OPTIMAL ELEMENT SIZE-SHAPE-SPACING COMBINATIONS FOR A 5 X 7 DOT MATRIX VISUAL DISPLAY UNDER HIGH AND LOW AMBIENT ILLUMINANCE

by

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INTRODUCTION

The demands on each person's already overworked visual system increase daily; likewise, the need for more efficient aids in the processing of visual information increases. As Reingold (1974) has stated, display engineering is a particularly fertile field for providing the necessary improvements. However, VanderKolk, Herman, and Hershberger (1975); Vartebedian (1971); Semple, Heapy, Conway, and Burnette (1971); Shurtleff (1966; 1970a; 1970b; 1974) and others have shown the complexities involved with display research. Among these are the intrinsic confounding of element size, interelement spacing and overall character size; how to explore the effect of the shape of the element on reading or searching speed; what is the optimal font or character style, or even is there such an optimal font for all types of displays; what effect do environmental conditions, such as ambient illuminance (room lighting), display to operator distance, and glare, have on operator performance; and many other, mostly interacting, factors.

The dot matrix, or discrete element, displays area is a relatively unexplored one, though more and more applications of these displays are developed every day. Everyone is probably familiar with these displays in the forms of time/temperature signs on many banks, and displays for calculators or airline terminals' flight arrival/departure information; however, the most important use of these displays in the future will probably be as computer terminals' output devices. Therefore, it has become important to determine whether it is possible to generalize from stroke character display principles, or if not, to develope separate guidelines just for discrete element displays. Recent research, such as VanderKolk, *et al.*, has shown that the latter is probably necessary.

VanderKolk, *et al.* (1975) provided a thorough review of research pertinent to dot matrix displays. They mentioned a partial list of variables which included percent active area ((dot size/dot space)^2 X 100), symbol definition (vertical elements), symbol subtense, viewing angle, symbol orientation, display surround luminance, contrast, symbol motion, font, matrix size, emitter chrominance, and vibration of either the entire display or the symbol alone.

It would be difficult to perform a factorial experiment on this many variables. Partitioning these variables could produce one group of variables that VanderKolk, *et al.* called visibility factors (as opposed to factors of higher mental processing such as symbol definition, rotation and orientation). Visibility factors are the variables that affect detection of the element, whether as a single element or as an element of a character, such as percent active area, surround luminance, and contrast. Percent active area could be divided into element size and interelement spacing. Implicit in the percent active area factor is another variable, overall symbol subtense. Semple, *et al.* (1971) concluded from several studies that symbol legibility is affected by character subtense up to 27 minutes of visual arc. Howell and Kraft (1959) showed that other factors, such as blur, could affect the optimum symbol subtense predictions.

Spacing at least up to 26% of symbol height, was also indicated by Semple, *et al.* to have an effect on symbol legibility. Casperson (1950), as referenced in VanderKolk, *et al.* showed that there were effects of element shape. VanderKolk, *et al.* and Semple, *et al.* disagree with the direction of Casperson's results, but each of these researchers does indicate that there is a main effect from element shape and that there are interactions of shape and other display variables.

From all of these variables, four have been chosen as making up a practical unit to be studied simultaneously (Figure 1). Element size, interelement spacing, element shape, and ambient illuminance all are thought to interact to affect the detectability and the recognition of a character. The effect of each of these variables on visual performance is discussed briefly below.

Ambient Illuminance

VanderKolk, *et al.* (1975) and Semple, *et al.* (1971) show a relationship among element size, interelement spacing, and contrast. Semple, *et al.* and Taylor (1975) stated that the smaller the character, the greater the character-to-background contrast must be. Carel (1965) showed that if the ambient illuminance at the display is more than 10 times greater than the display's background illuminance, and if the operator is adapted to this ambient illuminance level, symbol-to-display background illuminance contrast ratios must be significantly greater than when the ambient-to-display background illuminance ratio is less than 10. Contrast was given by VanderKolk, *et al.* as

$$\text{Contrast} = \frac{B_{max} - B_{min}}{B_{min}} \tag{1}$$

for a light character on a darker background, where B is display luminance. As Gould (1968) has pointed out, within the normal ambient illuminance range of 550-1100 lux (Taylor, 1975) this ambient illuminance can and should be added to the display's element luminance and surround luminance in the form

$$\text{Contrast} = \frac{B_{max} - B_{min}}{B_{min} + B_{ambient}} \tag{2}$$

and can be isolated to study its effects on visual displays.

Element Shape

Vartebedian (1970), as reported in VanderKolk, *et al.*, showed that element shape can be a determinant of subjects' performance. He found that elliptical elements were inferior to circular elements in speed and accuracy of identification measures. As VanderKolk, *et al.* pointed out, "the eye can integrate luminous flux over a finite area" (p. 120), so the effect that element shape has on legibility is probably one of luminous density. Hence, circles are more luminous per some finite area than are triangles that can be inscribed within the circles, for example, and should be more detectable. Casperson, as VanderKolk, *et al.* stated, found that rectangles are more detectable than are squares. Gould (1963), Biberman (1973), Groves (1973), and Thompson (1957), as reported in VanderKolk, *et al.*, all have stated that stroke simulated characters, *i.e.*, characters with no percepible spaces between adjacent elements, are better than discrete element characters. This would imply that elongated, relatively less dense elements are better if oriented vertically to minimize spacing. Vartebedian (1970), contrary to Gould, Biberman, Groves, Thompson, and Semple, *et al.*, stated that circular elements are superior to elongated elements for accuracy and speed of identification, at least for cathode ray tube applications. As Ketchel and Jenny (1968) summarized, there can be little doubt that element shape, at the least, interacts with other variables in determining character or symbol legibility.

Element Size and Interelement Spacing

Element size and interelement spacing have been studied from several approaches. Actually, there are three interdependent variables; the third variable is overall character subtense. Setting the sizes of any two of these variables will automatically and inevitably set the size of the third.

Howell and Kraft (1959) used overall subtense to study legibility of stroke characters projected on a ground glass screen. Their results indicate that 16.4 minutes of visual arc were sufficient for 97% accuracy of identification. Shurtleff, Marsetta, and Showman (1966) determined that up to 36 minutes of arc might be required for equivalent performance on a raster display. Ellis, Burrell, Wharf, and Hawkins (1974), as cited in VanderKolk, *et al.*, showed that a dot-to-space ratio of 2:1 was preferable to a ratio of 1:1 when total luminance (integrated over the entire character) for both types of characters was equal. This means that a character composed of larger, dimmer elements is more legible than a character of smaller, brighter elements (assuming the same overall character size).

Research Objectives

The four variables, *i.e.*, element size, element shape, inter-element spacing, and ambient illumination, were studied to determine how they affect legibility and, more importantly, some optimal combinations of these four variables. Due to the confusion surrounding the effects of these variables, a broad range of combinations was selected (54 combinations of the variables, total). Also, since different tasks require disparate combinations of the variables for optimal subject performance, it was necessary to use three separate, but representative, subject tasks and to analyze each task's results independently of the other tasks. With the results of this study, it is hoped that industrial designers, for instance, can fabricate a dot matrix visual display superior to displays of the past in terms of individual and contextual character legibility.

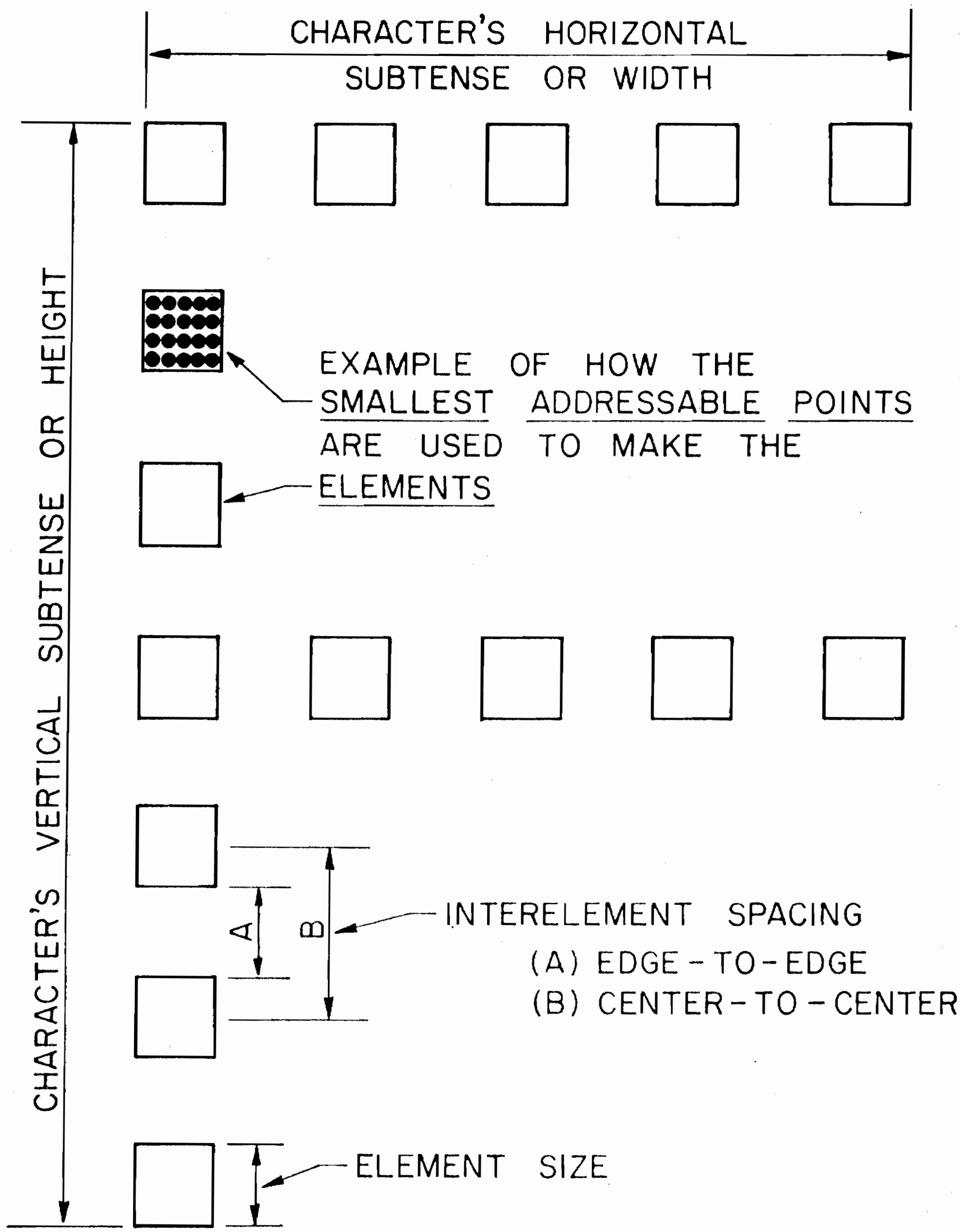


Figure 1. Typical Character

METHOD

Pilot Study - An Optimal Font

There has been no demonstrated superior font for dot matrix characters. VanderKolk, *et al.* (1975) concluded that legibility differences between dot matrix fonts were minimal, so they chose the Lincoln/Mitre (L/M) font for their experiments due to its popularity as a stroke font. Maddox, Burnette, and Gutmann (1977) showed significant differences among three 5 X 7 fonts. They created two of the fonts; the third was the L/M font, as adapted by VanderKolk, *et al.* to dot matrix displays. The greatest number of errors was obtained with the Lincoln/Mitre font; the best font let to 18% fewer errors than did the L/M. This shows that improvements are possible over the L/M for 5 X 7 dot matrix applications.

Though the three fonts can be ranked in order of total number of errors, any of the three fonts may have been best on one particular alphanumeric character. It is advantageous to further minimize total errors for a proposed alphanumeric font by picking the best font of the three for each alphanumeric character. This "composite font" (Figure 2) would theoretically have 46% fewer total errors than would the L/M and was used as an optimal 5 X 7 dot matrix font during the following research.

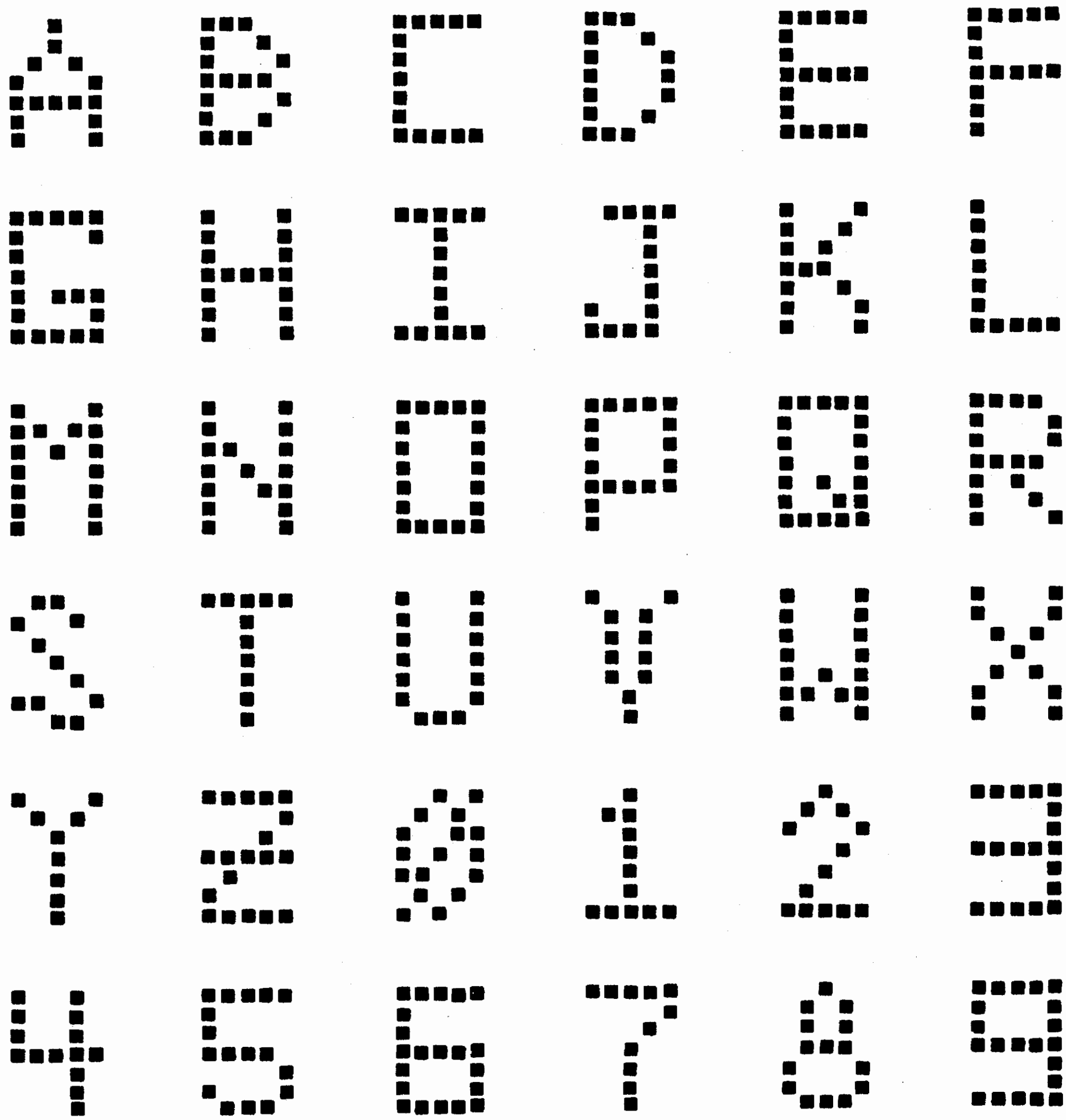


Figure 2. Composite Font

Experimental Design

The four fixed-effects variables - element size, interelement spacing, element shape, and ambient illuminance - were combined in a full factorial design (Figure 3). Three of these variables - element size, element shape, and interelement spacing - were studied as between-subjects variables. There were three levels of each of these variables. Subjects were assigned randomly to treatment levels, with four subjects in each of the 27 cells. Each cell's conditions were repeated for each subject under both high and low ambient illuminance levels.

