of both eye movement and response time data, the following conclusions can now be made:

(1) Eye movements used in solving static spatial imagery problems do take place in a direction which is appropriate to the identical percept.

(2) Visual deflections generated for the solutions to a static, spatial imagery problem are significantly smaller in terms of visual angle subtended than are those generated for the identical perceptual problem. As a rule of thumb, about twice the deflection is used for solving a perceptual problem than for an imagery problem.

(3) As a corollary to the conclusion (2) above, the amount of eye movement generated for the

solution to a visual spatial imagery problem is heavily dependent upon the complexity of the problem. Generally speaking, the more complex the problem, the greater the eye movement generated.

(4) A serial position effect is found for the solution to a two-dimensional spatial imagery problem; furthermore, this serial position effect can be described not only in terms of response times, but also in terms of eye movements, and, quite possibly, scanpaths.

(5) Learning effects for solutions to spatial imagery problems were found in regard to response times, but not in regard to visual fixation deflections. This finding may be due to the possibility that the internalizing of a visual image would require more than three learning trials.

There are several suggestions open to further research on visual fixations and imagery. First, since little attempt was made to determine the scanpaths through which the Ss solved the problems, it would be interesting if one were to make such a determination. As has been found by Noton and Stark (1971) for scanpaths about a percept, it is predicted that such scanpaths would be specific to the individual subject. In addition, it is suggested that when a visual image is internalized, portions of the scanpath are bypassed and tend to drop out until the entire image is internalized. Tikhomirov (1969) noted that a reliance by experienced chess players on eye movements is found even at the grand master level, although not to the degree that is found at the novice and candidate master level. It appears even here that the complete internalizing of the visual image is a slow process. The finding of a learning curve for visual image scanpaths would be a most informative first step.

Second, there exists the possibility that eye movements are not necessary for the generation of a visual image, but that they are merely helpful. The reconstruction of a spatial image through, for example, finger movements might be every bit as valuable as reconstruction of an image through eye movements.

Finally, it is concluded that reliance on eye movements or another equivalent motor movement for the generation of a static visual spatial image is a universal phenomenon. This conclusion is drawn from the observation that all Ss (excepting the S who substituted head movements for eye movements), at one time or another during the solutions to all spatial problems, relied on eye movements, and these eye movements were in the appropriate direction. In other words, some Ss relied on eye movements all of the time, and some Ss relied on eye movements part of the time, but under no circumstances did any Ss fail to use eye movements completely.

BIBLIOGRAPHY

(1) *Air Navigation*. United States Air Force Manual 51-40, Vol. 1 (1 August 1968), 5-33 to 5-36.

(2) Antrobus, John S., Judith S. Antrobus, and Jerome L. Singer. "Eye Movements Accompanying Daydreaming, Visual Imagery, and Though Suppression." *Journal of Abnormal and Social Psychology*, Vol. 69 (1964), 244-252.

(3) Berger, R. J., P. Olley, and I. Oswald. "The EEG, Eye Movements and Dreams of the Blind." In *Thinking: Studies of Covert Language Processes*. Ed. F. J. McGuigan. New York: Appleton-Century-Crofts, 1966, 271-277.

(4) Brooks, L. "Suppression of Visualization by Reading." *Quarterly Journal of Experimental Psychology*, Vol. 19 (1967), 289-299.

(5) Deckert, G. H. "Pursuit Eye Movements in the Absence of a Moving Visual Stimulus." *Science*, Vol. 143 (1964), 1192-1193.

(6) Dement, William, and Edward A. Wolpert. "The Relation of Eye Movements, Body Motility, and External Stimuli to Dream Content." *Journal of Experimental Psychology*, Vol. 55 (1958), 543-553.

(7) Gould, John D., and David R. Peeples. "Eye Movements During Visual Search and Discrimination of Meaningless, Symbol, and Object Patterns." *Journal of Experimental Psychology*, Vol. 85 (1970), 51-55.

(8) Haber, Ralph N., and Ruth B. Haber. "Eidetic Imagery: I. Frequency." *Perceptual and Motor Skills*, Vol. 19 (1964), 131-138.

(9) Hebb, D. O. *The Organization of Behavior*. New York: John Wiley and Sons, 1949, 33-37.

(10) Hebb, D. O. "Concerning Imagery." *Psychological Review*, Vol. 75 (1969), 466-477.

(11) Kelley, Joe R. "Verbal Control of Visual and Auditory Imagery." (Unpub. M. S. thesis, Oklahoma State University, 1971.)

(12) Lenox, John R., Arthur P. Lange, and Kenneth R. Graham. "Eye Movement Amplitudes in Imagined Pursuit of a Pendulum With Eyes Closed." Psychophysiology, Vol. 6 (1970), 773-777.

(13) Moore, C. S. "Control of the Memory Image." Psychological Review Monograph Supplements, Vol. 4 (1903), 277-305.

(14) Neisser, U. "Decision Time Without Reaction-Time: Experiments in Visual Scanning." American Journal of Psychology, Vol. 76 (1963), 376-385.

(15) Neisser, U. Cognitive Psychology. New York: Appleton-Century-Crofts, 1967, 138-158.

(16) Noton, David, and Lawrence Stark. "Scanpaths in Eye Movements During Pattern Perception." Science, Vol. 171 (1971), 308-311.

(17) Paivio, Allan. Imagery and Verbal Processes. New York: Holt, Rinehart and Winston, 1971, 30-31, 149, 388.

(18) Postman, L., and L. Rau. "Retention as a Function of the Method of Measurement." University of California Publication of Psychology, Vol. 8 (1957), 224-225.

(19) Richards, Whitman, and Lloyd Kaufman. "'Center-of-Gravity' Tendencies for Fixations and Flow Patterns." Perception & Psychophysics, Vol. 5 (1969), 81-84.

(20) Tikhomirov, O. K. The Structure of Human Thinking Activity. tr. Foreign Technology Division, U. S. Air Force, JPRS 53983 (September, 1971), and JPRS 52199 (January, 1971), 110-144. "Struktura Myslitel'noy Deyatel'nosti Cheloveka." Moscow: Moscow University Printing House, 1969, Chapter 5.

(21) Totten, Edith. "Eye Movements During Visual Imagery." Comparative Psychology Monographs, Vol. 3 (1935), 1-43.

(22) Weber, R. J., and M. Bach. "Visual and Speech Imagery." British Journal of Psychology, Vol. 60 (1969), 199-202.

(23) Weber, R. J., and J. Castleman. "The Time It Takes To Imagine." Perception & Psychophysics, Vol. 8 (1970), 165-168.

(24) Weber, R. J., J. Kelley, and S. Little. "Is Visual Imagery Under Verbal Control?" Journal of Experimental Psychology (in press).

(25) Yarbus, A. L. Eye Movements and Vision. tr. Lorrin A. Riggs. New York: Plenum Press, 1967, 111, 115, 125, 139-140, 170.

APPENDIX A

INSTRUCTIONS TO *S*s IN THE EXPERIMENT

INSTRUCTIONS TO Ss IN THE EXPERIMENT

The purpose of this experiment is to measure your pupillary dilations; pupillary dilations can tell us a great deal about your attitude towards a particular type of problem I might want to present you. For example, if I were to present you with an aversive stimulus, such as a poisonous snake, your pupils would constrict -- markedly so. Likewise, if I were to present you with a rewarding stimulus, such as a beautiful woman, your pupils would expand -- significantly. What is interesting to me is that you have no conscious control over this response by your eyes.

What you're looking at here is an eye movement monitor which has been modified and rewired to measure pupillary dilations. If you'll look at these glasses frames, you'll note that they have mounted on them some very phase-sensitive photocells which measure reflected light off the surface of the eyeball. The output from the reflected light goes into this pupillometer and then into this recorder, where your pupillary dilation is traced accurately on this tracing paper.

Now, if you'll make yourself comfortable on this stool, I'll adjust it so you can rest your cheekbones in this headrest; just look straight ahead and look at this arrangement of letters.

Note that this grid of letters can be memorized quite easily by observing that it starts in the center with the letter "C" and unwinds clockwise in alphabetical sequence, [points] C-D-E-F, and so on.

What I'd like you to do is take a few practice trials with some of the types of questions I'd ask you. Place your hand over here on this key. When you press it, you stop a clock which I can activate with another control. When you arrive at the correct answer, say the answer aloud and, at the same instant, press your key. Don't jump the gun on either your verbal response or on your key press, O.K.? Let's try some questions. Ready?

Only one-third of the Ss received the following practice trials.

What is the letter above F?
What is the letter to the left of I?
What is the letter to the right of K?

Only one-third of the Ss received the following practice trials.

Be very careful you don't confuse the words "second" and "seventh", and answer the following questions:

Of the letter series, what letter is third?
Of the letter series, what letter is seventh?
Of the letter series, what letter is ninth?

Only one-third of the Ss received the following practice trials:

I'm going to ask you to count backwards by threes. Repeat the digit I give you to begin with and press the key every time you come up with a number until I tell you to stop.

Count backwards by threes. Start at 74.
Count backwards by threes. Start at 72.
Count backwards by threes. Start at 78.

O.K., I think you've got the procedure down. What I'd like to do now is fit these glasses frames to you and go through a calibration procedure. Calibration is a touchy procedure, so if you move the frames after I fit them to you, I may have to stop the apparatus and recalibrate. Try to keep your head movements to a minimum, but feel free to breath normally.

Look at this tic-tac-toe grid I've presented, and when I say, "Look center", or look to a particular clock position, look directly at the spot which is plotted in the center of each square.

Look center.
Look 12:00 o'clock. Look center.
Look 1:30 o'clock. Look center.
Look 3:00 o'clock. Look center.
Look 4:30 o'clock. Look center.
Look 6:00 o'clock. Look center.
Look 7:30 o'clock. Look center.
Look 9:00 o'clock. Look center.
Look 10:30 o'clock. Look center.

While the equipment is warming up, just relax and look generally toward the center of the chart. [There was a pause of thirty seconds here while the S's blink rate was observed.]

Make yourself comfortable. Note this chart is very similar to the other one, except it starts in the center with the letter "K". Do you think you have this chart memorized?

The four stimulus probe items were presented in random order over each of the three separate learning trials. In addition, each S was also concurrently presented questions of difficulty levels 3, 5, 7, and 9; however, these questions were designated as "filler" questions which were not used in the final analysis of the primary data, but were used both to prevent the S from anticipating the step size of the question being asked and to keep the problem difficulty challenging enough to the S. Nevertheless, the odd step size RT data was analyzed separately in an AOV, which can be found in Appendix B, Table VIII. The corresponding means can be found in the graphs in Figures 13, 14, and 15, Appendix C.

Only one-third of the Ss received the following questions. For all these Ss, they received the questions in random order for three consecutive trials. One-half of this group of Ss were left with the actual letter matrix present; for the remaining half of this group, the matrix was removed and replaced with the empty grid along with the statement, "O.K., let's try the following questions without the letters."

What is the letter above K?
What is the letter to the right of L?
What is the letter to the right of K?
What is the letter below N?
What is the letter below K?
What is the letter to the left of P?
What is the letter to the left of K?
What is the letter above R?

Only one-third of the Ss received the following questions. For all these Ss, they received the questions in random order for three consecutive trials. One-half of this group of Ss were left with the actual letter matrix present; for the remaining half of this group, the matrix was removed and replaced with the empty grid along with the statement,"O.K., let's try the following questions without the letters."

Of the letter series, what letter is second?
Of the letter series, what letter is third?
Of the letter series, what letter is fourth?
Of the letter series, what letter is fifth?
Of the letter series, what letter is sixth?
Of the letter series, what letter is seventh?
Of the letter series, what letter is eighth?
Of the letter series, what letter is ninth?

Only one-third of the Ss recieved the following questions. For all these Ss, they received the questions in random order for three consecutive trials. One-half of this group of Ss were left with the actual letter matrix present; for the remaining half of this group, the matrix was removed and replaced with the empty grid along with the statement, "O.K., let's try the following questions without the letters."

Count backwards by threes. Start at 91.
Count backwards by threes. Start at 94.
Count backwards by threes. Start at 95.
Count backwards by threes. Start at 93.
Count backwards by threes. Start at 97.
Count backwards by threes. Start at 92.
Count backwards by threes. Start at 99.
Count backwards by threes. Start at 98.

All the Ss were given the following final instructions:

That was very good. Now, as one last favor, I'd like you to go through another clock position calibration sequence. [Another calibration sequence.]

While the equipment is winding down, relax and look generally toward the center of the chart. [There was another pause of thirty seconds here while the S's final blink rate was observed.]

That's the end of the experiment. Thank you for your cooperation. I have only one request, and that's you don't discuss the experiment with anyone who hasn't participated in it yet. I'll explain everything to you after I've finished running all my subjects. Thank you again.

APPENDIX B

TABLES

TABLE VI

RAW DATA AND CENTROIDS OF VISUAL FIXATIONS PLOTTED IN VISUAL ANGLE (DEGREES) AND ROTATIONAL ANGLE (∠ DEGREES) FROM CENTER OF GRID TO EXPECTED CENTERLINE

		C_1 Directional Position Matrix											
		B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
		D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1	s1	12.0∠0	10.5∠0	9.0∠0	9.5∠0	7.5∠0	12.0∠0	9.0∠0	7.5∠0	9.5∠+20	13.5∠0	10.5∠0	10.5∠0
	s2	11.0∠0	11.0∠0	13.5∠0	12.0∠0	2.5∠0	5.0∠0	13.5∠0	4.0∠0	3.0∠0	2.5∠0	7.5∠0	3.5∠0
	s3	7.0∠0	13.5∠0	6.5∠0	12.0∠0	6.0∠0	14.0∠0	8.0∠0	10.5∠0	9.0∠0	14.0∠0	8.5∠0	10.0∠0
	s4	12.0∠0	8.5∠0	12.5∠0	10.5∠0	12.0∠0	0.0∠0	0.0∠0	10.0∠0	4.5∠0	11.5∠0	14.0∠0	12.0∠0
	s5	8.0∠0	4.5∠+135	9.0∠0	12.0∠0	4.0∠0	13.5∠0	10.0∠0	12.0∠0	7.0∠0	11.5∠0	12.0∠0	12.0∠0
	s6	5.5∠0	10.5∠0	11.0∠0	9.5∠0	3.5∠0	10.0∠0	10.5∠0	10.0∠0	4.5∠0	10.5∠0	8.5∠0	9.0∠0
	s7	10.0∠0	8.0∠+45	6.5∠0	7.5∠0	0.0∠0	4.5∠+90	7.5∠0	8.5∠0	9.0∠0	8.0∠0	12.0∠0	8.5∠0
	s8	10.0∠0	10.5∠0	7.5∠0	10.0∠0	8.0∠0	8.5∠0	7.5∠0	11.0∠0	10.5∠0	11.5∠0	6.0∠0	9.0∠0
	s9	10.0∠0	9.0∠0	15.5∠0	12.0∠0	7.0∠0	8.5∠0	12.0∠0	11.0∠0	6.5∠0	8.5∠0	11.5∠0	12.0∠0
	s10	7.0∠0	8.5∠0	6.5∠0	10.0∠0	8.0∠0	9.0∠0	9.0∠0	10.0∠0	8.0∠0	7.0∠0	7.5∠0	7.0∠0
Centroid		9.5∠0	9.0∠+5	9.5∠0	10.5∠0	6.0∠0	8.0∠+3	7.5∠0	9.5∠0	7.5∠+3	9.5∠0	9.5∠0	9.0∠0
Image A_2	s1	6.0∠+180	3.5∠+90	4.0∠0	4.0∠+180	3.0∠0	6.5∠0	5.5∠0	0.0∠0	3.5∠0	8.5∠+35	7.0∠0	4.5∠-90
	s2	2.5∠0	6.5∠0	2.5∠0	0.0∠0	2.0∠0	12.5∠+10	8.5∠0	6.5∠0	3.0∠0	0.0∠0	6.0∠0	5.0∠0
	s3	0.0∠0	5.0∠0	2.5∠0	2.0∠0	0.0∠0	0.0∠0	2.0∠0	1.5∠0	0.0∠0	0.0∠0	1.0∠0	1.0∠0
	s4	13.0∠0	8.5∠0	8.0∠+12	10.5∠+10	7.5∠0	10.0∠0	9.0∠0	11.0∠0	10.0∠0	10.0∠0	10.0∠0	10.0∠0
	s5	0.0∠0	3.0∠0	0.0∠0	3.0∠0	0.0∠0	0.0∠0	0.0∠0	5.0∠0	0.0∠0	0.0∠0	4.0∠0	0.0∠0
	s6	0.0∠0	3.0∠+30	10.0∠0	6.0∠-25	0.0∠0	9.5∠-13	10.0∠0	8.5∠0	7.0∠0	2.5∠0	8.5∠0	0.0∠0
	s7	0.0∠0	3.0∠0	4.0∠0	2.0∠0	0.0∠0	0.0∠0	4.0∠0	3.0∠-45	3.5∠+180	0.0∠0	2.0∠0	2.0∠-45
	s8	5.5∠0	0.0∠0	7.0∠0	10.0∠0	0.0∠0	0.0∠0	9.0∠0	5.0∠0	4.5∠0	5.5∠0	0.0∠0	4.5∠0
	s9	0.0∠0	0.0∠0	13.5∠0	10.5∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s10	0.0∠0	14.5∠0	7.0∠0	10.5∠-15	7.5∠0	13.0∠0	14.5∠0	11.0∠0	12.5∠0	8.0∠0	12.0∠0	10.5∠0
Centroid		1.5∠0	4.5∠+7	6.0∠+2	5.0∠-3	2.5∠0	5.0∠0	6.5∠0	5.0∠-3	3.5∠0	3.0∠+9	5.0∠0	3.5∠-10

TABLE VI (Continued)

C_2

Ordinal Position Matrix

		B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
		D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1	s1	13.0∠-40	12.0∠0	10.0∠0	12.0∠-20	10.0∠+60	13.5∠-15	13.0∠0	19.5∠0	13.5∠+65	14.5∠-20	13.0∠0	11.5∠0
	s2	5.0∠0	12.0∠0	0.0∠0	9.5∠0	3.0∠0	10.5∠0	7.0∠0	9.5∠0	2.5∠0	0.0∠0	9.0∠0	10.0∠0
	s3	2.0∠0	0.0∠0	7.0∠+45	12.5∠0	0.0∠0	9.5∠0	7.5∠+80	6.0∠0	0.0∠0	4.0∠-45	16.0∠+13	6.5∠0
	s4	9.0∠0	11.0∠0	14.0∠+15	10.5∠-15	11.5∠0	10.5∠0	14.0∠0	7.0∠0	9.5∠0	11.0∠0	13.5∠0	12.0∠0
	s5	13.0∠0	10.0∠0	13.5∠0	11.0∠0	14.0∠0	9.0∠0	10.5∠0	14.0∠-17	13.0∠0	12.5∠0	10.5∠0	12.0∠0
	s6	10.0∠0	6.0∠0	10.5∠0	11.0∠+45	11.0∠0	9.5∠0	10.5∠0	10.5∠-45	0.0∠0	9.5∠0	10.0∠0	11.0∠-12
	s7	13.0∠0	0.0∠0	7.0∠0	11.0∠0	3.5∠0	8.5∠0	4.0∠0	11.0∠0	12.0∠0	9.0∠0	8.5∠0	9.0∠0
	s8	7.0∠0	8.5∠0	10.5∠0	12.0∠0	5.0∠0	9.5∠0	9.5∠0	10.0∠0	6.0∠0	10.5∠0	10.0∠0	10.5∠-22
	s9	9.0∠0	0.0∠0	7.0∠0	10.0∠-45	0.0∠0	9.5∠0	12.0∠0	9.0∠0	5.0∠0	0.0∠0	0.0∠0	0.0∠0
	s10	0.0∠0	12.0∠0	8.0∠0	12.5∠0	2.0∠0	12.0∠+90	21.0∠0	9.5∠0	2.5∠0	8.5∠0	14.5∠0	10.0∠0
Centroid		7.0∠-8	7.0∠0	8.5∠+12	10.5∠-6	5.0∠+9	9.0∠+5	10.5∠+4	11.0∠+4	6.0∠+12	8.0∠-5	10.0∠+2	9.0∠-4
Image A_2	s1	10.5∠0	10.5∠0	10.0∠-10	12.5∠0	6.5∠0	7.0∠+45	3.5∠0	9.0∠-25	9.0∠0	11.0∠+20	10.0∠+10	9.5∠-15
	s2	3.0∠0	12.0∠0	10.5∠0	12.0∠0	13.5∠0	11.0∠0	12.0∠0	13.5∠0	12.0∠0	14.0∠0	8.5∠0	12.0∠0
	s3	11.5∠0	8.5∠0	9.5∠0	6.5∠0	0.0∠0	0.0∠0	3.5∠0	0.0∠0	11.0∠0	7.0∠+45	11.0∠0	9.5∠0
	s4	7.0∠0	9.5∠0	7.0∠0	9.0∠0	13.5∠0	13.5∠0	11.0∠0	8.0∠0	0.0∠0	4.5∠0	0.0∠0	0.0∠0
	s5	0.0∠0	2.0∠0	0.0∠0	6.5∠0	0.0∠0	0.0∠0	0.0∠0	2.5∠0	4.5∠0	0.0∠0	0.0∠0	0.0∠0
	s6	0.0∠0	6.5∠0	10.0∠+45	3.0∠0	0.0∠0	1.5∠0	6.5∠0	0.0∠0	0.0∠0	3.0∠0	0.0∠0	2.5∠0
	s7	0.0∠0	7.0∠0	7.0∠0	6.5∠0	0.0∠0	0.0∠0	7.5∠0	3.5∠0	0.0∠0	0.0∠0	3.5∠0	0.0∠0
	s8	2.0∠0	7.0∠+25	7.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s9	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	3.0∠0	0.0∠0	2.5∠0	0.0∠0
	s10	1.0∠0	9.5∠0	8.5∠0	8.0∠-45	2.0∠0	1.0∠-90	7.5∠0	0.0∠0	1.5∠0	7.5∠-17	2.5∠0	1.0∠+90
Centroid		3.5∠0	7.0∠+2	6.5∠+4	6.0∠-5	2.5∠0	3.0∠+7	5.0∠0	3.0∠-6	4.0∠0	4.5∠+10	3.5∠+4	4.5∠-2