Three separate tasks were used and are described later. A counterbalanced procedure controlled order effects of the two types of search tasks, the ambient illuminance levels, and the two different forms of the reading test.

Experimental Conditions

There were three levels each of element shape, element size, and interelement spacing, and two levels of illuminance.

Element shape. Due to dot blooming and the general irregularity of each of the small points on the display, it is not possible to create exact replicas of geometric shapes such as squares, circles, or rectangles. If enough of these points are combined, these shapes and orientations can be approximated closely, however.

For the research discussed in this report, squares and rectangles were simulated. The latter were divided into vertically and

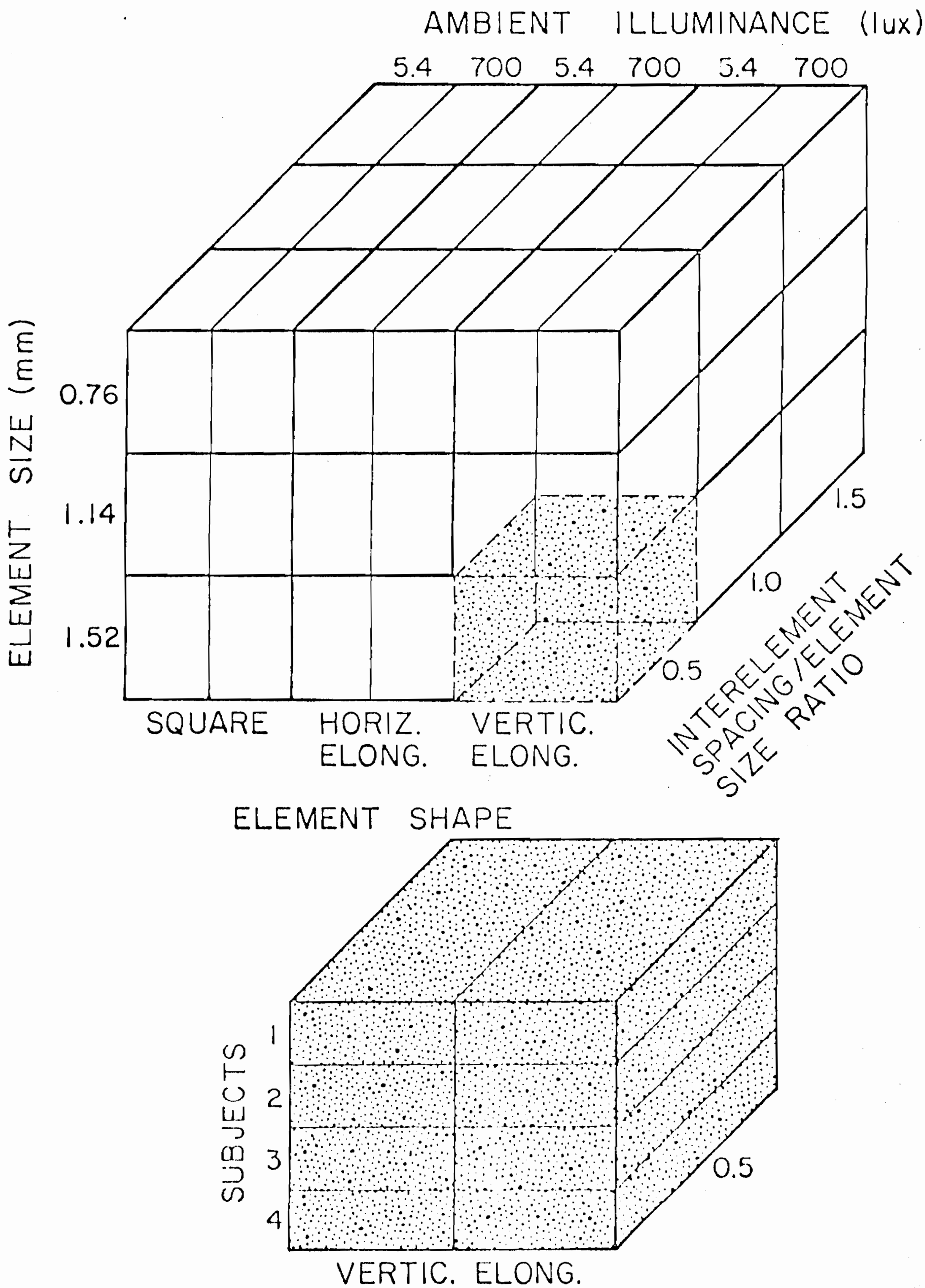


Figure 3. Experimental Design

horizontally oriented rectangles, *i.e.*, the longest dimension fell along the vertical or horizontal axes, respectively (Figure 4).

Element size. The three levels of element size were 0.76 mm, 1.14 mm, and 1.52 mm. These sizes were subjectively determined to present readily detectable differences in size (Figure 4).

Interelement spacing. Three levels of spacing ratios were used so that the edge-to-edge space/element size ratios were 0.5, 1.0, and 1.5. There were nine size-space conditions as the actual spacing was different for each element size, but the spacing ratios were constant across element size. The rectangles were actually centered within a larger cell the size of the corresponding square. This minimized the total number of overall character side dimensions while providing a simple method of setting the interelement spacing (Figures 1, 5, 6; Table 1). All of the characters exceeded 23 minutes of vertical subtense to minimize the effects of overall character size (Semple, *et al.*, 1971).

Ambient illuminance. As mentioned before, the two illuminance levels were a moderately subdued level and a much more subdued level of approximately 700 and 5.4 lx, respectively.

Subjects

There were 108 college age subjects used in this research, 61 male and 47 female, randomly assigned to the experimental conditions. All subjects were screened for 20/25, or better, corrected visual acuity as well as normal phoria, color vision, and depth perception

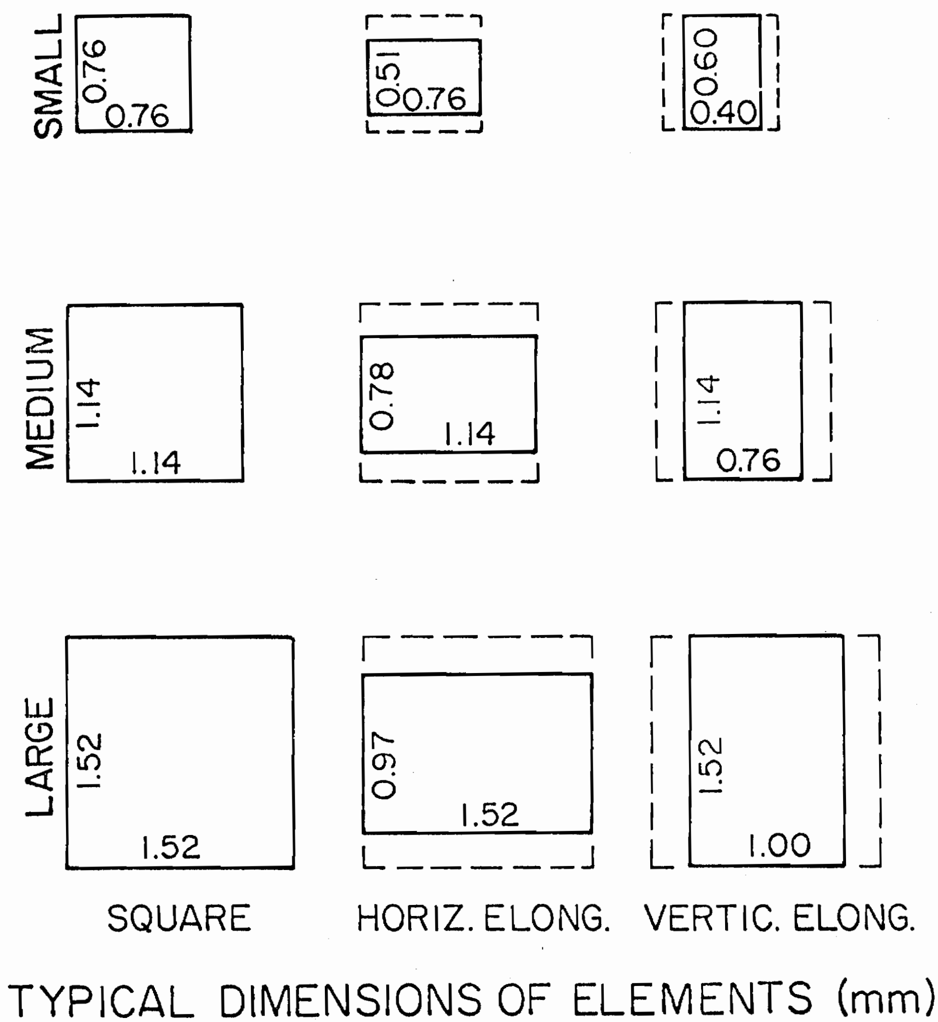


Figure 4. Typical Element Side Dimensions

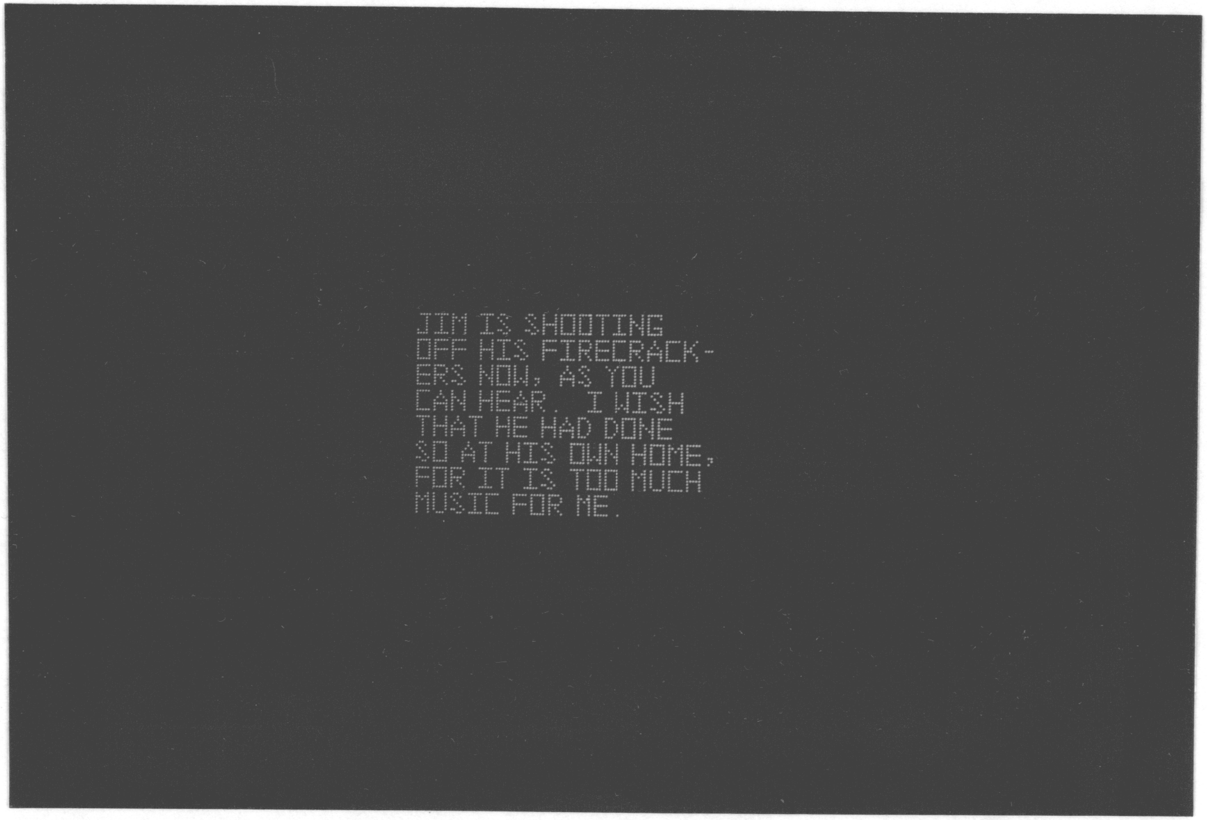


Figure 5. Smallest Element Size - Spacing Ratio Combination

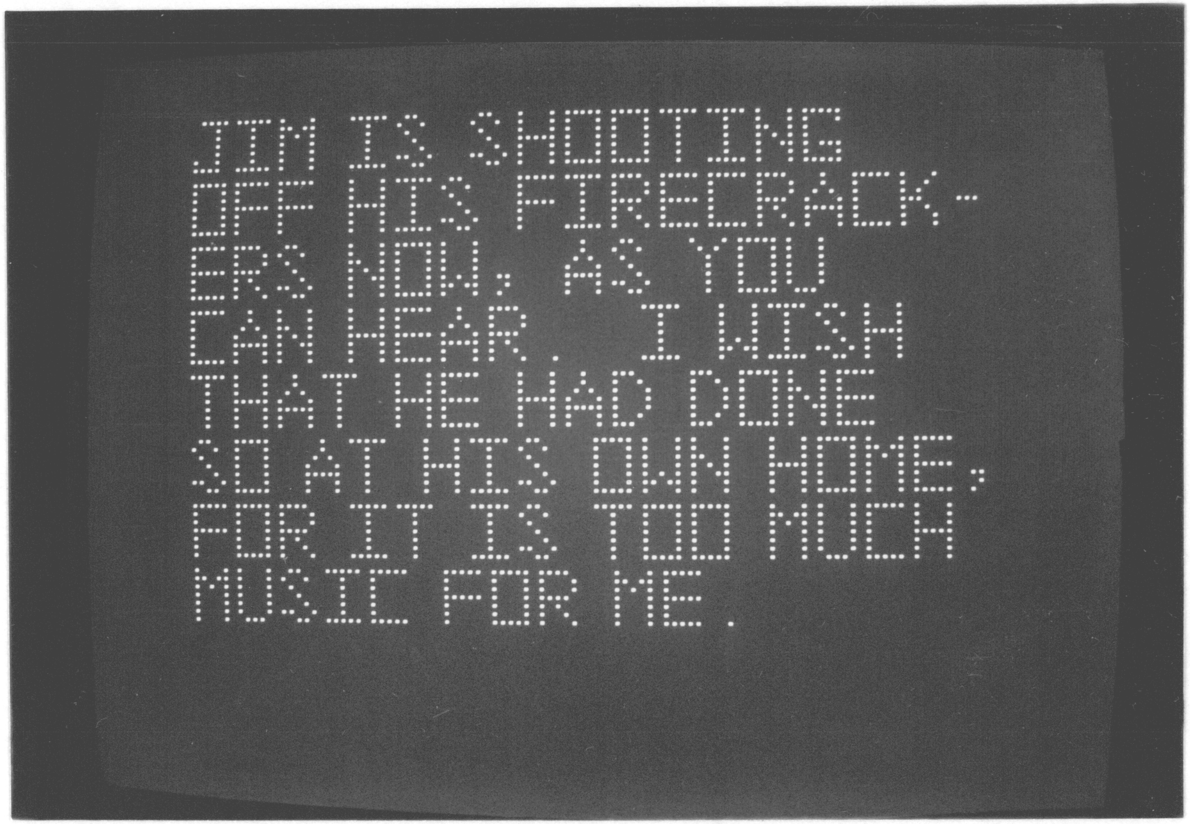


Figure 6. Largest Element Size - Spacing Ratio Combination

TABLE 1

Edge-to-Edge Dimensions of Character Matrices

Element Size(mm)	*Interelement Space/Size Ratio*	*Interelement Horizontal Space(mm)*			*Interelement Vertical Space(mm)*			*Character Size(mm)***	
		■	▬	▮*	■	▬	▮*	*Width*	*Height*
	0.5	0.38	0.38	0.74	0.38	0.63	0.54	5.32	7.60
0.76	1.0	0.76	0.76	1.12	0.76	1.01	0.92	6.84	9.88
	1.5	1.14	1.14	1.50	1.14	1.39	1.30	8.36	12.16
	0.5	0.57	0.57	0.95	0.57	0.93	0.57	7.98	11.40
1.14	1.0	1.14	1.14	1.52	1.14	1.50	1.14	10.26	14.82
	1.5	1.71	1.71	2.09	1.71	2.07	1.71	12.54	18.24
	0.5	0.76	0.76	1.28	0.76	1.31	0.76	10.64	15.20
1.52	1.0	1.52	1.52	2.04	1.52	2.07	1.52	13.68	19.76
	1.5	2.28	2.28	2.80	2.28	2.83	2.28	16.72	24.32