TABLE VI (Continued)

		C_3 Non-Spatial Problems Matrix											
		B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
		D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1	s1	0.0/0	0.0/0	3.0/0	0.0/0	0.0/0	7.0/+90	0.0/0	0.0/0	6.5/0	7.0/+90	4.5/+180	5.5/-90
	s2	5.0∠+180	0.0∠0	4.0∠0	5.5∠+90	0.0∠0	2.5∠+90	0.0∠0	0.0∠0	0.0∠0	3.0∠0	5.5∠0	5.5∠-90
	s3	0.0∠0	0.0∠0	2.0∠-90	10.5∠+180	0.0∠0	0.0∠0	2.5∠+90	0.0∠0	0.0∠0	0.0∠0	1.5∠-90	8.5∠+180
	s4	4.0∠-45	4.5∠+90	5.5∠0	7.0∠-90	5.0∠+180	5.5∠+90	7.0∠0	8.5∠-90	5.0∠+180	6.0∠+90	6.0∠0	13.5∠-90
	s5	11.0∠-45	0.0∠0	7.0∠+180	0.0∠0	0.0∠0	0.0∠0	8.5∠+135	3.5∠+180	2.0∠+90	2.5∠0	8.5∠+135	8.0∠+90
	s6	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	7.5∠+180	0.0∠0	0.0∠0	0.0∠0
	s7	4.0∠0	2.0∠-90	0.0∠0	0.0∠0	2.5∠0	2.5∠-90	5.5∠+180	2.0∠+90	0.0∠0	3.0∠-90	5.0∠+180	3.5∠+90
	s8	6.5∠+180	0.0∠0	3.0∠+180	0.0∠0	0.0∠0	2.5∠-90	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s9	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s10	1.5∠0	9.5∠0	7.0∠+180	0.0∠0	9.5∠-90	13.5∠-45	6.5∠+180	0.0∠0	0.0∠0	4.5∠-90	8.0∠+180	3.5∠+90
Centroid		1.0/-70	1.0/+15	0.5/-35	1.0/+175	1.0/-130	1.0/+15	1.5/+140	1.0/-130	1.0/+150	1.0/+65	1.5∠+160	1.0/-145
Image A_2	s1	0.0/0	0.0/0	0.0/0	0.0/0	0.0/0	2.5/+90	3.0/0	8.5/-90	1.0/+180	0.0/0	0.0/0	1.5/-90
	s2	4.5∠+180	3.0∠+135	5.0∠+45	5.0∠-90	3.5∠-130	2.0∠+130	5.0∠0	3.5∠-105	3.0∠-130	3.0∠+180	4.0∠0	5.0∠-90
	s3	0.0∠0	0.0∠0	0.0∠0	6.5∠-90	0.0∠0	0.0∠0	0.0∠0	4.0∠-90	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s4	4.5∠+180	3.0∠+90	3.5∠0	2.5∠+135	4.5∠+180	0.0∠0	0.0∠0	4.0∠-90	3.5∠+180	5.5∠+90	6.0∠0	11.0∠-90
	s5	0.0∠0	0.0∠0	2.5∠0	4.0∠+90	0.0∠0	0.0∠0	4.0∠0	0.0∠0	0.0∠0	3.5∠+90	4.0∠0	0.0∠0
	s6	0.0∠0	0.0∠0	5.5∠0	0.0∠0	0.0∠0	4.5∠+90	0.0∠0	0.0∠0	5.0∠+180	4.0∠+90	4.0∠0	2.0∠-90
	s7	9.0∠+180	6.5∠+90	0.0∠0	5.0∠-90	4.5∠+180	4.5∠+90	0.0∠0	4.5∠-90	6.0∠+180	3.0∠+90	4.0∠0	0.0∠0
	s8	4.0∠+180	5.5∠+90	4.0∠0	4.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
	s9	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	5.0∠0	9.0∠+90	0.0∠0	0.0∠0	0.0∠0	3.5∠+90
	s10	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	2.0∠+180	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0	0.0∠0
Centroid		2.0∠+180	1.5∠+90	2.0∠+5	1.0∠-85	1.0∠-175	1.5∠+100	1.5∠0	2.0∠-90	1.5∠-175	1.5∠+100	2.0∠0	1.5∠-90

TABLE VII

RAW DATA AND MEANS OF RESPONSE TIMES (SECS) FOR EVEN STEP SIZE PROBLEMS

		C_1 Directional Position Matrix											
		B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
		D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1	s1	1.15	.83	.73	.80	.88	.58	.70	.67	.88	.57	.50	.57
	s2	2.09	.95	1.30	.64	.77	.75	1.01	.86	.76	.84	.88	.83
	s3	.56	.60	.46	.66	.46	.48	.39	.70	.48	.55	.44	.40
	s4	.89	.60	.88	.88	.74	.58	.91	.74	.85	.70	.55	.72
	s5	1.20	.89	.66	.88	.94	.90	.75	.88	.68	.56	.78	.64
	s6	.58	.62	.58	1.50	.60	.51	.58	.69	.39	.39	.68	.48
	s7	.64	1.48	.68	.70	.44	.55	.98	.73	.52	.51	.66	.51
	s8	.72	.87	.68	.82	.42	.52	.53	.66	.69	.65	.66	.54
	s9	.92	1.05	.83	.58	.82	1.02	.72	.88	.68	.68	.80	.87
	s10	.63	.63	.66	.66	.61	.52	.69	.63	.71	.78	.56	.58
	Mean	.94	.85	.75	.81	.67	.64	.73	.74	.66	.62	.65	.61
Image A_2	s1	1.07	3.30	1.50	1.66	.85	1.07	1.78	1.25	.87	1.14	.80	.79
	s2	.78	1.10	1.07	1.50	.80	2.14	2.04	1.90	.87	1.00	1.30	1.22
	s3	1.02	3.28	1.84	2.44	.90	2.04	1.52	2.42	.88	.76	1.25	1.00
	s4	1.56	3.51	3.35	4.23	1.50	1.84	2.68	3.40	1.14	1.90	5.00	1.56
	s5	.70	1.76	3.21	.76	1.06	.60	.68	1.40	1.00	1.02	.98	1.19
	s6	.90	1.69	3.15	2.50	1.28	2.71	3.00	3.37	.70	1.00	1.72	1.15
	s7	.96	2.35	3.10	3.79	1.50	2.48	2.88	2.50	1.18	1.80	2.25	1.90
	s8	1.20	1.61	4.44	3.78	1.88	2.11	6.27	6.58	2.13	4.36	7.46	3.36
	s9	.69	1.24	.90	.58	.69	.65	2.61	1.09	.84	.63	1.93	1.06
	s10	1.32	1.83	6.16	6.32	1.36	2.32	3.66	2.18	.80	1.30	1.51	1.30
	Mean	1.02	2.17	2.87	2.76	1.18	1.80	2.71	2.61	1.04	1.49	2.42	1.45

TABLE VII (Continued)

		C_2 Ordinal Position Matrix											
		B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
		D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1	s1	.72	.89	1.20	.55	.53	.60	.48	.50	.59	.69	.89	.67
	s2	.58	.74	.78	.40	.88	.87	1.00	.64	.80	.55	.44	.62
	s3	1.87	.83	1.39	1.10	.83	1.15	1.58	1.09	1.00	1.18	1.76	1.13
	s4	.80	.73	.60	.78	.62	.90	.80	.68	.88	.83	.82	.74
	s5	.90	1.02	.62	.96	.88	.92	1.01	.84	.64	.56	.74	.69
	s6	.89	.68	.42	.75	.58	.78	.98	.54	.97	.64	.61	1.19
	s7	1.08	.83	2.00	1.25	.98	1.04	1.25	1.13	.86	.87	1.62	.93
	s8	.50	.92	.60	.83	.87	.60	.90	.87	.70	.70	.80	.78
	s9	.90	.78	2.85	1.10	1.00	.48	1.21	1.00	.68	.62	.30	1.00
	s10	1.02	1.90	1.25	3.26	.80	1.24	2.41	2.75	1.13	2.42	.87	1.14
	Mean	.93	.93	1.17	1.10	.80	.86	1.16	1.00	.83	.91	.89	.91
Image A_2	s1	1.46	1.90	6.90	2.68	1.14	1.58	2.12	1.19	.96	1.35	2.42	.95
	s2	1.40	2.16	2.95	3.87	.66	2.13	1.10	.70	.80	.70	2.95	1.48
	s3	.72	1.20	3.44	3.80	.55	.60	.35	1.00	.84	2.72	2.85	1.15
	s4	1.17	1.85	2.47	1.50	1.10	2.27	2.22	1.75	1.35	2.37	.83	1.32
	s5	1.40	1.17	3.24	4.75	.85	1.01	1.92	1.47	1.16	.80	.96	1.62
	s6	1.43	1.80	3.12	1.90	1.75	1.15	.90	1.41	1.05	1.52	1.35	.92
	s7	1.68	2.59	7.23	1.56	1.72	2.70	4.64	4.45	2.00	1.45	.70	.56
	s8	1.10	1.86	2.78	4.55	.76	2.05	2.42	4.82	1.40	1.88	.75	.56
	s9	1.19	4.46	2.93	2.15	.86	1.10	2.85	1.86	1.09	.62	.30	.30
	s10	.98	2.00	3.94	3.53	1.62	.70	2.27	3.40	.92	1.44	.92	.84
	Mean	1.25	2.10	3.90	3.03	1.10	1.53	2.08	2.21	1.16	1.49	1.40	.97

TABLE VII (Continued)

C_3

Non-Spatial Problems Matrix

	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step	B_1 2-Step	B_2 4-Step	B_3 6-Step	B_4 8-Step
	D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
Percept A_1												
s1	1.60	2.78	6.25	6.69	1.42	2.14	4.41	6.05	1.42	2.85	4.45	5.80
s2	2.06	4.66	6.55	12.14	1.65	3.82	6.15	7.12	1.60	3.50	5.34	8.15
s3	1.25	2.84	3.58	5.56	1.25	2.40	4.26	5.25	1.22	2.53	3.66	4.88
s4	2.21	4.50	6.66	8.65	2.14	4.82	7.00	8.72	2.09	3.66	6.85	7.47
s5	2.10	4.58	10.01	10.65	2.00	4.00	5.27	6.46	1.88	4.12	5.62	8.29
s6	2.48	5.10	6.55	9.35	2.20	4.52	7.72	9.52	1.94	4.42	5.88	7.20
s7	2.30	3.32	7.65	8.65	1.66	5.10	6.07	7.30	2.00	3.83	5.76	6.22
s8	2.92	3.55	5.30	9.61	1.80	3.24	4.95	5.96	1.80	3.24	4.95	5.96
s9	1.65	3.94	4.93	6.83	1.49	3.35	4.84	6.13	1.45	2.63	4.68	5.04
s10	2.50	4.90	6.28	10.08	1.83	4.27	6.15	9.75	1.66	4.24	6.00	7.67
Mean	2.11	4.02	6.38	8.82	1.74	3.77	5.68	7.23	1.71	3.50	5.32	6.67
Image A_2												
s1	1.47	2.74	3.57	6.10	.84	3.27	4.12	4.87	.87	2.57	3.84	4.53
s2	1.55	2.62	4.55	4.37	1.17	2.07	3.60	2.80	1.25	2.36	5.01	4.75
s3	2.40	5.21	6.76	11.14	2.14	4.63	6.98	9.90	2.38	4.60	7.56	9.33
s4	3.00	4.75	8.73	12.12	2.30	4.00	7.00	8.35	2.36	4.00	8.64	9.12
s5	.95	2.89	3.83	4.65	1.28	2.55	4.00	5.27	1.24	2.82	3.78	4.85
s6	2.38	5.20	9.82	10.21	1.98	3.92	7.76	8.18	2.40	4.10	7.82	8.05
s7	2.90	6.02	8.29	11.25	2.64	5.65	8.00	10.88	2.82	6.78	8.75	11.33
s8	3.47	5.00	8.90	13.19	3.32	7.36	10.70	12.76	3.80	6.01	9.20	14.78
s9	5.40	5.17	9.53	10.75	2.76	5.42	7.70	15.86	2.38	4.95	8.00	12.40
s10	2.40	4.50	6.42	10.05	1.68	3.92	6.03	7.32	2.02	3.90	5.90	7.30
Mean	2.59	4.41	7.04	9.38	2.01	4.28	6.59	8.62	2.15	4.21	6.85	8.64

TABLE VIII

AOV OF MAIN AND INTERACTION EFFECTS FOR RESPONSE TIMES (SECS) ON ODD STEP SIZES

Source of Variation	D.F.	S.S.	M.S.	F.
Between Subjects	59	4705.526		
A (Percept-Image)	1	297.246	297.246	18.403**
C (Directional-Ordinal Non-Spatial)	2	3566.630	1783.315	117.524**
AC	2	22.248	11.124	.733
S w. Groups [error (between)]	54	819.402	15.174	
Within Subjects	660	1499.170		
B (Step Size)	3	527.997	175.999	114.702**
AB	3	18.962	6.321	4.119**
BC	6	945.238	157.540	102.672**
ABC	6	4.973	.829	.540
B x S w. Groups [error (within)]	162	248.576	1.534	
D (Trials)	2	45.529	22.764	36.157**
AD	2	9.487	4.744	7.534**
CD	4	5.813	1.453	2.308*
ACD	4	13.990	3.497	5.555**
D x S w. Groups	108	67.995	.630	
BD	6	12.447	2.074	3.254**
ABD	6	7.054	1.176	1.844
BCD	12	8.020	.668	1.048
ABCD	12	7.845	.654	1.025
BD x S w. Groups [error (within)]	324	206.566	.638	

*$p < .05$

**$p < .01$

TABLE IX

AOV OF MAIN AND INTERACTION EFFECTS FOR RESPONSE TIMES (SECS) ON DIRECTIONAL AND ORDINAL PROBLEMS ONLY

Source of Variation	D.F.	S.S.	M.S.	F.
Between Subjects	39	240.920		
A (Percept-Image)	1	136.288	136.288	48.739**
C (Directional-Ordinal)	1	.459	.459	.164
AC	1	3.507	3.507	1.254
S w. Groups [error (between)]	36	100.666	2.796	
Within Subjects	440	131.404		
B (Step Size)	3	38.588	12.863	22.582**
AB	3	29.755	9.918	17.377**
BC	3	.066	.022	.039
ABC	3	1.421	.474	.831
B x S w. Groups [error (within)]	108	61.574	2.796	
D (Trials)	2	25.751	12.875	17.681**
AD	2	12.324	6.162	8.580**
CD	2	2.873	1.436	2.000
ACD	2	3.959	1.980	2.756
D x S w. Groups [error (within)]	72	51.713	.718	
BD	6	10.418	1.736	4.214**
ABD	6	10.089	1.682	4.080**
BCD	6	4.949	.825	2.001
ABCD	6	2.522	.420	1.020
BD x S w. Groups [error (within)]	216	89.016	.412	

**$p < .01$

TABLE X

MEANS OF RESPONSE TIMES (SECS) FOR ODD STEP SIZE PROBLEMS

	B_1 3-Step	B_2 5-Step	B_3 7-Step	B_4 9-Step	B_1 3-Step	B_2 5-Step	B_3 7-Step	B_4 9-Step	B_1 3-Step	B_2 5-Step	B_3 7-Step	B_4 9-Step
	D_1 Trial 1				D_2 Trial 2				D_3 Trial 3			
	C_1 Directional Problems Matrix											
Percept A_1	.78	.76	.89	.77	.83	.83	.85	.78	.74	.83	.97	.77
Image A_2	2.19	3.12	3.51	3.38	2.62	2.54	3.97	2.26	1.78	2.07	2.42	1.29
	C_2 Ordinal Problems Matrix											
Percept A_1	.96	.89	1.13	.74	.91	1.13	1.04	.83	.80	1.01	.90	.82
Image A_2	1.37	2.58	3.31	2.23	1.32	2.66	2.22	1.22	1.39	1.67	1.94	1.08
	C_3 Non-Spatial Problems Matrix											
Percept A_1	2.88	5.09	7.21	9.82	2.72	4.62	6.28	9.09	2.48	4.30	6.32	7.99
Image A_2	3.24	6.33	8.50	10.32	3.26	5.75	7.73	10.11	3.38	5.43	7.42	9.93

TABLE XI

MEAN EYE BLINK RATES FOR CONTROL (C), MESSAGE (M), RESPONSE TIME (R_t), AND RECOVERY (R_e) INTERVALS DURING SOLUTIONS TO ALL PROBLEMS

	B1 2-Step				B2 4-Step			B3 6-Step			B4 8-Step		
	E_1 C	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re
Trial 1 D_1													
C_1 Directional Position													
Percept A_1	23.0	10.3	93.8	26.0	10.3	0.0	46.0	17.3	10.3	32.0	11.0	0.0	38.0
Image A_2	12.6	3.4	14.4	16.0	8.6	3.7	18.0	3.4	16.3	24.0	6.9	11.2	26.0
C_2 Ordinal Position													
Percept A_1	17.7	6.9	6.7	24.0	34.2	8.8	24.0	12.0	3.0	18.0	8.6	0.0	22.0
Image A_2	27.8	22.3	50.3	40.0	17.1	29.6	32.0	24.0	23.5	50.0	25.7	23.2	50.0
C_3 Non-Spatial Problem													
Percept A_1	13.5	6.8	9.7	14.0	8.6	4.3	6.0	6.7	3.4	28.0	6.7	11.3	28.0
Image A_2	23.1	15.4	2.8	26.0	8.6	5.7	32.0	6.8	5.9	42.0	13.7	8.4	46.0

TABLE XI (Continued)

	B₁ 2-Step				B₂ 4-Step			B₃ 6-Step			B₄ 8-Step		
	E_1 C	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re
Trial 2 D_2 — C_1 Directional Position													
Percept A_1	23.0	10.3	13.6	28.0	10.3	0.0	28.0	12.0	6.1	30.0	10.3	15.0	32.0
Image A_2	12.6	3.4	3.2	18.0	0.0	5.1	20.0	6.9	6.8	28.0	8.6	4.5	24.0
C_2 Ordinal Position													
Percept A_1	17.7	10.3	21.7	26.0	8.6	10.0	20.0	10.3	13.6	28.0	5.1	0.0	26.0
Image A_2	27.8	22.3	23.2	44.0	18.9	33.6	32.0	34.0	41.2	36.0	17.1	31.8	38.0
C_3 Non-Spatial Problem													
Percept A_1	13.5	15.2	10.2	18.0	12.0	1.8	20.0	6.8	3.0	22.0	6.8	2.2	26.0
Image A_2	23.1	15.4	0.0	22.0	13.7	6.4	30.0	13.7	9.0	42.0	17.1	6.5	48.0

TABLE XI (Continued)

	Trial 3 D_3												
	B_1 2-Step				B_2 4-Step			B_3 6-Step			B_4 8-Step		
	E_1 C	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re	E_2 M	E_3 Rt	E_4 Re
C_1 Directional Position													
Percept A_1	23.0	13.7	8.8	20.0	12.0	17.7	30.0	8.6	19.3	34.0	12.0	20.2	20.0
Image A_2	12.6	3.4	8.8	18.0	5.1	1.4	22.0	5.1	12.3	26.0	8.6	7.0	24.0
C_2 Ordinal Position													
Percept A_1	17.7	6.8	0.0	20.0	6.8	10.9	24.0	5.1	13.6	20.0	6.7	0.0	16.0
Image A_2	27.8	29.1	31.8	32.0	13.7	35.0	28.0	17.3	53.0	40.0	25.7	74.3	22.0
C_3 Non-Spatial Problem													
Percept A_1	13.5	6.9	6.4	14.0	8.6	3.0	12.0	10.3	2.1	16.0	8.6	3.7	20.0
Image A_2	23.1	10.3	11.0	30.0	18.8	12.1	42.0	6.9	13.2	46.0	13.7	13.7	40.0

APPENDIX C

FIGURES

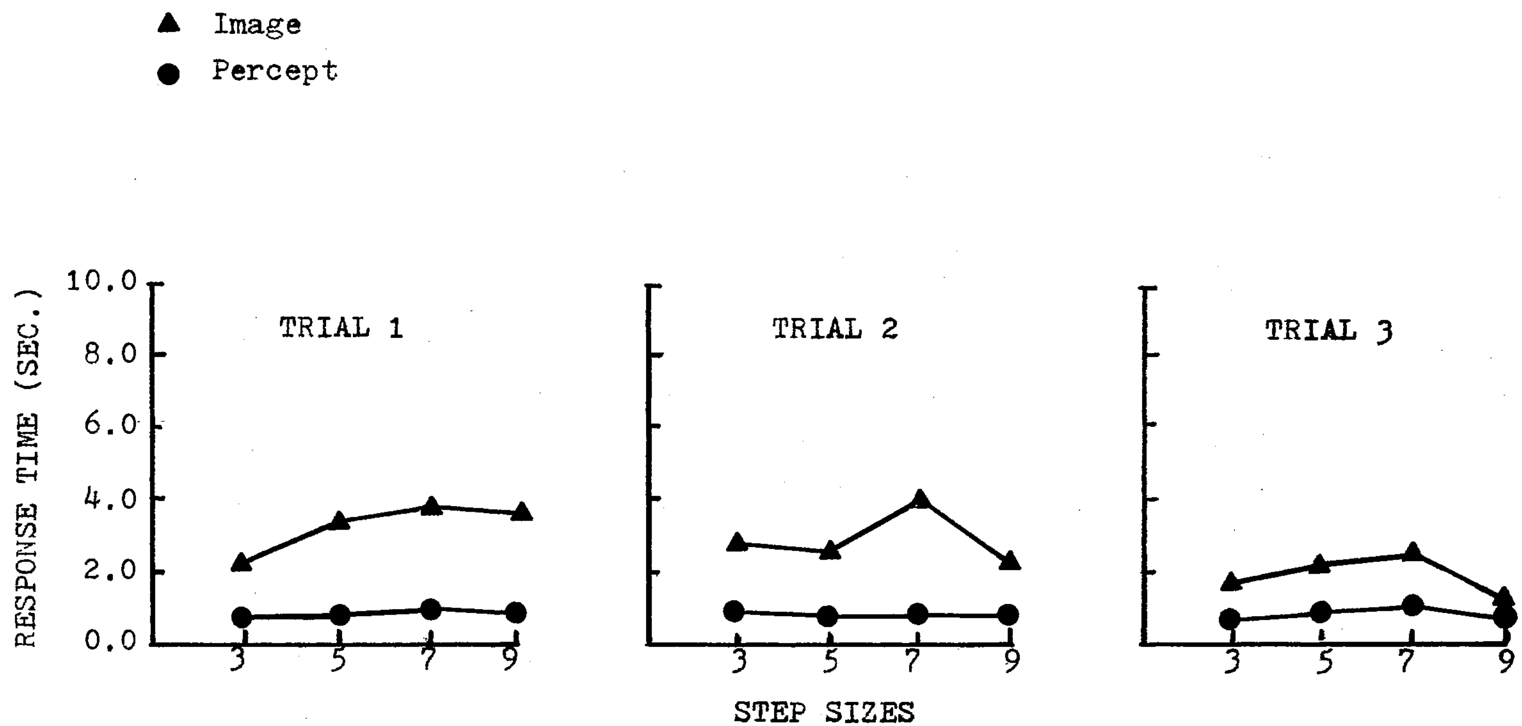


Figure 13. Directional Problems (Odd Step Sizes). Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