* Space is unavoidably larger for the 0.76mm size than is desirable (see p. 52 for explanation).
** There are only insignificant differences in character size for all element shapes.

with an Orthorater vision tester. These tests were performed at near (0.33m) and far (6.1m) equivalent distances.

Dependent Measures

There were three performance measures taken during the study to measure legibility of the characters created by the variables. These measures were a reading rate score and two search task scores, one random in two-dimensional location of the characters and one structured somewhat like a menu. The reading task was used because it is similar to the task a person faces when participating in a training course using computer-generated training passages and instructions. Also, an effort is being made to have computer programming languages written in dialog form and, therefore, be more widely usable. The random search task is similar to the situation on a Combat Information Center tactical display in which the user must search the display, usually in a random manner, to find the symbols or characters of interest. The other search (menu) was thought to represent a more structured task, such as a parts number search in a catalog. All three tasks, in other words, represent real-life situations.

Reading task. The Basic Reading Rate Scale (Tinker, 1947) is a reading rate test taking five minutes (as revised by Carver (1970)). The test has been developed as an experimental tool for analyzing legibility variables (Buros, 1959). It has been shown to have high (r=.96) parallel forms reliability and has a high (r=.75) correlation with the *Davis Reading Test's Speed of Comprehension* variable. The content validity of the test would seem to be high due to the construction of the test, but an apparent weakness is the relatively small number of validation attempts. Specifically, only a few correlational studies have been performed, all by the author of the test.

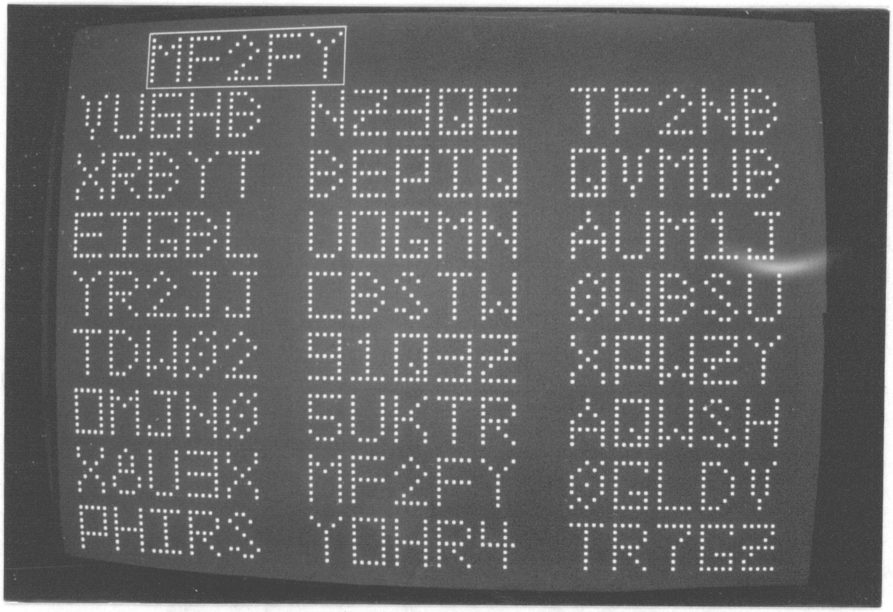
The test consists of two parallel forms, A and B, with 98 and 97 passages, respectively. Each passage is made up of one or two sentences with a total of 30 words per passage. The subject is instructed to read as fast as possible and, as a comprehension check, to cross out one word in each passage that does not fit in with the meaning of the rest of the passage. The actual measure taken is the total number of passages completed at the end of five minutes. It is nearly impossible to finish all the passages within five minutes and the material is simple enough so that few, if any, mistakes are made in crossing out the incongruous word.

As implemented in this research, the passages were taken from the Tinker *Speed of Reading Test*. Fifty passages from each form were given to each subject, one passage on the display at a time in the appropriate experimental variable combination (*e.g.*, Figures 5 and 6). When the inappropriate word was found, the subject depressed the "Stop Clock" key and then spoke the incongruous word into a recorder. Responses were checked to verify that an unusual (>4) number of errors was not made. Due to the time that it took the minicomputer to compile and print each passage, the entire test took about 25 minutes per form. Appendix A contains some examples of reading passages as printed on the display.

Menu search. A search display consisting of three columns of eight "words" each was used. Each word consisted of five randomly selected alphanumeric characters. One of the 24 words was the target. Once all of the words had been written on the display, an example of the target was written at the top center of the display, within a box. This signalled the start of the clock and told the subject which word to search for. The example remained on the screen throughout the trial to minimize memory requirements (Figure 7). All subjects received the same order of target locations for the 12 trials. This minimized between-subjects positional effects. Also, to control positional effects, the target was located once within each area of the display.

Random search. Single nonoverlapping characters were positioned randomly on the display. All 36 alphanumeric characters were displayed constantly during a trial. All but the target character were displayed only once per trial. Therefore, there were 71 characters on the display at any one time. The display was divided into 12 equal areas and the target was located in each of the areas once for each subject. Again, as in the structured search, an example of the target was constantly displayed within a box, top center on the display, so that the subjects did not have to memorize the target but simply find it and give its location. All subjects received the same presentations of characters and all characters were oriented normally, that is, vertically.

For both search tasks the performance measure was average search



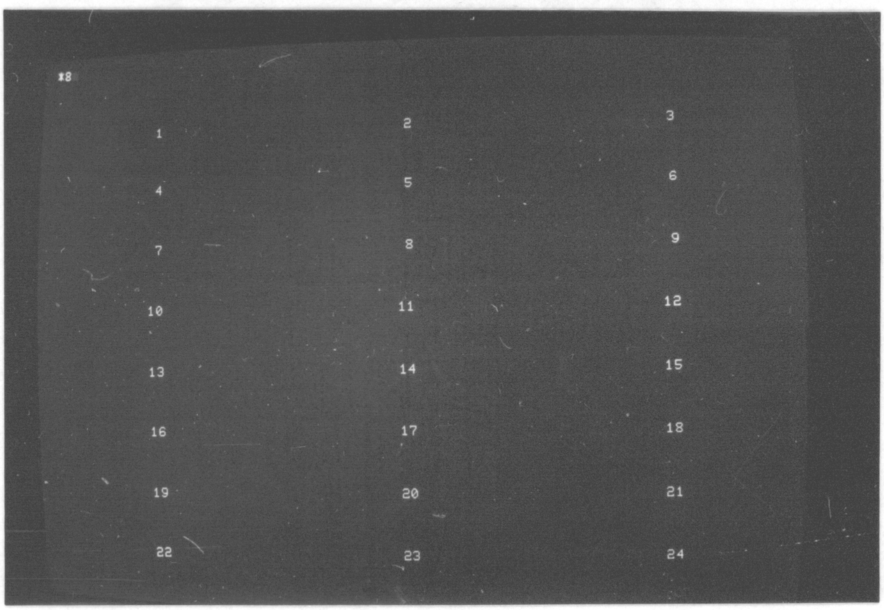


Figure 7.. Menu Search Task - Pseudoword Lists and Location Numbers

time per trial. This was computed by summing search times across all of the trials on which the subject found the target and entered the correct location. This sum was then divided by the total number of these correct trials per form for each subject.

The subjects' task was to locate the target and then depress the "Stop Clock" key on the small keyboard directly in front of them. This response stopped the real-time clock in the computer. For the random search, depressing this key also caused a grid to appear on the display that divided the screen into 12 equal sections. Each section was numbered and the subject entered the number corresponding to the target's location. It should be noted that the stimuli disappeared when the grid appeared (Figure 8). During the menu search depressing the "Stop Clock" key caused a number between 1 and 24 to appear where each of the words was and the subject entered the target's location number on the small keyboard (Figure 9). For both search tasks, the subjects' responses were echoed on the display and, after correcting any typing errors, the subject initiated another trial by depressing the "Next" key on the small keyboard.

Laboratory Equipment

The CRT display used for this research was a Tektronix 4014-1 direct view storage tube. The total size of the usable portion of the tube face was approximately 0.36 m wide by 0.27 m high. The smallest addressable point on the display was approximately 0.40 mm wide by 0.50 mm high. These addressable points had 0.09 mm center-

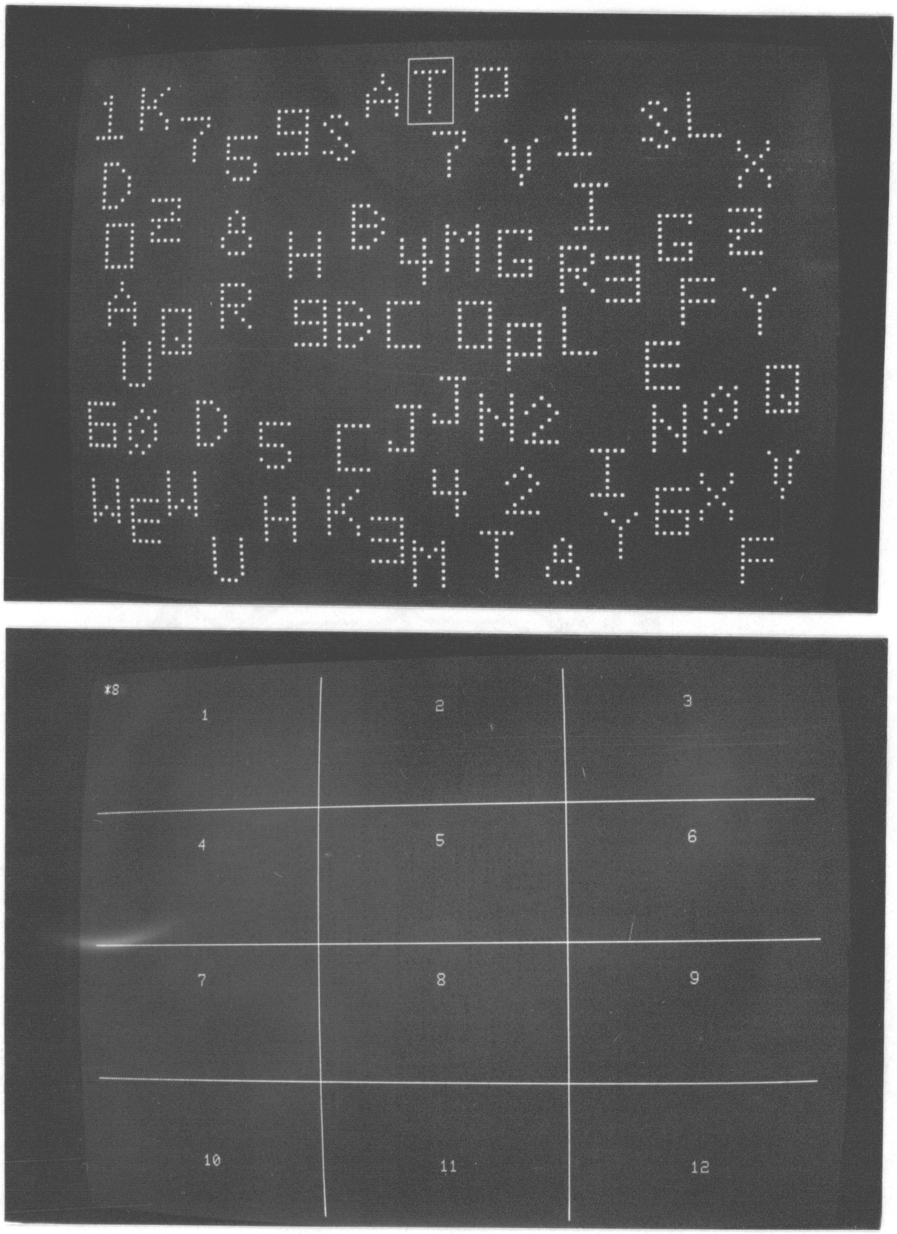


Figure 8. Random Search Task-Random Characters and Location Grid

Figure 9. Small Keyboard

to-center spacings, so there was considerable overlap of adjacent points. There were 3072 X 4096 of these addressable points. The display had a green chrominance with a background luminance of about 2 cd/m^2, as measured in a darkened room. The points had a luminance near 17 cd/m^2, again measured in a room with low illumination.

The experiment was run and data were collected by a Digital Equipment Corporation (DEC) PDP 11/10 minicomputer with a 1.2 M word disc unit. A DEC Laboratory Peripherals System (LPS-11) was used for exact timing of operations. Data were output on a Centronix 306-C medium speed printer. Appendix B contains the master flow-chart for the computer programs used in this research.

Experimental Area

The display was located in an enclosed area 1.68 m by 2.13 m with a light-colored curtain on one side and light-colored walls on the other side and in front of the subject behind the display. Behind the subject was a dark-colored curtain to reduce extraneous reflections from the display's surface. If the subject wore light-colored clothing, a black drape was placed on the subject, again to reduce reflections.

Ambient lighting was provided by a fluorescent fixture with two 1.22 m tubes which diffused through an overhead screen at ceiling height for the higher lighting level. The lower ambient lighting level was provided by a small incandescent light diffusing through the same screen. The higher level approximated typical office lighting and the lower level was near that of representative low lighting conditions.

Also in the experimental area were a subject's chair, a forehead restraint to position the subject's head at the desired viewing distance of 1.02 m, a tape recorder to record verbal responses, and a small keyboard mounted directly in front of the subject to be used to stop the timer and to record the target location in the search tasks (Figure 10).