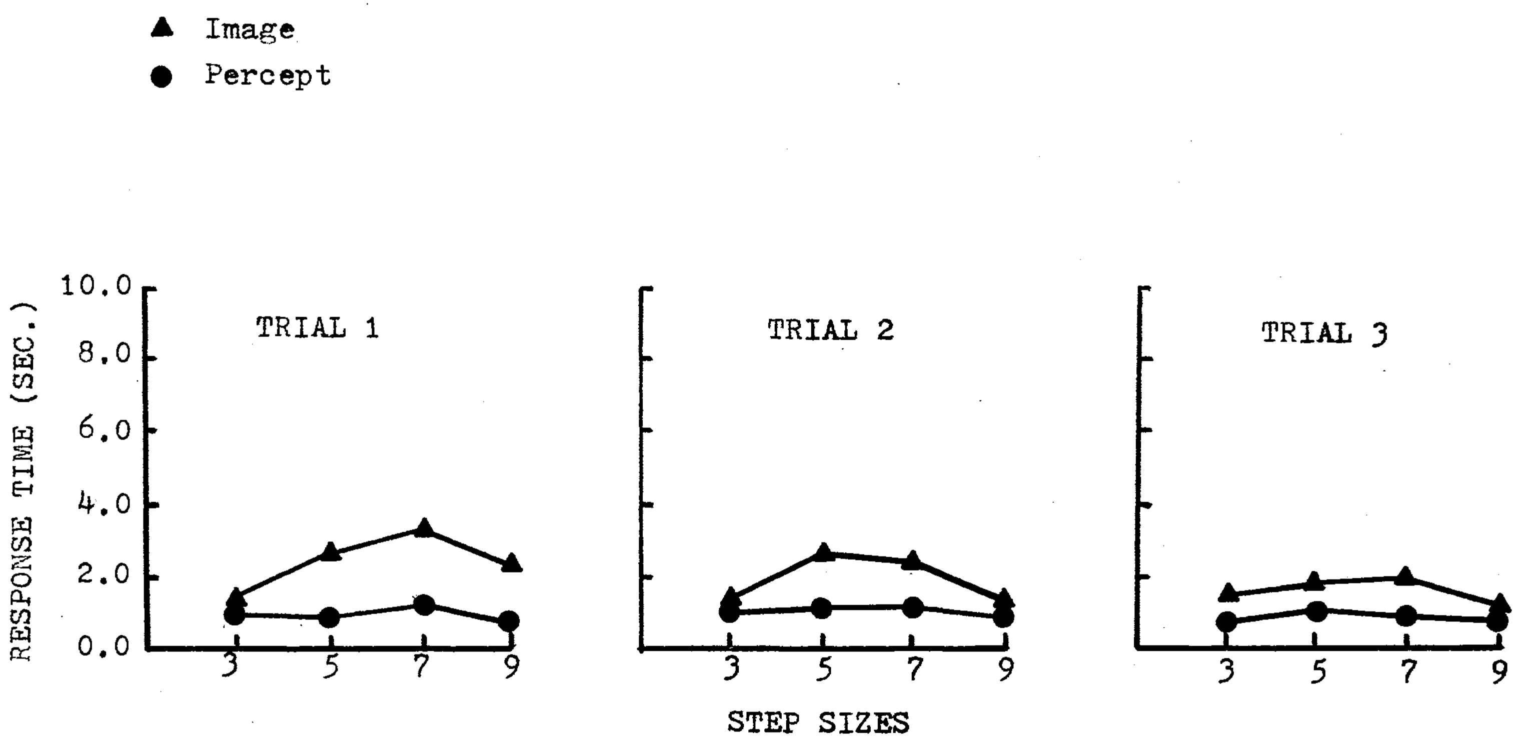


Figure 14. Ordinal Problems (Odd Step Sizes). Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

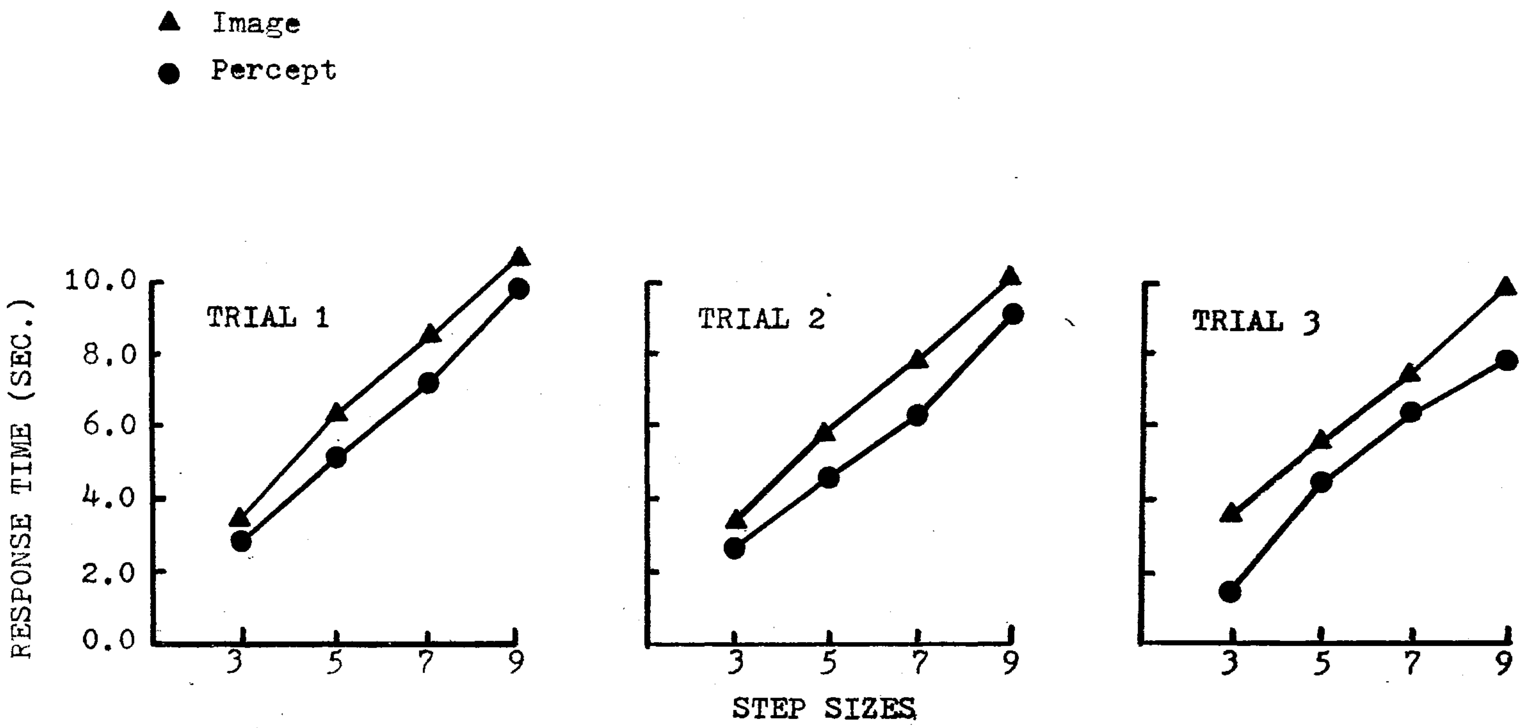


Figure 15. Non-Spatial Problems (Odd Step Sizes). Mean Response Times (Secs.) as a Function of Step Size Over Three Consecutive Trials

APPENDIX D

DATA RECORDING PROCEDURES

DATA RECORDING PROCEDURES

Reading the Recorder Traces

Reading the recorder traces off the Sanborn 320C dual channel heat sensitive paper may present some problems for those persons unfamiliar with the equipment. Therefore, actual data used in this experiment is presented in Figures 16 and 17, along with explanatory notes. The S presented is number 57, who was presented the image-ordinal problems. In these figures, the actual size of the tracing paper has been reduced by approximately 30%.

Figure 16 shows the calibration sequence during which the S was instructed to look at the various clock positions. Because of the variations in shapes of Ss' eyeballs, the tracings do not show equivalent needle deflections from right to left nor from up to down. A full needle deflection to the 12:00 o'clock (up) position shows 12.0 degrees VA. Crosstalk in the recorder is an undesirable electronic phenomenon. Crosstalk appears when movement in one eye shows up on the opposite trace; unless this is disregarded in the calibration procedure, it will falsely be plotted as additional eye movements. Reference to Figure 16 shows the S looking in the 3:00 position (12.0 degrees VA); however, the tracing from the right eye (vertical eye movement trace