Experimental Procedure

The subjects were screened for acceptable vision before they reported for the single experimental session. Upon arriving for the session, each subject was seated in the experimental room where he/she read a set of instructions. During this time his/her eyes were adapting to the appropriate illuminance level. Semple, *et al.* (1971) stated that adaptation of the subject's eyes was not critical in a situation where the element's luminance was as much higher than the background's as it was in this research (17 and 1.7 cd/m^2, respectively). Therefore, only a minimum of time (5-10 min) was provided for adaptation.

Next, the subject was seated comfortably in the experimental cubicle and the head restraint was adjusted. Each subject received the reading test first under the appropriate conditions. Then the subject received the random and the menu search tasks, completing one type of search before starting the other. After both searches were

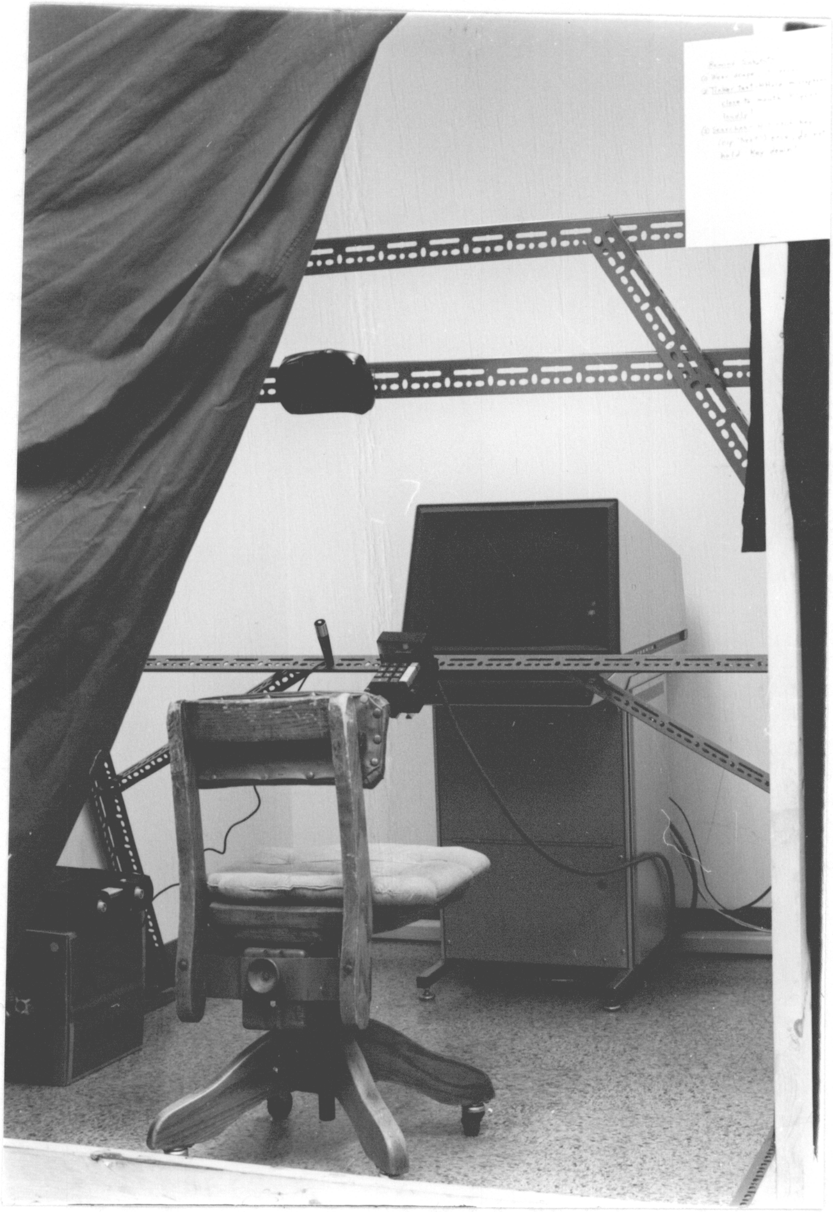


Figure 10. Experimental Area

finished, the ambient illuminance was changed and the same procedure of tasks was performed using the other forms of each task. The entire experimental session took approximately two hours per subject (Appendix C). At the end of each subject's session a printout was obtained of the times per passage and per search for the subject as well as the incorrect responses that were made on the search trials. At the end of each subject's session he/she received ten additional passages at the high illuminance level written with characters generated internally by the Tektronix display. These were simulations of stroke-generated characters and were smaller than the experimental characters, so the subjects could read these passages faster than those in the rest of the experiment. These passages were used as baseline refinements to the reading time scores of each subject by subtracting the mean time of each subject's baseline passages from his/her experimental mean time per passage. This removed effects of individual reading speed.

RESULTS

An analysis of variance was computed for each task using the *Statistical Applications System* (Barr, Goodnight, and Service (Ed.), 1972). Additionally, Newman-Keuls analyses of multiple comparisons were performed on any significant main effects and interactions to identify the significant differences. Appendix D lists the cell means associated with the 54 combinations of the experimental variables.

Tinker Reading Task

Technique. For each subject the mean time per passage was computed. From this mean was subtracted the mean time per passage of the baseline reading task. The analysis of variance and Newman-Keuls computations were performed on these difference scores (Table 2).

Element size. The overall effect of element size was significant ($p<.05$), as shown by the analysis of variance. The 0.76 mm and the 1.14 mm elements produced approximately equal reading times, both of which were shorter ($p<.05$) than the time taken to read passages constructed of the 1.52 mm elements, as shown by Figure 11.

Element shape. The effect of element shape was also statistically significant ($p<.05$). The square elements resulted in shorter times (Figure 12) than did the horizontally elongated rectangles (HER) ($p<.05$). The differences between the vertically elongated rectangles (VER) and the other shapes were not significant ($p>.05$).

TABLE 2

Analysis of Variance Summary for Tinker Reading Test

Source of Variance	*df*	*MS*	*F*	*p*
Size (SI)	2	7.87	3.317	0.04
Shape (SH)	2	7.267	3.063	0.05
SI X SH	4	3.403	1.434	0.229
Space (SP)	2	30.733	12.954	0.0001
SI X SP	4	0.622	0.262	0.901
SH X SP	4	2.876	1.212	0.312
SI X SH X SP	8	0.916	0.386	0.925
Illumination (I)	1	2.745	3.04	0.081
SI X I	2	1.917	2.123	0.124
SH X I	2	1.297	1.437	0.242
SI X SH X I	4	3.731	4.132	0.005
SP X I	2	1.34	1.484	0.231
SI X SP X I	4	1.871	2.072	0.091
SH X SP X I	4	1.318	1.459	0.221
SI X SH X SP X I	8	1.71	1.893	0.072
Total	53			

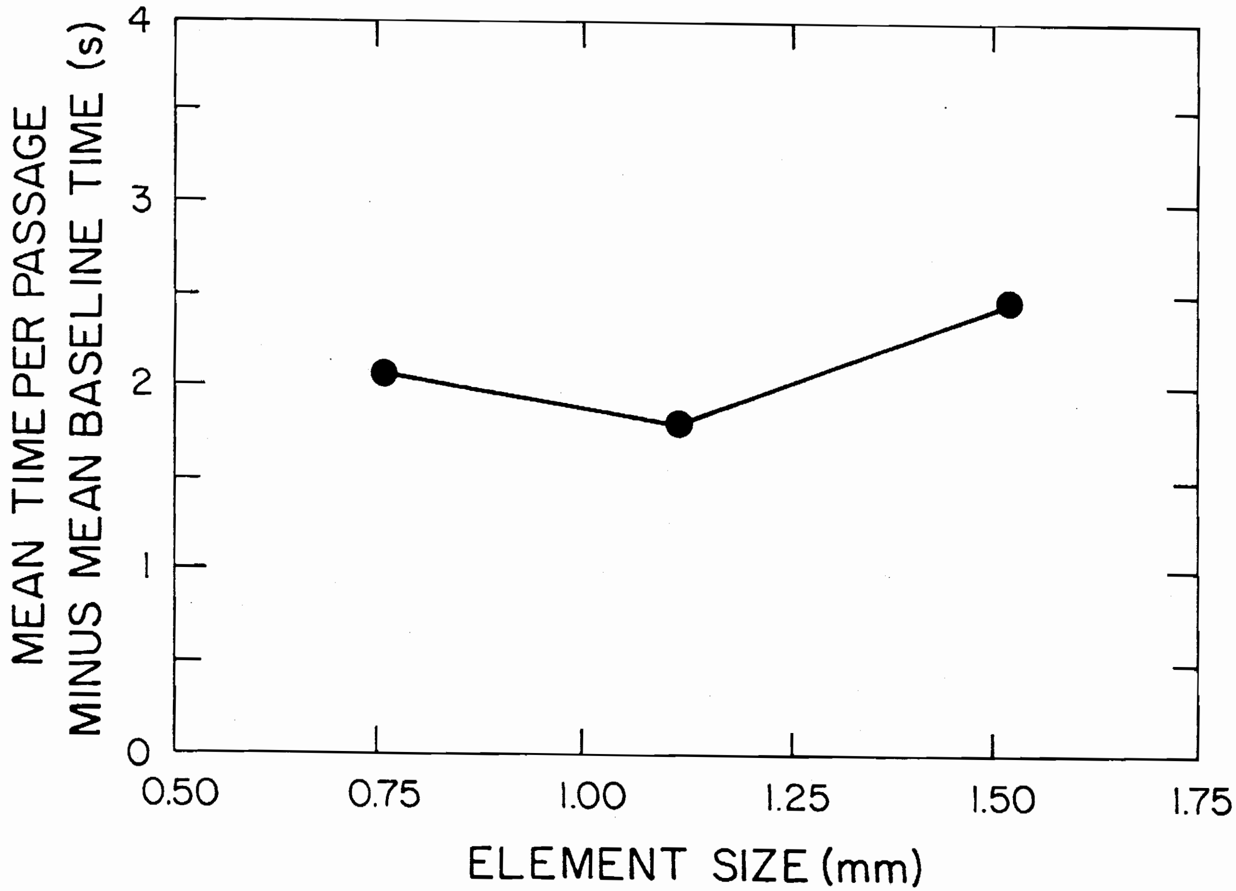


Figure 11. Element Size Main Effect (Tinker)

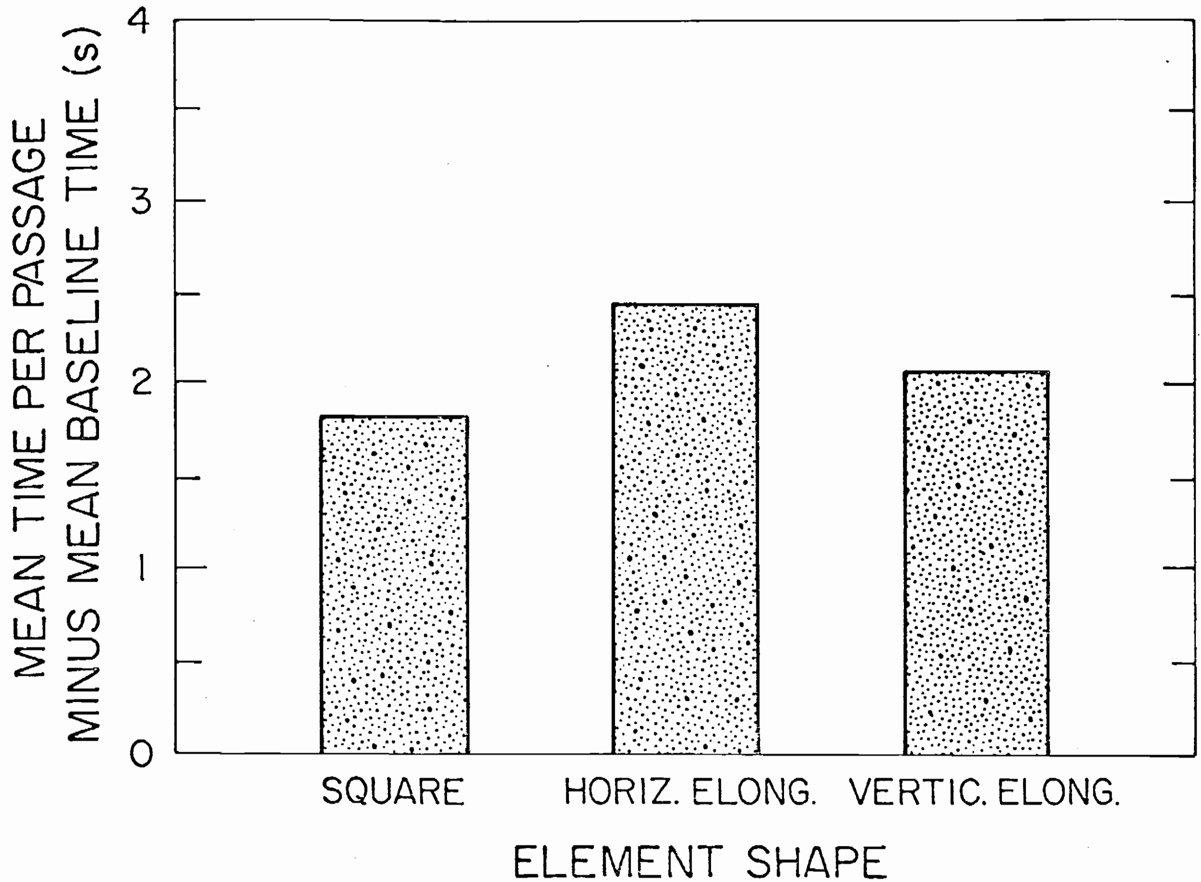


Figure 12. Element Shape Main Effect (Tinker)

Interelement space/element size ratio. This highly significant ($p<.0001$), linear appearing effect (Figure 13) indicates that the closer together the elements were, the quicker the subjects could read the passages ($p<.01$). All differences among the three means are statistically significant ($p<.01$).

Element size X element shape X ambient illuminance. Though the overall interaction is highly significant statistically ($p<.005$), there are only two combinations of the variables that are different enough from the other points ($p<.01$) to merit much attention. The largest HER (1.52 mm) at 700 lx is only different from the medium (1.14 mm) HER at 700 lx and the smallest (0.76 mm) HER at 5.4 lx. The greatest number of differences comes from the smallest (0.76 mm) VER at 700 lx, which produces significantly longer reading times than do all other combinations of the variables for the VER shape ($p<.01$) (Figure 14). There were no significant differences ($p>.05$) among the square element means.

Random Search Task

Technique. The average time per search for each subject was computed only from the trials during which the subject found the target and responded with the correct target location. Due to the closeness of some of the targets to the lines of the location grid and the potential for inadvertent errors in target location estimation a correct location was considered to include any of the areas adjacent to, as well as, the actual target location. Of the 108 subjects, each

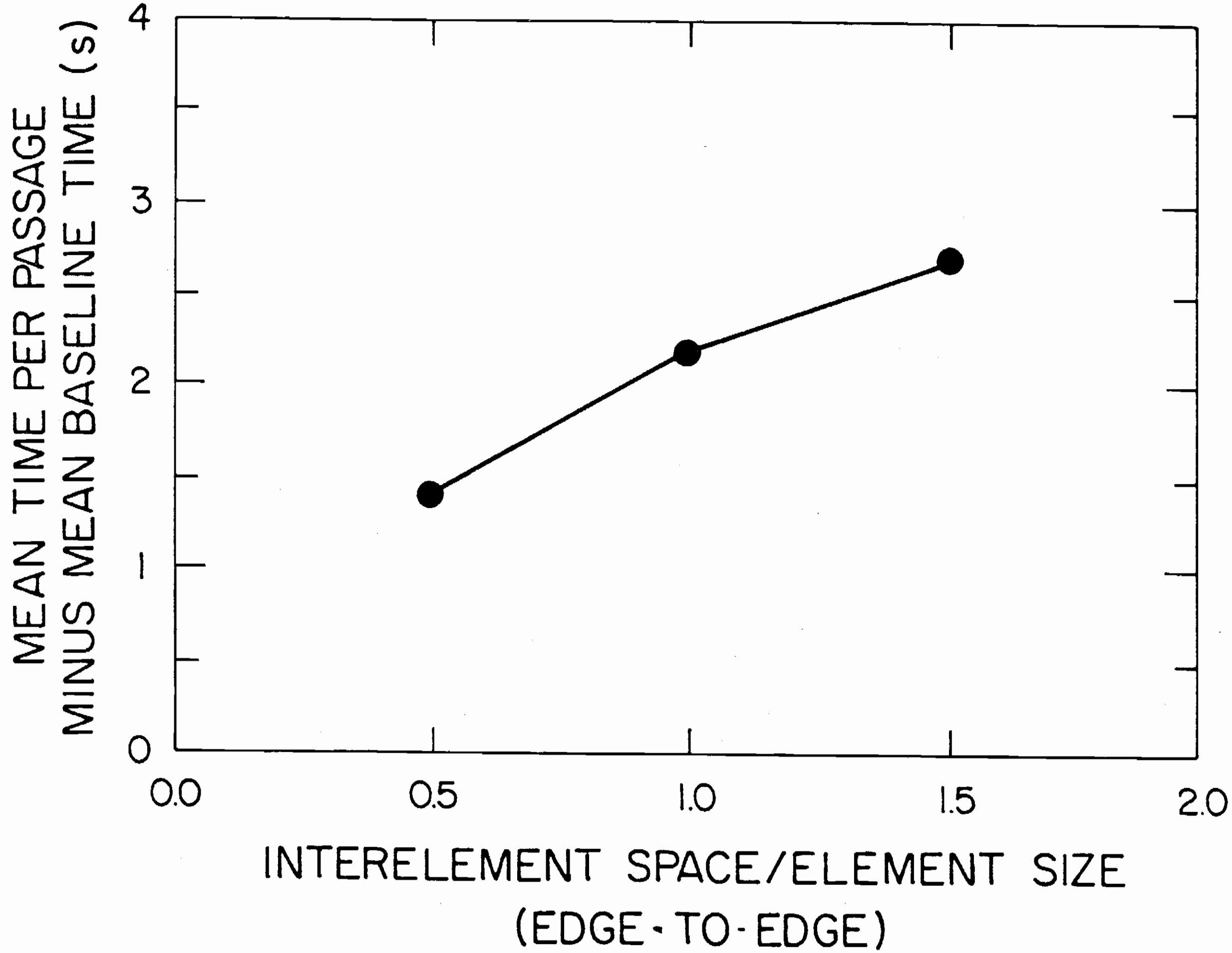


Figure 13. Interelement Spacing Ratio Main Effect (Tinker)

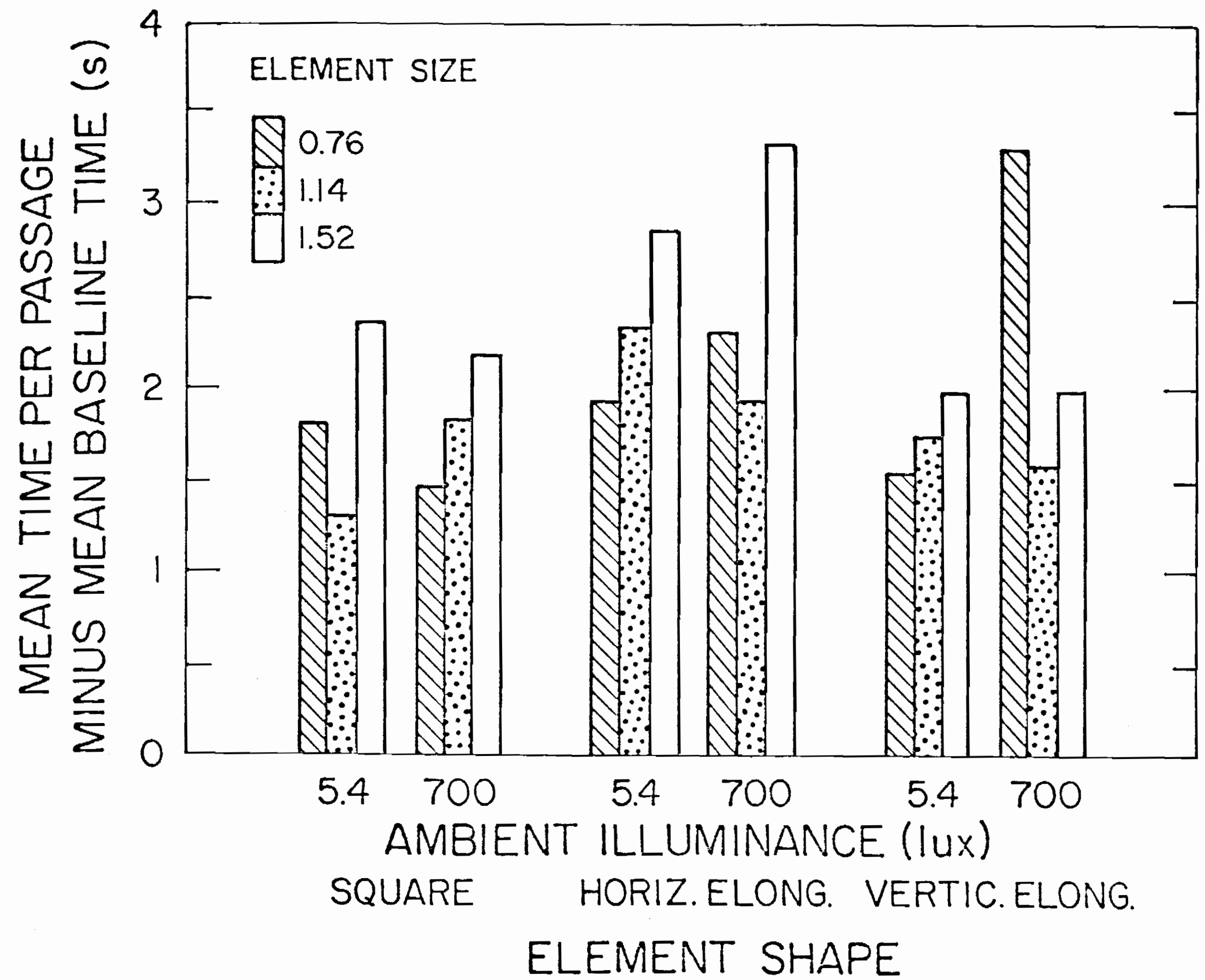


Figure 14. Size X Shape X Ambient Illuminance Interaction (Tinker)

having 24 trials (2160 trials total), there were only nine errors made and no single subject made more than one error. Table 3 summarizes the analysis of variance.

Element size. The overall significance of element size ($p<.0001$) was brought about by the effect of the small element (Figure 15). The 1.14 mm and 1.52 mm sizes are not significantly different from each other, while the 0.76 mm size produces longer search times ($p<.01$).

Element shape. As with the reading task, the effect of element shape ($p<.02$) is due to the square element being better than either of the rectangular elements ($p<.05$), while the two rectangular elements produced essentially equal ($p>.05$) search times (Figure 16).

Ambient illuminance. The 5.4 lx illuminance produces much lower search times than the 700 lx level ($p<.0001$) (Figure 17).

Element size X element shape. Though highly significant ($p<.0005$), this interaction is caused by the small VER being so much worse ($p<.01$) than all the other means (Figure 18). None of the other means differed from one another ($p>.05$).

Element size X ambient illuminance. This entire interaction ($p<.003$) is caused by the mean search time for the 0.76 mm element at 700 lx being greater ($p<.01$) than the mean search time for all other size-illumination combinations (Figure 19). There were no other significant differences among the means ($p>,01$).

Element shape X ambient illuminance. The square element produces shorter mean search times and is affected less by the higher illuminance level (700 lx) than either of the two rectangular

TABLE 3

Analysis of Variance Summary for Random Search Task

Source of Variance	*df*	*MS*	*F*	*p*
Size (SI)	2	116.451	13.843	0.0001
Shape (SH)	2	35.591	4.231	0.017
SI X SH	4	50.111	5.957	0.0005
Space (SP)	2	3.049	0.362	0.702
SI X SP	4	2.861	0.34	0.851
SH X SP	4	7.816	0.929	0.547
SI X SH X SP	8	23.23	2.761	0.01
Illumination (I)	1	330.586	62.377	0.0001
SI X I	2	35.066	6.616	0.003
SH X I	2	19.969	3.768	0.026
SI X SH X I	4	14.88	2.808	0.03
SP X I	2	12.592	2.376	0.097
SI X SP X I	4	6.424	1.212	0.312
SH X SP X I	4	22.409	4.228	0.004
SI X SH X SP X I	8	23.515	4.437	0.0003
Total	53			

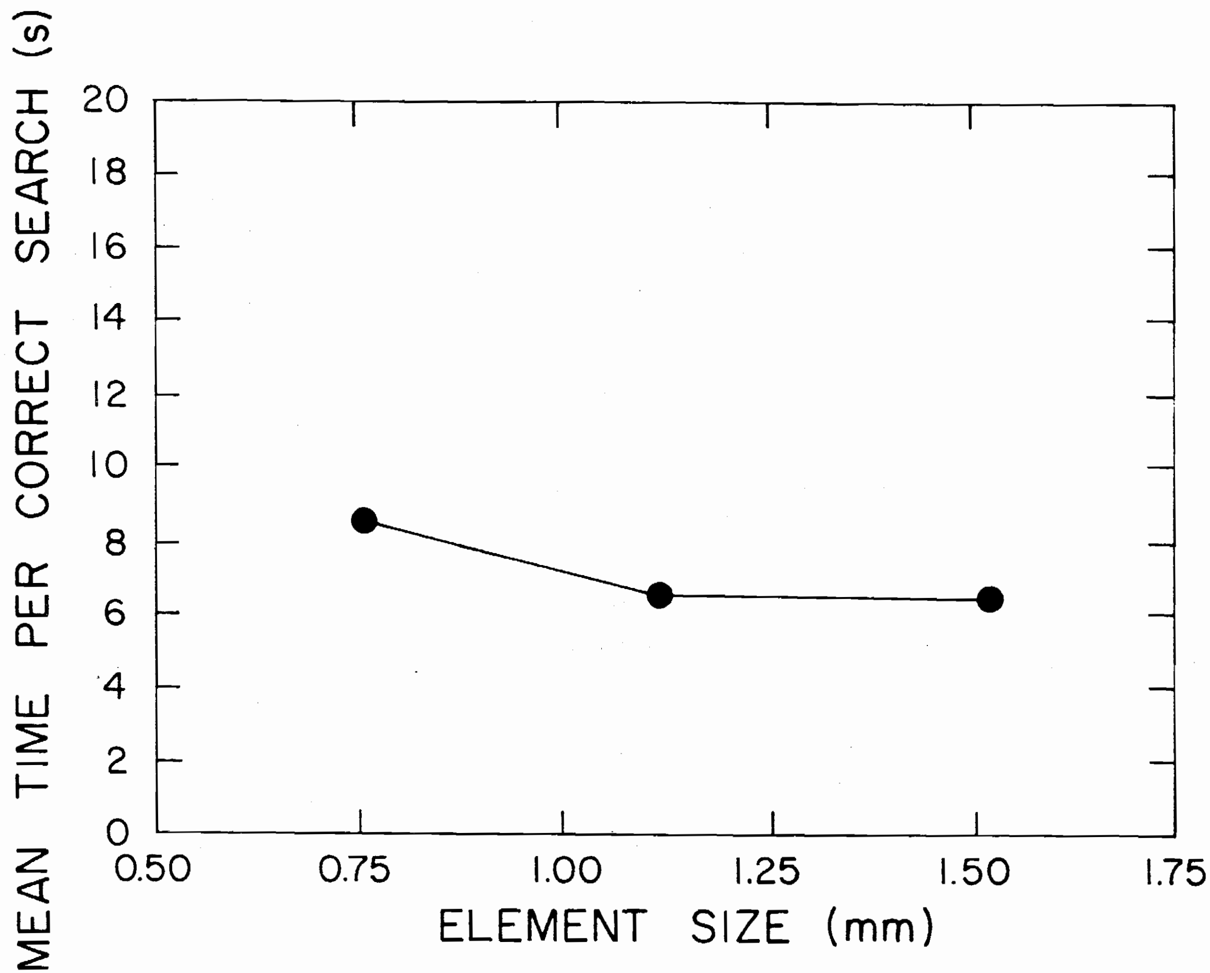


Figure 15. Element Size Main Effect (Random Search)

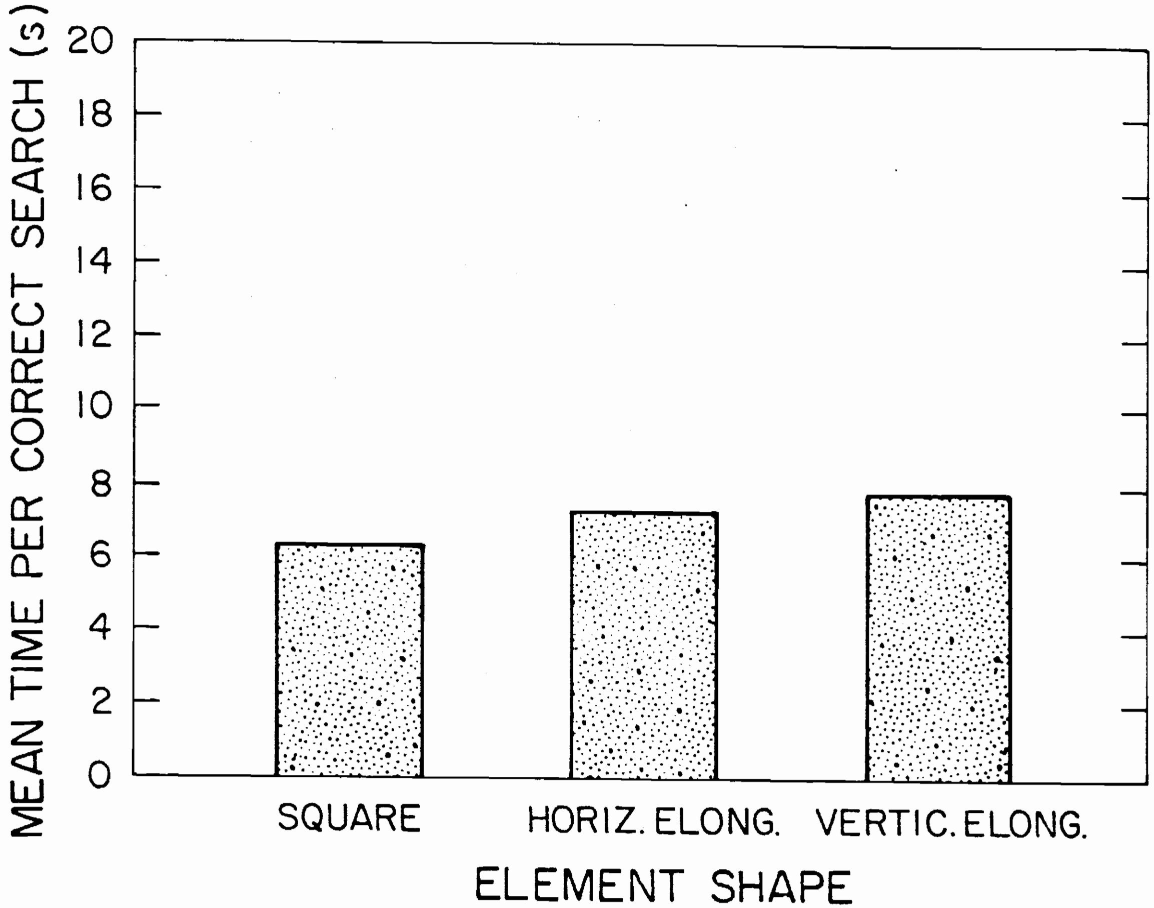


Figure 16. Element Shape Main Effect (Random Search)