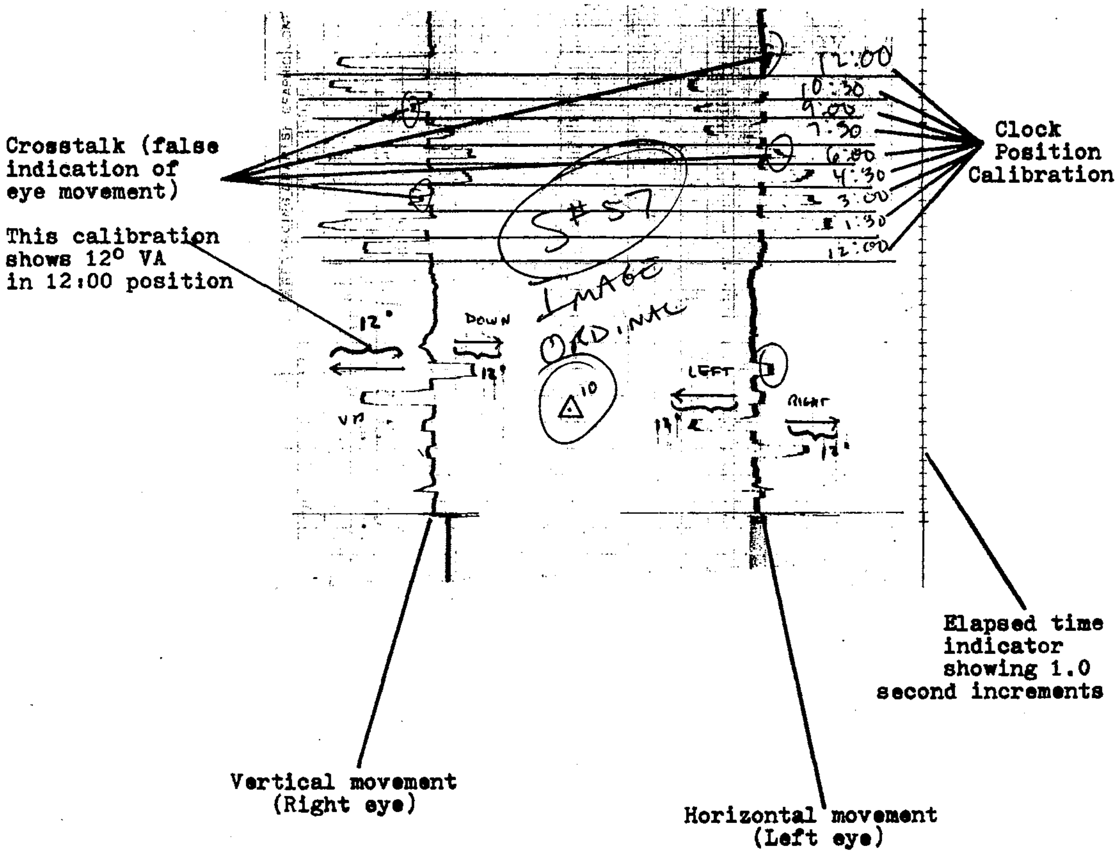


Figure 16. Recorder Trace. Sample Calibration

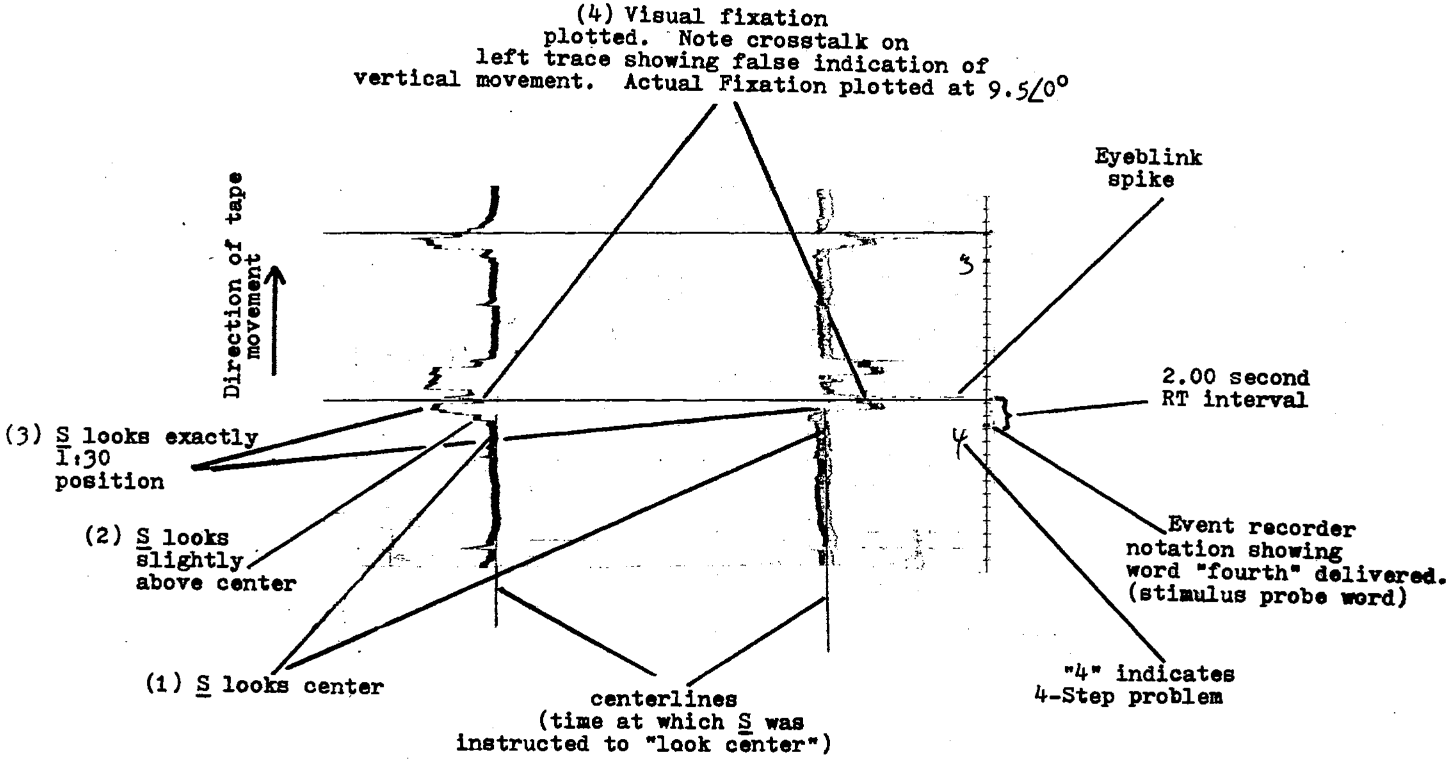


Figure 17. Recorder Trace. Reading the Fixation

seen on the left) would apparently indicate the S is also looking 1/3 or 4.0 degrees VA towards 3:00 o'clock -- in other words, slightly beyond the 2:00 o'clock position. Because the S was instructed to look specifically at the 3:00 o'clock position, the apparent vertical movement is disregarded as crosstalk. Furthermore, anytime the S's fixation is plotted as falling in the 3:00 general area, and the apparent vertical movement is approximately half the needle trace as the horizontal trace, crosstalk is suspected.

Figure 17 shows the sequence of fixations after the S was asked, "Of the letter series, what letter is fourth?" The event recorder notation on the right edge of the tracing paper indicates when the word "fourth" (the stimulus probe item) was delivered. Since the RT interval was 2.00 seconds, a 2.00 interval is measured off from the time of the stimulus probe item delivery. The end of the RT interval is denoted by the horizontal line drawn above the handwritten number "4". The sequence of fixations shows that this S started to look slightly upwards towards 12:00 o'clock, then directly at the 1:30 position, and finally 80% of the way towards the 3:00 position (80% of 12.0 degrees = approximately 9.5 degrees VA).

Method for Finding Centroids

Once the actual visual fixation for a S is determined, it becomes convenient to describe an average visual fixation for several Ss. The graphical method of averaging these fixations is ideally suited to this problem. The procedure used in this experiment is identical to the method an aircraft navigator uses when determining an average wind over a desired flight course. Further details on this method can be found in Volume 1 Air Navigation, United States Air Force Manual 51-40, pages 5-33 to 5-36, dated 1 August 1969.

An example problem is shown in Figures 18 and 19. The problem is to find the average visual fixation from three hypothetical visual fixations.

GIVEN: 3 visual fixations 11.0/-21, 20.5/-22, and 15.0/+6. This is a 4-step problem, so assume the expected centerline at the 3:00 o'clock position.

FIND: Centroid, or average visual fixation.

SOLUTION: Treat the fixations as vectors, each having a magnitude and a direction. (Bold print denotes a vector.)

(1) Plot the first fixation at the center of the grid, 11.0/-21 (V_1).

(2) Starting from the first fixation, plot the second fixation, 20.5/-22 (V_2).

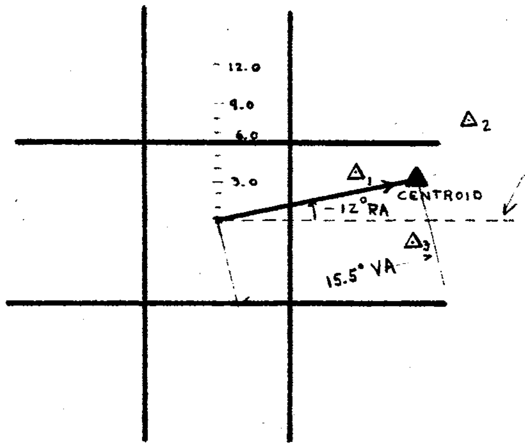
(3) From the second fixation, plot the third fixation, 15.0/+6 (V_3).

(4) From the third fixation, measure both the distance (46) and the direction (-12 degrees counterclockwise from the expected centerline) from the center of the grid.

(5) -12 degrees is the RA. 46/-12 is the resultant (R).

(6) Divide the distance (46) by the number of entries (3). This is the average geometric VA (15.5).

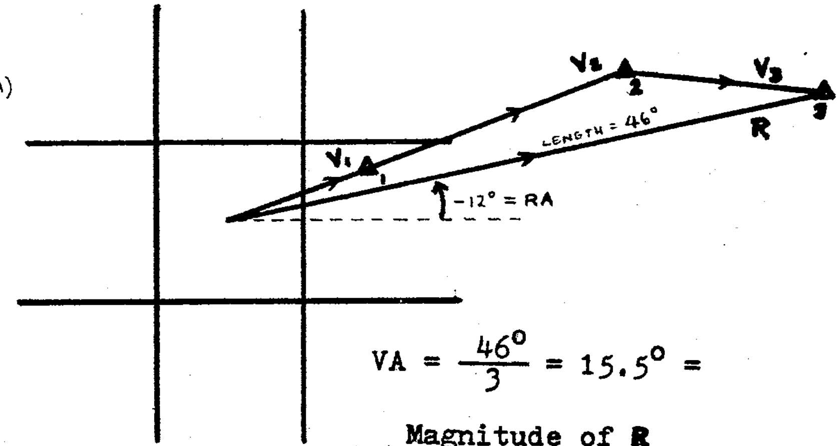
(7) Plot the point 15.5/-12. This is the centroid.



$$R = V_1 + V_2 + V_3$$

$$\text{Centroid} = \frac{R}{n} = VA\angle RA = 15.5\angle{-12^\circ}$$

Figure 18. Vector Problem. Find the Centroid



$$VA = \frac{46^\circ}{3} = 15.5^\circ = \frac{\text{Magnitude of } R}{\text{Number of Entries}},$$

RA = Actual Angle R Deviates from Expected Centerline

$= -12^\circ$

Figure 19. Vector Problem. Graphical Solution

APPENDIX E

THE EYE BLINK AS AN ERASER

THE EYE BLINK AS AN ERASER

Introduction

Although not a part of the original experiment, it was decided early during the data collection to monitor the Ss' eye blinks. Yarbus (1967) suggests that both the eye blink and the saccade signals a new process of seeing. It appeared, under most circumstances, that the Ss were most reluctant to blink while performing the solutions to a visual imagery problem. Since eye blinks were easily distinguished from other visual processes by the magnitude and size and rapidity of deflection, this part of the experiment could be analyzed completely separate from the main part of the experiment.

Method

A control (C) blink rate for each S was obtained by allowing him to look "generally toward the center of the calibration grid" for thirty seconds before the experiment began. Likewise, the S was instructed to "relax and look in the general direction of the matrix while the equipment cycles down", at the end of the experiment.

The message interval (M) eye blink rate was established by counting the actual number of eye blinks during each three and one-half second interval before the stimulus probe question item was delivered. Three and one-half seconds was chosen, because it was determined that was the average length of time it took the E to deliver the question to the S.

Similarly, the response time interval (R_t) eye blink rate was calculated by counting the actual number of eye blinks that occurred during the response time intervals, shown in Appendix B, Table VII.

Finally, it was estimated that there was approximately a three second interval from the time the S answered the question correctly until the E could record the response time data and reset the clock, and during this interval the S was not being spoken to. This interval was labelled the recovery time interval (R_e), and eye blink rates were established here, too.

The actual design of the eye blink experiment remains identical to the original experiment with the addition of a fifth level, E, of four intervals, C, M, R_t, and R_e. The level of E is, again, a within subjects condition.

Results and Discussion

No AOV was computed for the analysis of blink rates. Of 2220 discrete bits of data, exactly 1200 were zero entries, the AOV was not an appropriate statistic. Instead, the results are presented descriptively.

Under all conditions, percept and image, and for all problem types, spatial and non-spatial, there appears a strong tendency on the part of the S to refrain from blinking during both the message and the response time intervals. Likewise, there appears a strong tendency for the S to "catch up" on his blinking during the recovery interval, after he has solved the problem.

Table XI gives the mean eye blink rates for each set of ten Ss under each of the conditions of A (percept-image), C (directional-ordinal-non-spatial), B (step sizes 2, 4, 6, and 8), D (trials 1, 2, and 3), and E (control, message, response time, and recovery intervals).

The mean eye blink rates are plotted in Figures 20, 21, and 22, for trials 1, 2, and 3, respectively.

In only six of the seventy-two separate conditions is there a departure from the tendency of the Ss to follow the response time interval with a characteristic flurry of eye blinks. What is also interesting is that it seems to make no difference that the problem presented to the Ss was either spatial or non-spatial. If anything, blinking activity appeared to be even more inhibited during the non-spatial problem solving intervals.

There exists the possibility that the eye blink rates may have been encouraged by the presence of the admittedly uncomfortable eye glasses frames which the Ss were required to wear during the course of the experiment. However, this condition remained constant for all Ss.

C = Control or No Load Interval
M = Message Interval
Rt = Response Time Interval
R_e = Recovery Interval

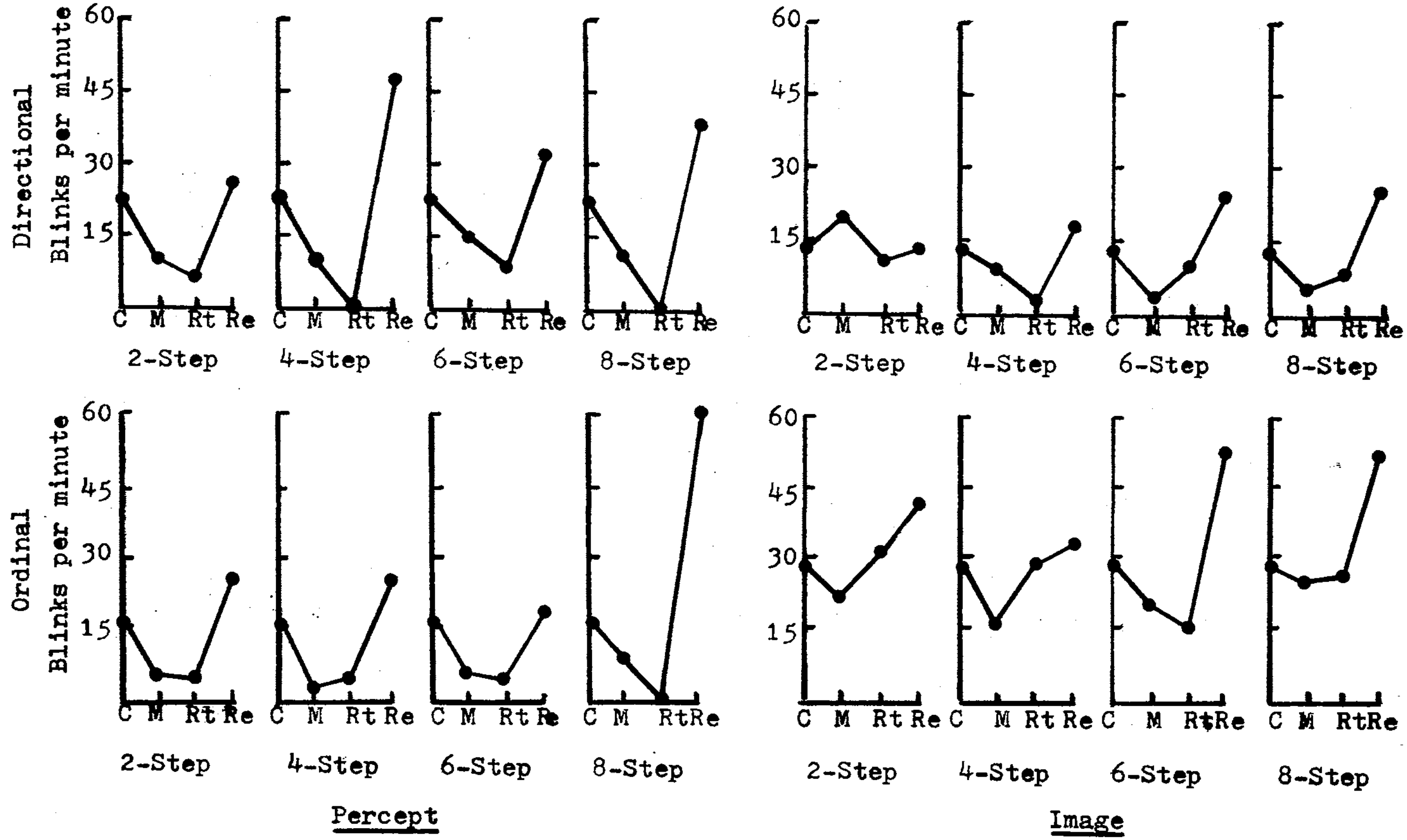


Figure 20. Mean Eye Blink Rates During Trial 1 of All Problem Conditions. Rates (Blinks/Minute) Plotted as a Function of Control, Message, Response Time, and Recovery Intervals

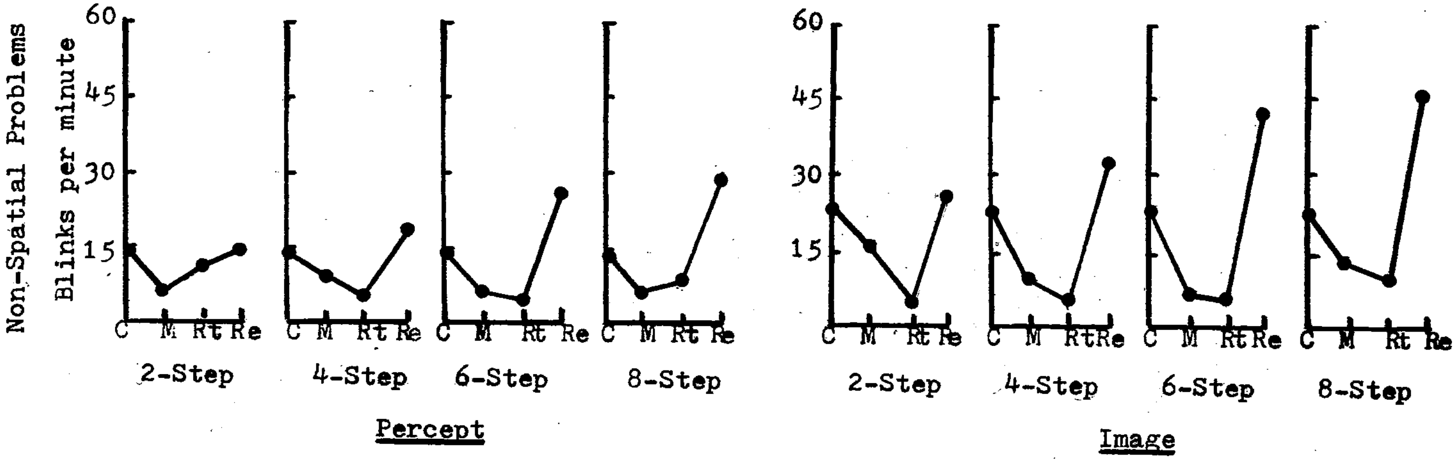


Figure 20. (Continued)

C = Control or No Load Interval
M = Message Interval
R_t = Response Time Interval
R_e = Recovery Interval

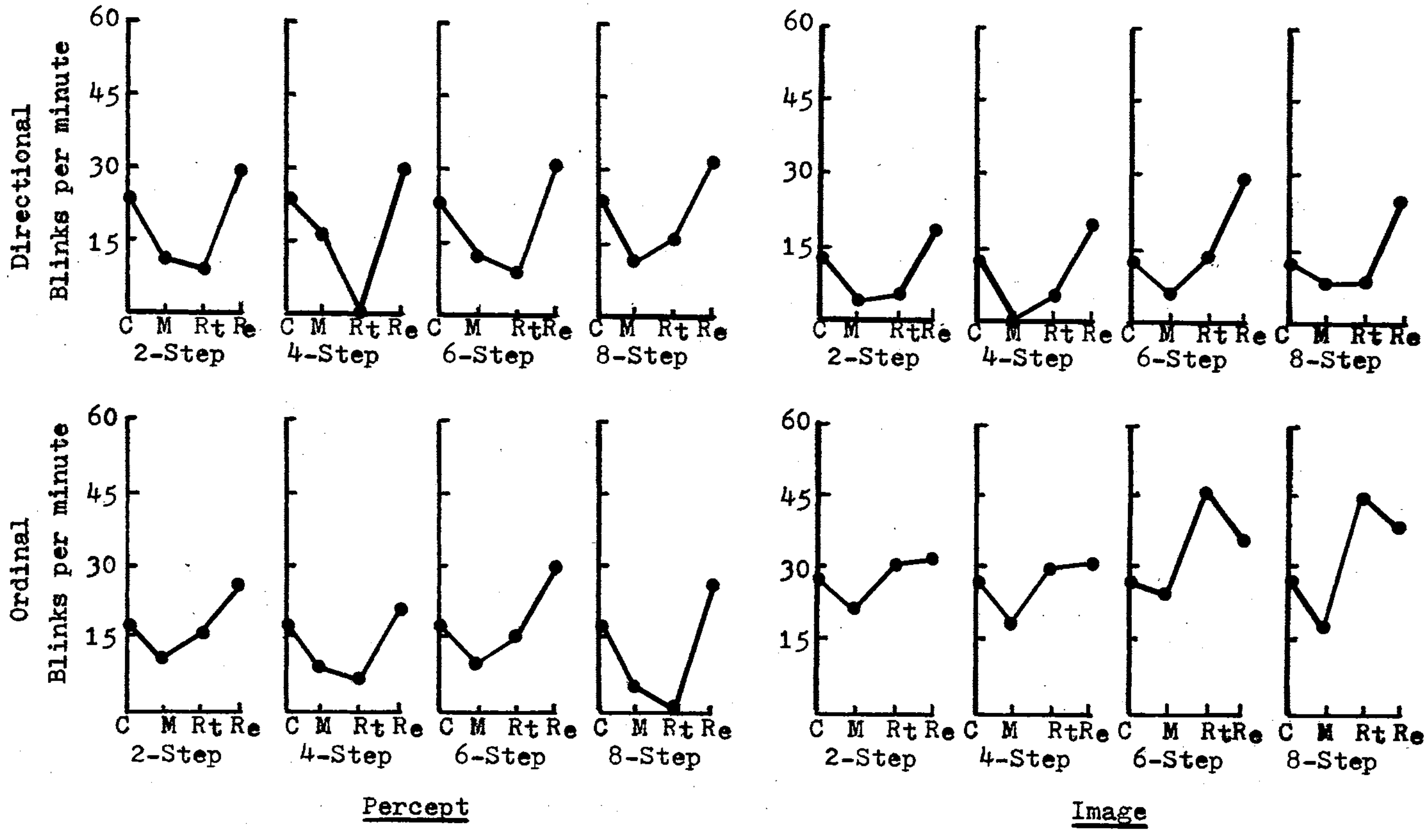


Figure 21. Mean Eye Blink Rates During Trial 2 of All Problem Conditions. Rates (Blinks/Minute) Plotted as a Function of Control, Message, Response Time, and Recovery Intervals