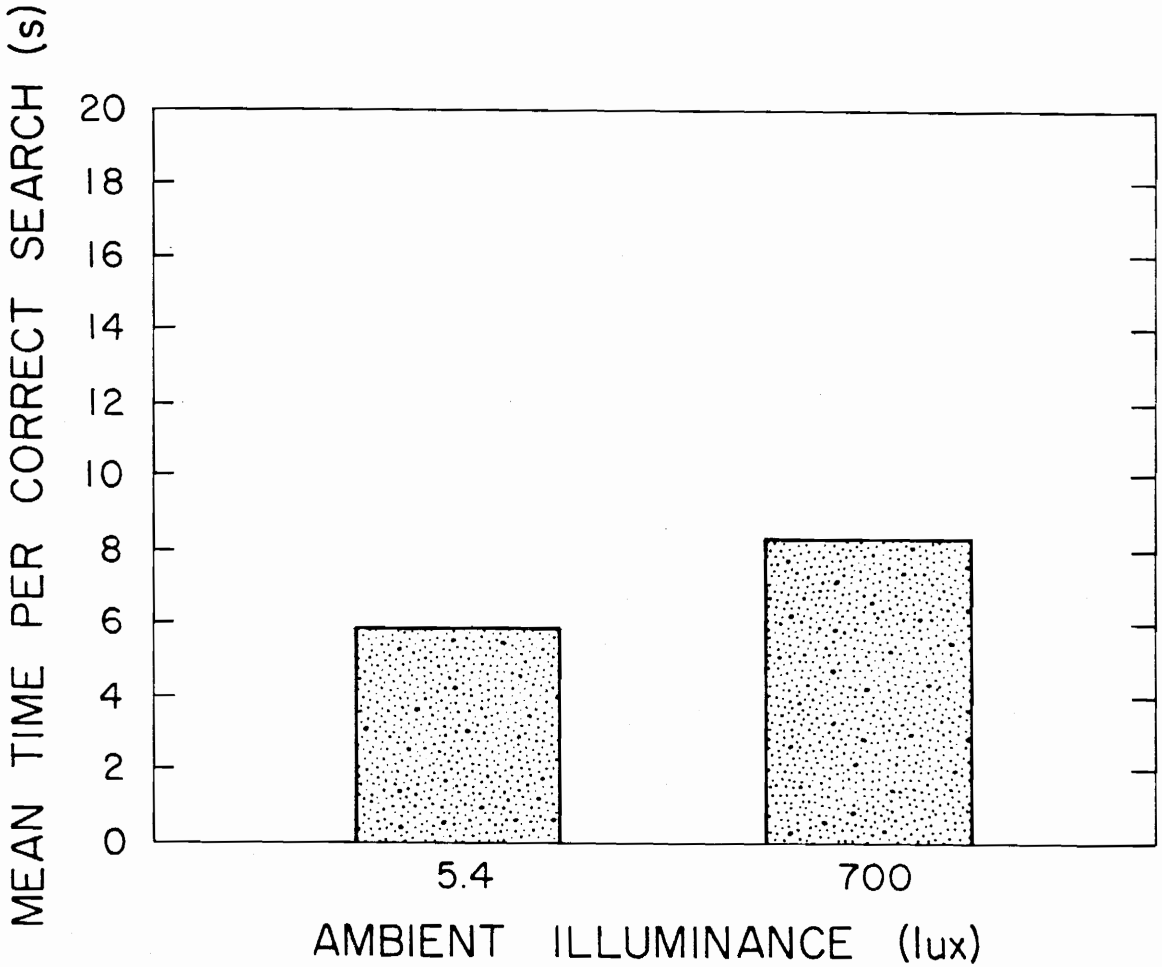


Figure 17. Ambient Illuminance Main Effect (Random Search)

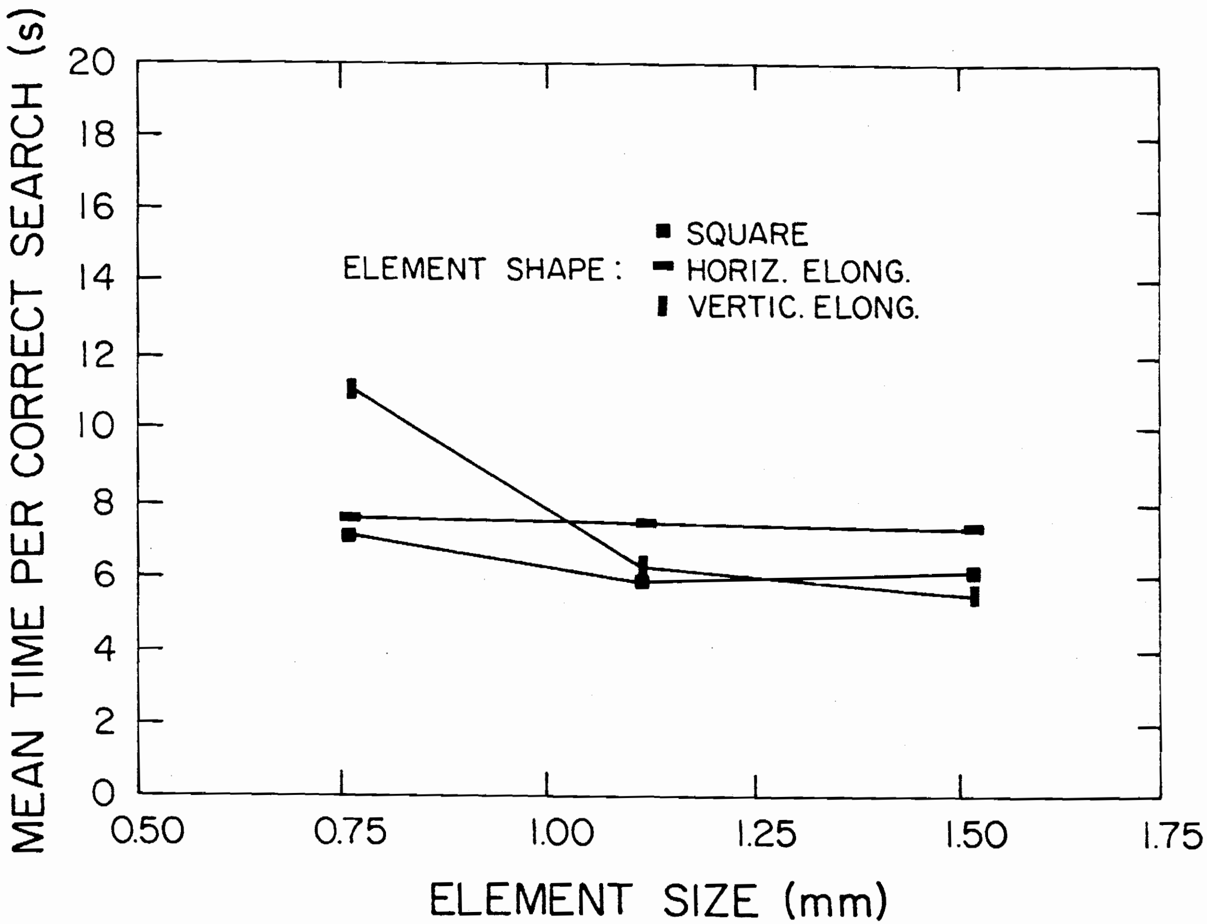


Figure 18. Size X Shape Interaction (Random Search)

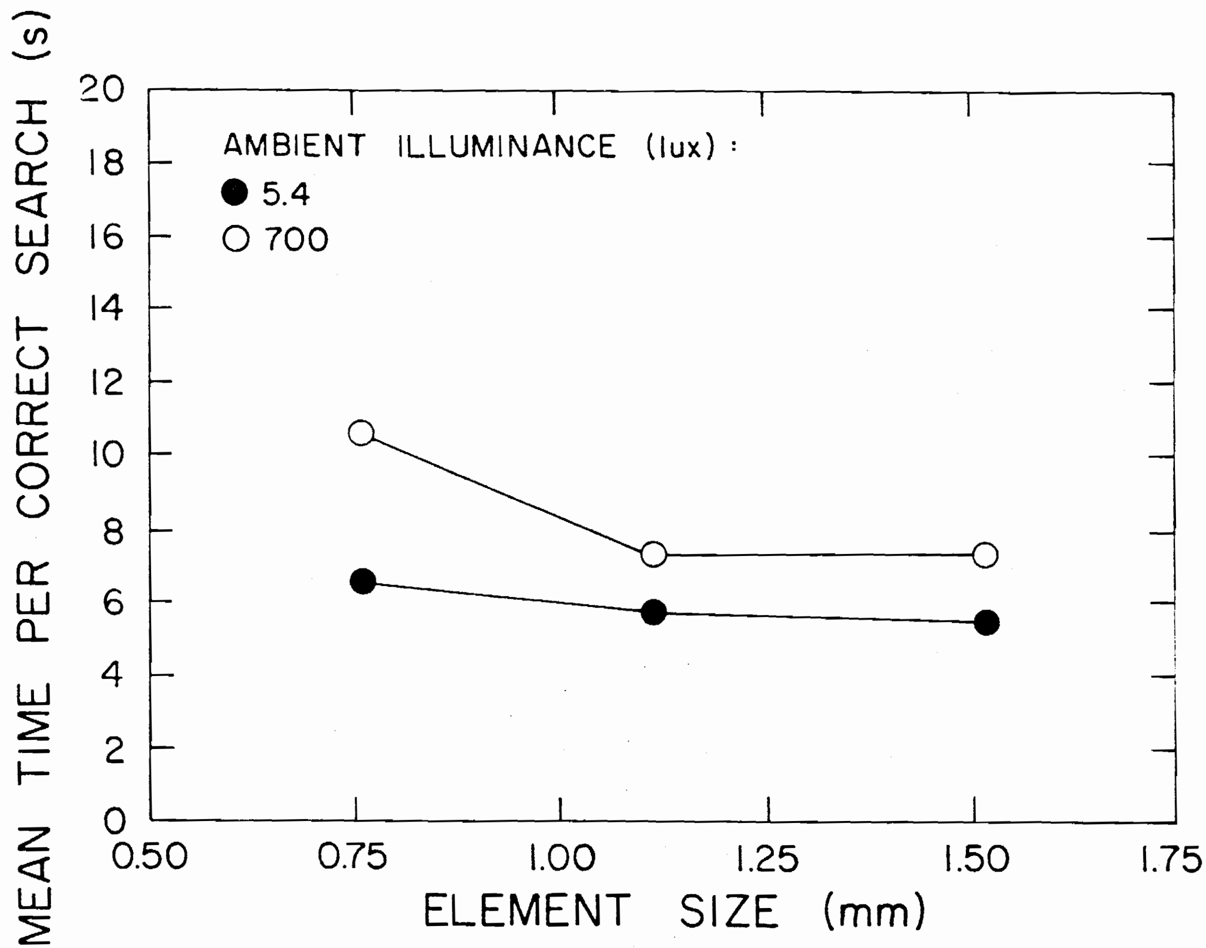


Figure 19. Size X Illuminance Interaction (Random Search)

elements (p<.01). This could be due to squares being more dense than are rectangles, but it should be noted that in this case the square actually has a greater area than did the rectangles of the same element size. The overall interaction (p<.03) comes from the VER at 700 lx being different from all other combinations of element shape and ambient illumination except the HER at 700 lx; this latter combination is different from all three 5.4 lx conditions (p<.01) (Figure 20).

Element size X element shape X interelement space/element size ratio. This seemingly complex interaction (Figure 21) (p<.01) is greatly simplfied when it is realized that only the small VER is significantly different (p<.01) from the other experimental combinations. It should be noted that the interelement spacing ratio of 1.5 produced an average search time of relatively short duration for the small VER.

Element size X element shape X ambient illuminance. The nature of this interaction (p<.03) is primarily related to only two experimental combinations. The VER at 700 lx is significantly different from all of the other shape-illuminance combinations at the 0.76 mm size (p<.01). The only other significant (p<.01) difference among all of the shape-illuminance combinations at any size is between the smallest HER at 700 and 5.4 lx for the 0.76 mm elements (Figure 22).