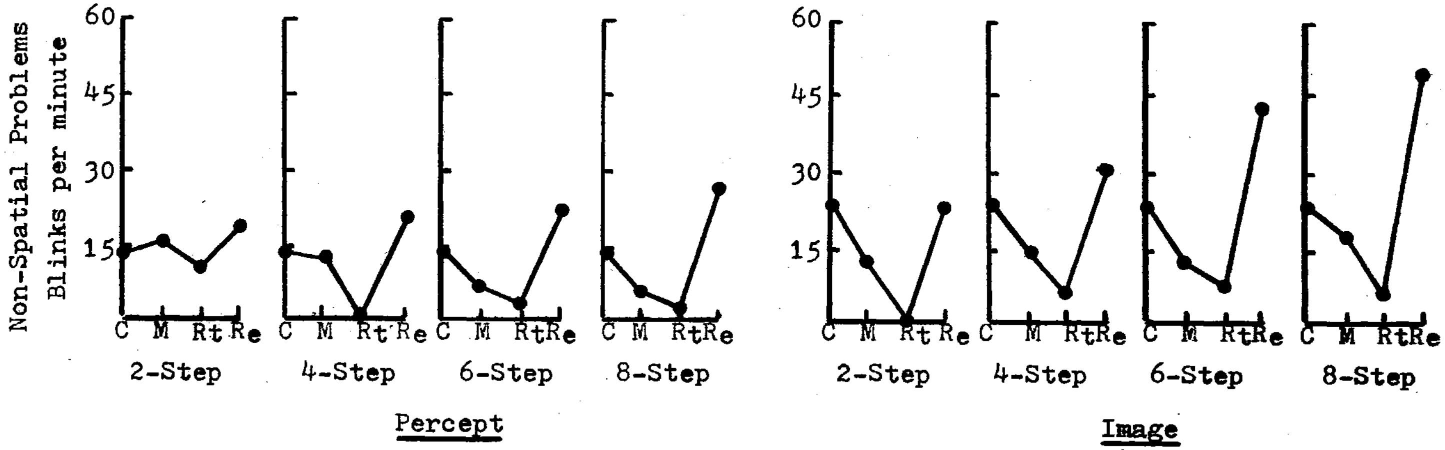


Figure 21. (Continued)

C = Control or No Load Interval
M = Message Interval
Rt = Response Time Interval
Re = Recovery Interval

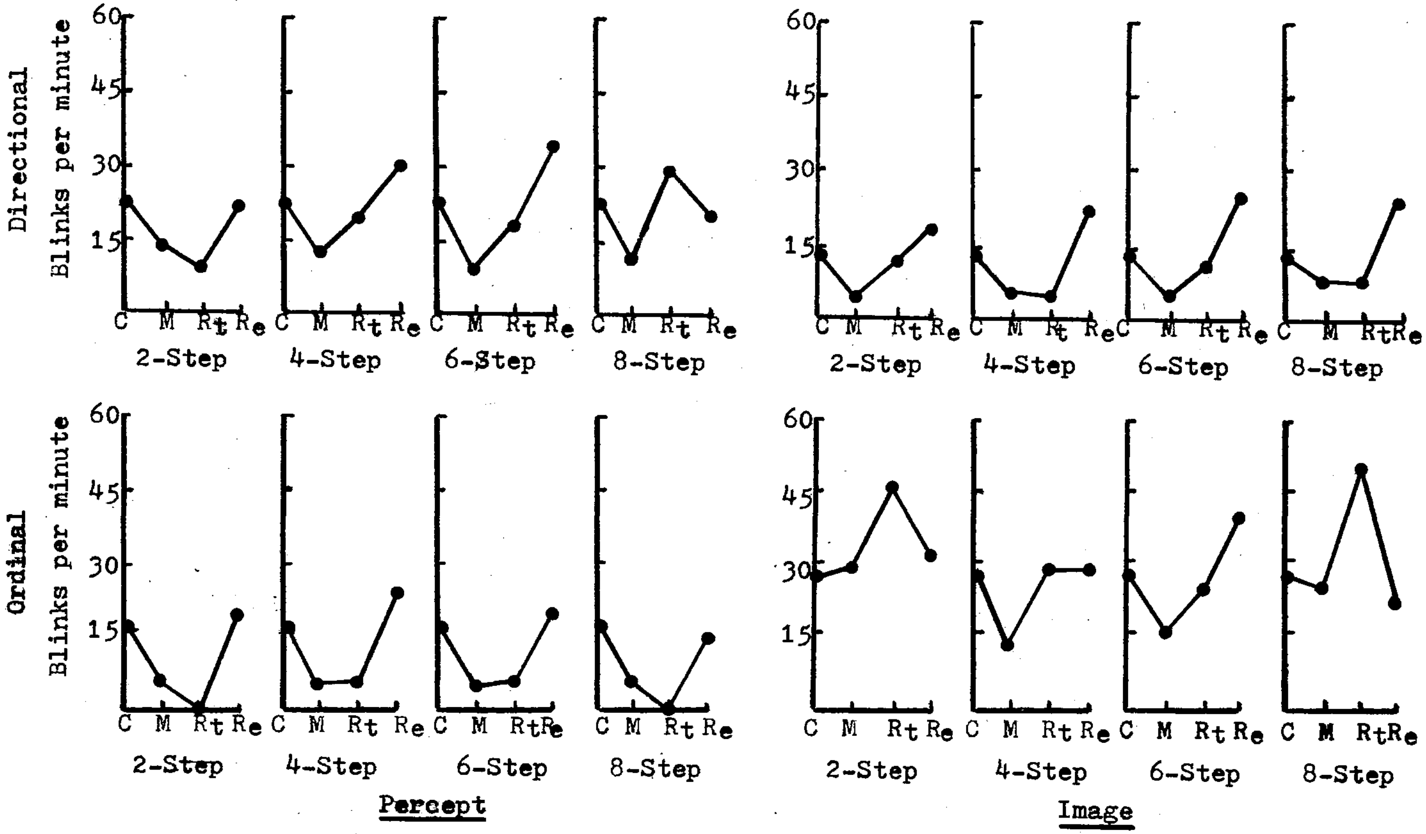


Figure 22. Mean Eye Blink Rates During Trial 3 of All Problem Conditions. Rates (Blinks/Minute) Plotted as a Function of Control, Message, Response Time, and Recovery Intervals

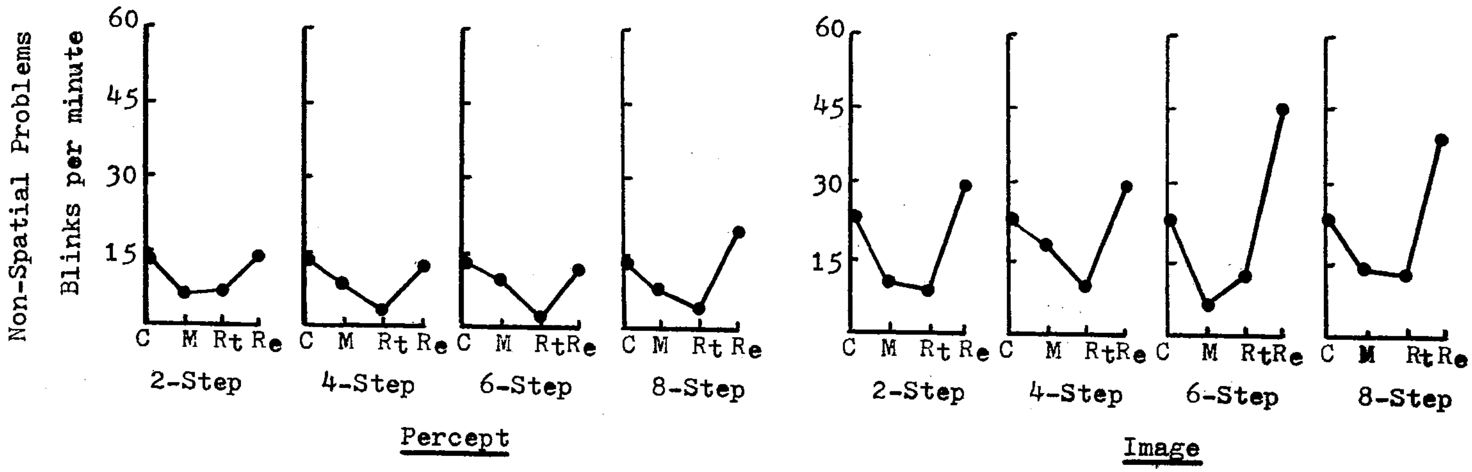


Figure 22. (Continued)

Summary and Conclusions

There is support for Yarbus's (1967) speculation that eye blinks do, indeed, signal ends of discrete thought processes. Furthermore, the fact that the thought process involves a spatial or a non-spatial problem seems to make no difference; there is a definite inhibition of the eye blink during the types of problem solving activity presented in this experiment.

There exists a possibility that the actual wearing of the photocells by the S may be a confounding factor, however, and this possibility needs to be investigated under conditions where the S does not wear such equipment.

Also, as mentioned in Chapter I, this observation holds only for a static condition of imagery. Imagining an event such as a swinging pendulum or a ping-pong game may involve entirely different patterns of eye blink activity.

VITA

Frederick Vincent Malmstrom

Candidate for the Degree of

Master of Science

Thesis: VISUAL FIXATIONS ABOUT AN IMAGINARY LETTER MATRIX

Major Field: Psychology

Biographical:

Personal Data: Born in Kalamazoo, Michigan, September 8, 1939, the son of Lt. Col. and Dr. Vincent F. Malmstrom.

Education: Graduated from the Leelanau Schools, Glen Arbor, Michigan, in June, 1957; received the Bachelor of Science degree from the United States Air Force Academy, Colorado in June, 1964; received the Degree of Master of Aerospace Operations Management from the University of Southern California, Los Angeles, California in January, 1970; completed the requirements for the Master of Science degree at Oklahoma State University in May, 1973.

Professional Experience: Air Force Navigator and Electronic Warfare Officer, 1965-1970; Academic Adviser, Course Director, and Instructor of Behavioral Sciences, Department of Life and Behavioral Sciences, United States Air Force Academy, Colorado, 1971-present.