Element shape X interelement space/element size ratio X ambient illuminance. This interaction (p<.0004) was caused by four combinations of shape-spacing ratio illuminance. At the 0.5 ratio, only

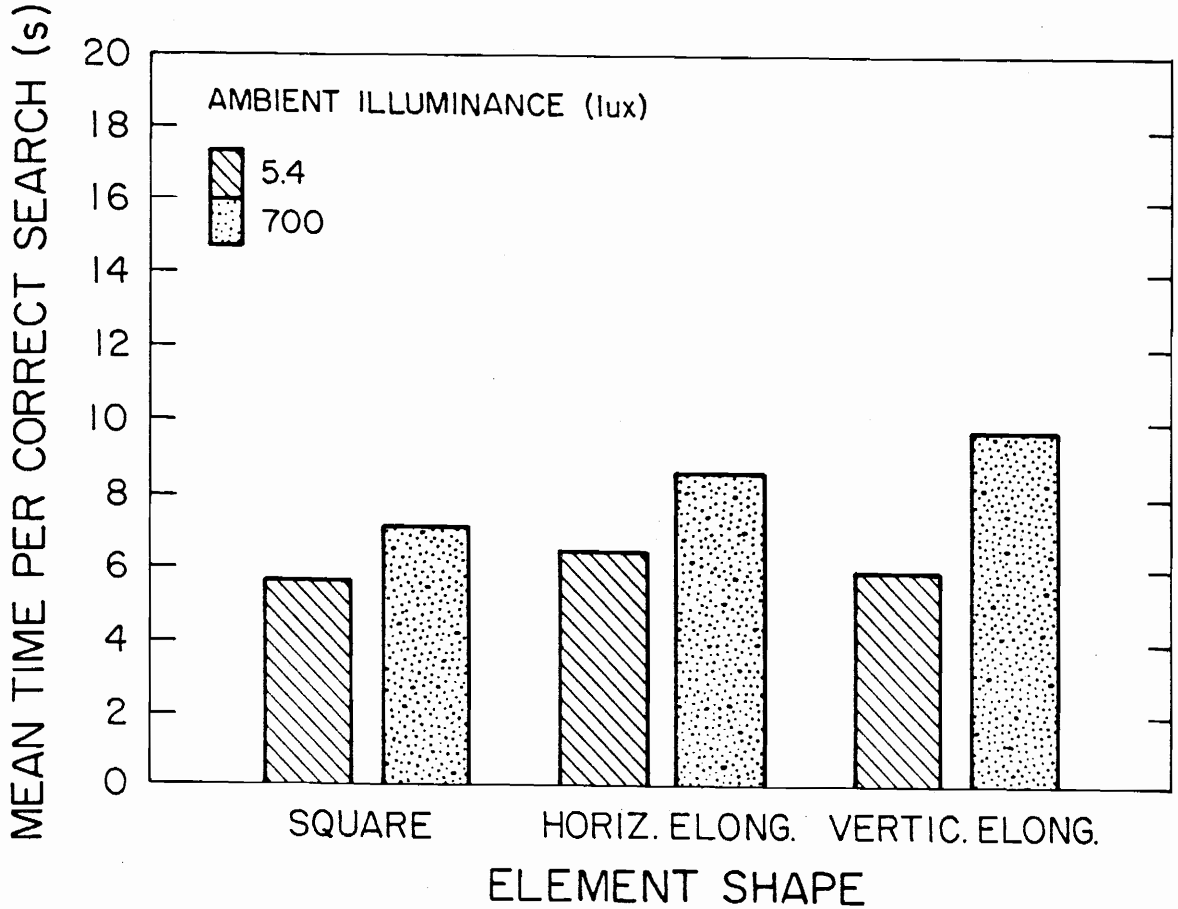


Figure 20. Shape X Illuminance Interaction (Random Search)

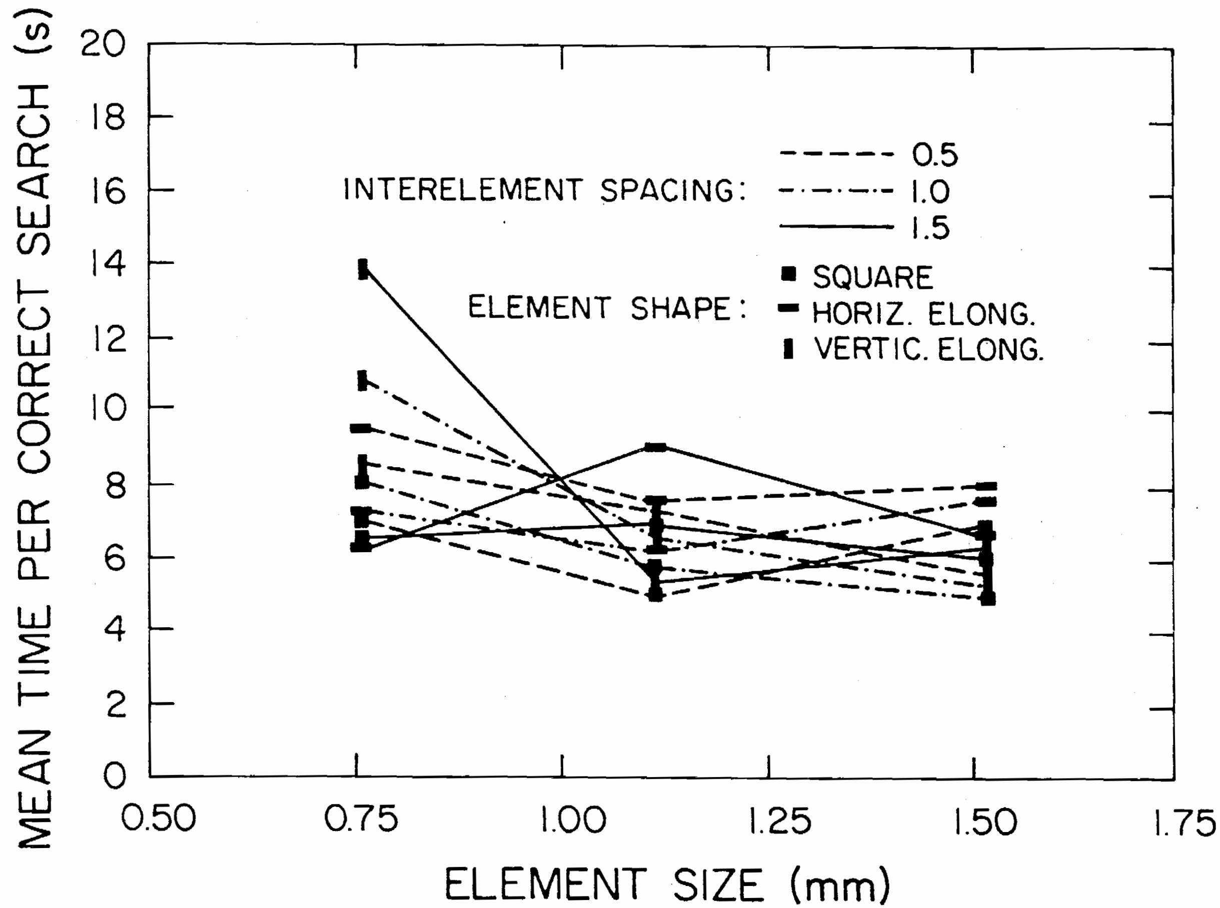


Figure 21. Size X Shape X Spacing Interaction (Random Search)

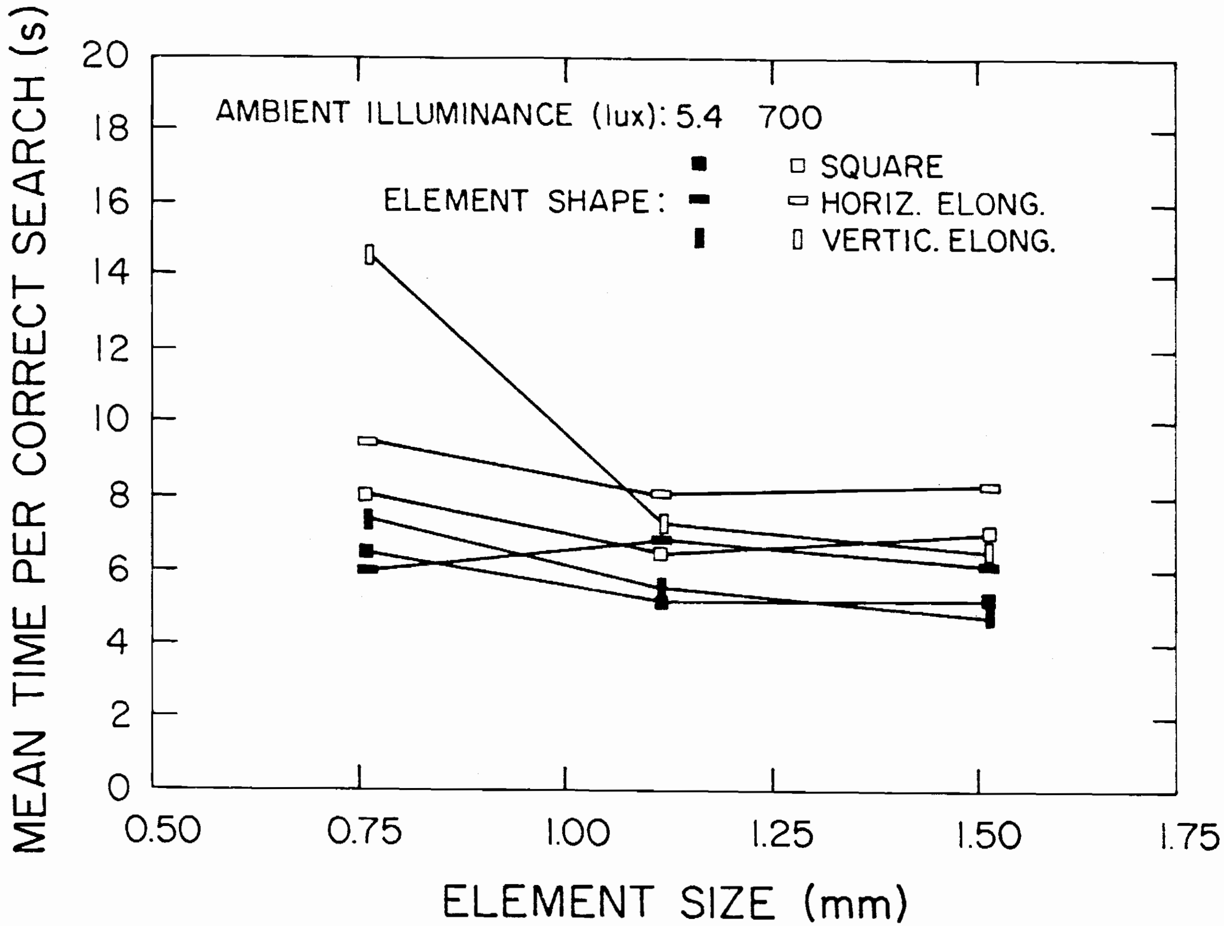


Figure 22. Size X Shape X Illuminance Interaction (Random Search)

the HER at 700 lx was significantly different from the other combinations ($p<.05$). At the 1.0 ratio, both the VER and the HER had significantly longer search times at 700 lx than did any of the shapes at 5.4 lx ($p<.05$). Only the VER at 700 lx was significantly different from all of the other combinations at the 1.5 interelement space/element size ratio ($p<.01$) (Figure 23).

Element size X element shape X interelement space/element size ratio X ambient illuminance. Though significant ($p<.0003$), this interaction has little practical value due to its complexity and because the entire interaction appears to be caused by the smallest VER coupled with some small effect of the HER, but only at 700 lx.

Menu Search Task

Technique. As with the random search, only the correct trials were used to compute each subject's mean time per search. A correct response was considered to be any of the numbers adjacent to, as well as, the actual target's location number. There were only 11 errors over the entire 2160 trials and, again, no single subject made more than one error. The analysis of variance is summarized in Table 4.

Element size. As with the random search task, the small element was the major cause of the experimental effect ($p<.01$), since it was slightly poorer than either of the larger element sizes ($p<.01$), which were not significantly different from each other ($p>.05$) (Figure 24).

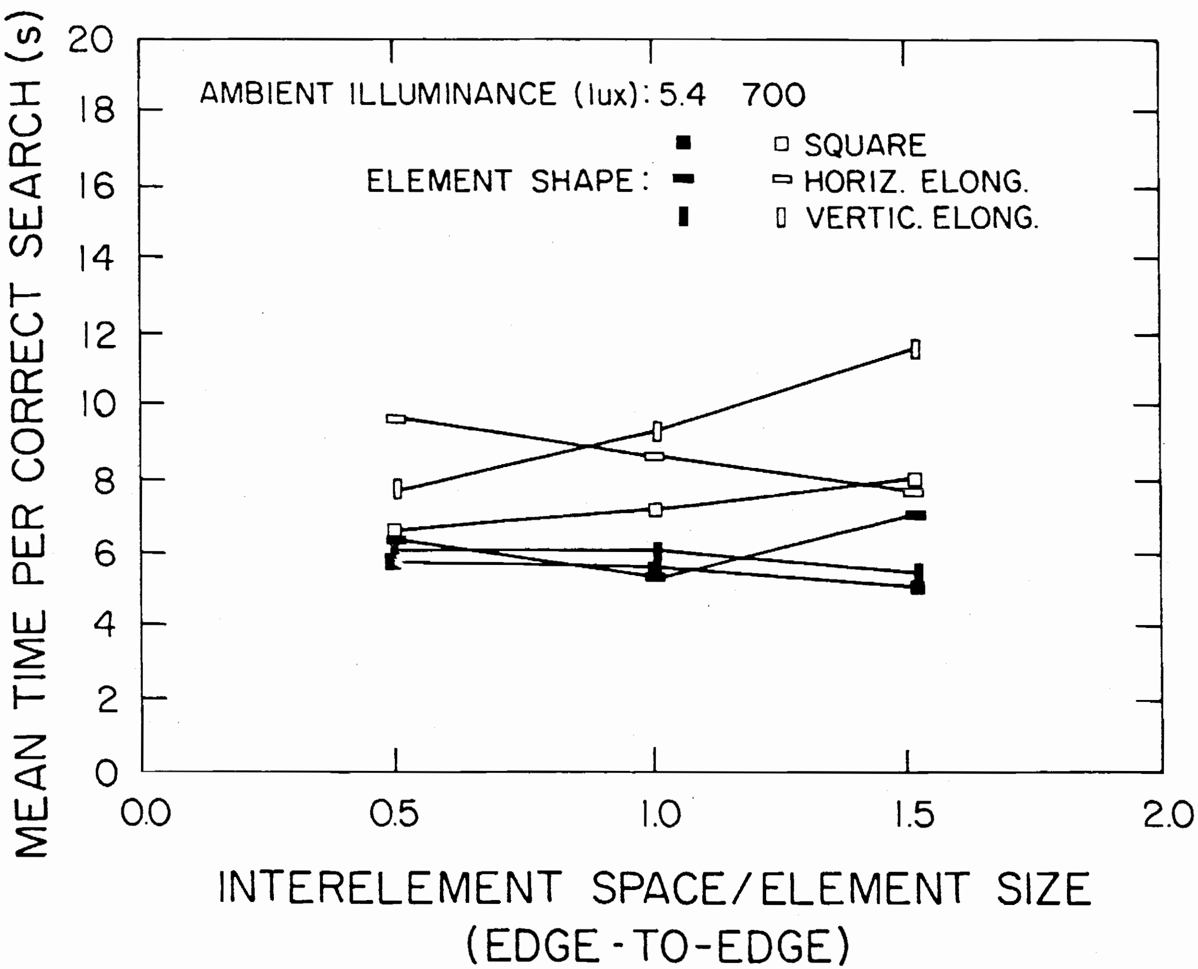


Figure 23. Shape X Spacing X Illuminance Interaction (Random Search)

TABLE 4

Analysis of Variance Summary for Menu Search Task

Source of Variance	*df*	*MS*	*F*	*p*
Size (SI)	2	16.681	4.795	0.01
Shape (SH)	2	8.643	2.484	0.088
SI X SH	4	2.041	0.587	0.676
Space (SP)	2	5.557	1.597	0.207
SI X SP	4	0.191	0.055	0.991
SH X SP	4	1.211	0.348	0.845
SI X SH X SP	8	2.259	0.649	0.735
Illumination (I)	1	4.547	5.739	0.018
SI X I	2	0.898	1.133	0.327
SH X I	2	0.029	0.036	0.964
SI X SH X I	4	0.643	0.812	0.523
SP X I	2	0.119	0.15	0.862
SI X SP X I	4	1.057	1.334	0.263
SH X SP X I	4	0.551	0.696	0.6
SI X SH X SP X I	8	0.366	0.462	0.88
Total	53			

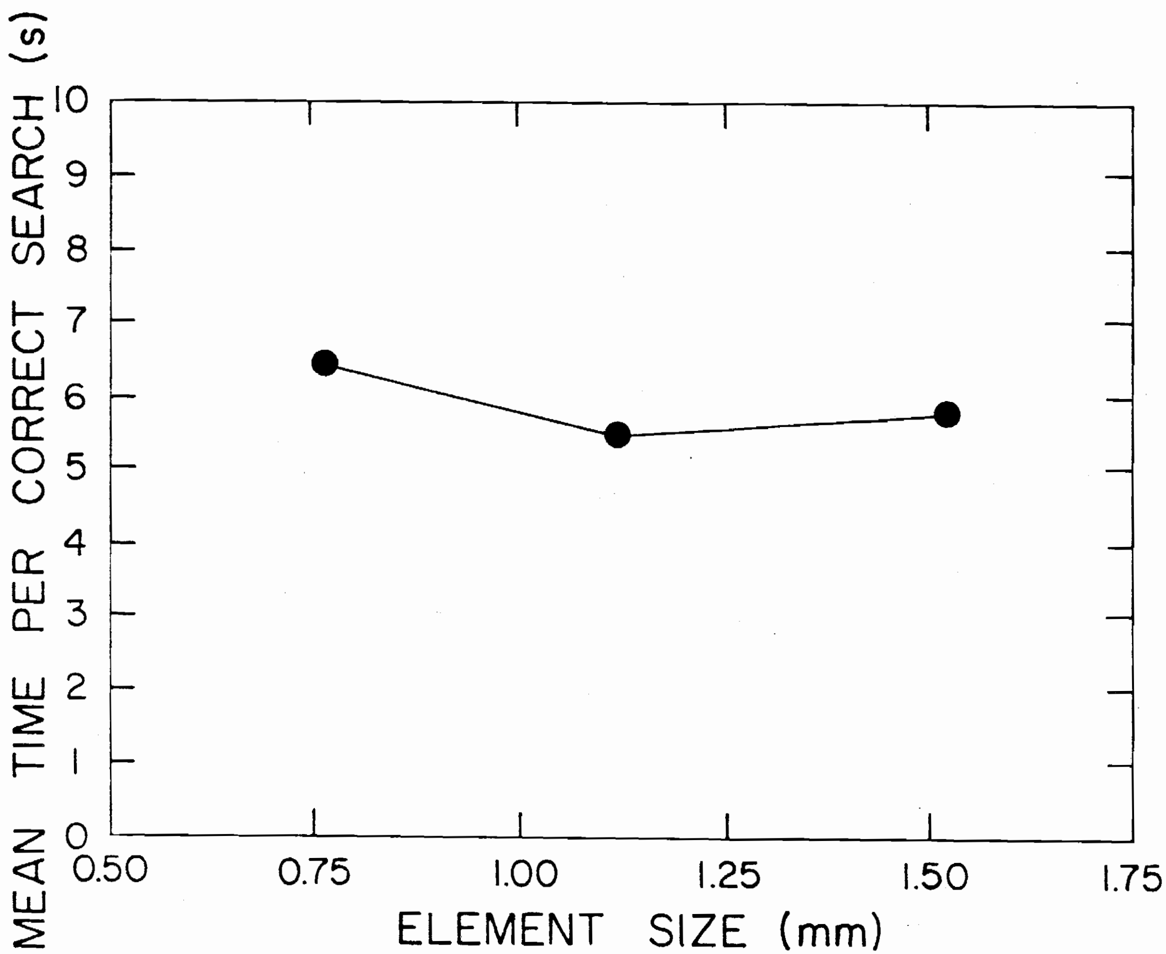


Figure 24. Element Size Main Effect (Menu Search)

Ambient illuminance. Though statistically significant ($p<.02$), the low illuminance level produced only slightly lower search times than did the high illuminance level (5.78 and 6.07 sec, respectively) (Figure 25). This difference, though statistically significant and in agreement with other results for this variable, is probably of little practical importance.

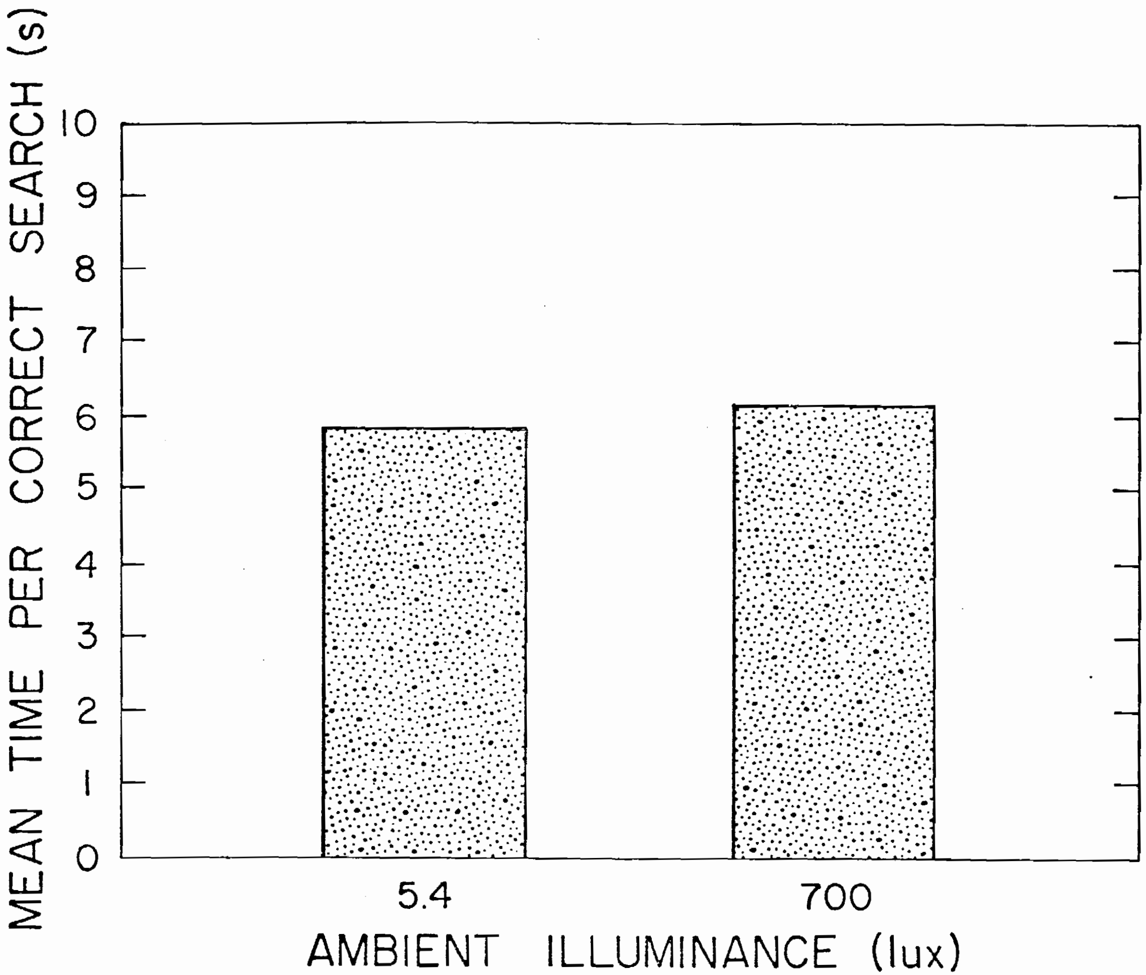


Figure 25. Ambient Illuminance Main Effect (Menu Search)

DISCUSSION

One of the most consistent effects was that of the small VER. Because the smallest (0.76 mm) rectangular elements were made up of a vectored arrangement of points (*i.e.*, 5 X 1 points for the HER and 1 X 2 points for the VER) and the points were less in width than in height (0.4 X 0.5 mm, respectively), the actual area of the small VER was much smaller than was that of the HER (0.24 *vs* 0.39 mm^2). This smaller area was unfortunate, but unavoidable because the points on the display do not overlap enough to allow adding another row or column of these points to increase the area of the small VER to that of the small HER. Instead, adding such a row or column increases the area of the VER to an area greater than that of the HER. A compromise had to be made.

While the smaller VER's area perhaps created spurious interactions, it did point out the importance of element size upon performance. Related to the conclusion that element size is important is the fact that the largest element, the square, also led to the best subjects' performances. Left mostly unresolved by the data is the matter of the overall effect of element shape and whether the effects of shape result from differences in percent active area, total area of the element, or from some interaction involving the total character size, which is a necessarily confounded variable, as noted in the Introduction. Because of these intrinsic confoundings, some secondary *post hoc* analyses are appropriate and follow.

Secondary Variables - Confounding of Character Heights and Widths with Independent Variables

Values for character vertical subtense (Height), horizontal subtense (Width), height X width (Area), element width X element height/center-to-center interelement spacing^2 X 100 (Percent Active Area), and character height X width X percent active area (Area X Percent Active Area) were computed at each of the 27 size-shape-spacing combinations (Table 5). These derived independent predictor variables were then correlated with subjects' performances on all three tasks (reading and search tasks). Table 6 gives the r- and associated p- values for each correlation.

Performance on the Tinker test correlates reasonably well with both character height (r=.567) and character width (r=.563), as well as with the product of height and width (r=.560), simply because height is proportional to width for the various conditions. As character size increases, mean corrected passage reading time increases, probably because more visual fixations are required to cover the entire displayed area of the passage. It should be remembered that all characters were reasonably large (>23 minutes of arc vertically), so that no acuity limits should have been involved.

Of interest, however, is the fact that the results from both search tasks correlate *negatively* with both height and width, although the correlations are significant only for the random search. As character size increases, search time decreases for these tasks. No reason for this relationship is apparent to the author.

TABLE 5A

Character Subtense and Percent Active Area for the 0.76 mm Elements

*Element Shape**	*Interelement Space/Size Ratio*	*Character Height(min)*	*Character Width(min)*	*Height X Width(min^2)*	*Percent Active Area*	*Height X Width X Percent Active Area*
S	0.5	25.62	17.93	459.37	44	20212.28
S	1.0	33.30	23.05	767.57	25	19189.25
S	1.5	40.99	28.16	1154.28	16	18468.48
H	0.5	23.93	17.93	429.06	29	12442.74
H	1.0	31.62	23.05	728.84	16	11661.44
H	1.5	39.30	28.16	1106.69	11	12173.59
V	0.5	24.54	15.50	380.37	18	6846.66
V	1.0	32.22	20.63	664.70	10	6647.00
V	1.5	39.91	25.75	1027.68	6	6166.08

*S=square; H=horizontally elongated rectangles; V=vertically elongated rectangles

TABLE 5B

Character Subtense and Percent Active Area for the 1.14 mm Elements

*Element Shape**	*Interelement Space/Size Ratio*	*Character Height(min)*	*Character Width(min)*	*Height X Width(min^2)*	*Percent Active Area*	*Height X Width X Percent Active Area*
S	0.5	38.42	26.90	1033.50	45	46507.50
S	1.0	49.95	34.58	1727.27	25	43181.75
S	1.5	61.48	42.27	2598.76	16	41580.16
H	0.5	36.00	26.90	968.40	30	29052.00
H	1.0	47.53	34.58	1643.59	17	27941.03
H	1.5	59.05	42.27	2496.04	11	27456.44
V	0.5	38.42	24.34	935.14	30	28054.20
V	1.0	49.95	32.02	1599.40	17	27189.80
V	1.5	61.48	39.71	2441.37	11	26855.07

*S=square; H=horizontally elongated rectangles; V=vertically elongated rectangles

TABLE 5C

Character Subtense and Percent Active Area for the 1.52 mm Elements

*Element Shape**	*Interelement Space/Size Ratio*	*Character Height(min)*	*Character Width(min)*	*Height X Width(min^2)*	*Percent Active Area*	*Height X Width X Percent Active Area*
S	0.5	51.23	35.86	1837.11	44	80832.84
S	1.0	66.60	46.11	3070.93	25	76773.25
S	1.5	81.97	56.36	4619.83	16	73917.28
H	0.5	47.53	35.86	1704.43	28	47724.04
H	1.0	62.90	46.11	2900.32	16	46405.12
H	1.5	78.27	56.36	4411.30	10	44113.00
V	0.5	51.23	32.36	1657.80	31	51391.80
V	1.0	66.60	42.60	2837.16	17	48231.72
V	1.5	81.97	52.85	4332.11	11	47653.21

S=square; H=horizontally elongated rectangles; V=vertically elongated rectangles

TABLE 6

Correlation of Secondary Variables with Dependent Variables

	Character Width	*Percent Active Area*	*Height X Width*	*Height X Width X Percent Active Area*	*Reading Test*	*Menu Search*	*Random Search*
Character Height	.99* .0001	-.36 .0626	.98 .0001	.70 .0001	.53 .0048	-.16 .4298	-.41 .0315
Character Width		-.34 .0839	.98 .0001	.71 .0001	.56 .0023	-.13 .5204	-.41 .0328
Percent Active Area			-.36 .0644	.33 .0904	-.77 .0001	-.53 .0044	-.30 .1270
Height X Width				.67 .0001	.56 .0024	-.09 .6607	-.38 .0511
Height X Width X Percent Active Area					.04 .8455	-.49 .0096	-.56 .0024
Reading Test						.53 .0043	.23 .2524
Menu Search							.70 .0001

*The upper number of each cell is the correlation coefficient (r); the lower number is the p-value associated with that r.

The percent active area measure correlates significantly with performance on both the Tinker test and the Menu search task. As percent active area increases, reading or search time decreases. The same result is suggested by the Random search data, although the correlation is not statistically significant (p=.127). Thus, these results agree with those of VanderKolk, *et al.* (1975), who showed that percent active area is a good composite predictor of the legibility of an alphanumeric character.

Weighting the percent active area by the total size of the character essentially eliminates the correlation with performance on the Tinker test (r=.039). That is, for reading contextual material, increases in percent active area are beneficial to performance, but overall character sizes above 23 arcminutes become detrimental, causing longer reading times.

Weighting the percent active area measure by character size increases search time predictability (r=.560) for the random search task, however, and has little effect upon predictability for the Menu search task. For search, rather than contextual reading, large percent active area characters, coupled with large character sizes, produce the best average performance.

Font Selection and Display Presentation

It could be argued that the composite font used in this research was not an optimal font when used in context since it was developed out of context. Even if this were true, there was no reason to avoid using this font, as an expedient, in this research. Choice of font in this case was arbitrary, as it was not an experimental variable.

The Tektronix display and DEC minicomputer could not interface as rapidly as might have been desirable. The theoretical interface rate was 307 kilobaud. Due to the increased capacitance of the more than 15 m of coaxial cable connecting the computer and the display, the actual interface rate was probably nearer 200 kilobaud. This means that the reading test passages were written more slowly than desirable. However, the worst-case writing time was 5.04 s (large square element and 1.5 interelement spacing ratio) and the fastest reading time was 5.94 s (small square element and 0.5 interelement spacing ratio). Therefore, the interface speed is not thought to have affected the results of the reading task. For the search tasks the subject did not know what character was the target until all of the characters were written on the display so there was no effect of interface speed.

Better methods of predicting performance on a display might use a Fourier analysis of the intensity distribution of the elements to derive the upper boundary of the modulation transfer function area (Snyder, 1973) or, perhaps a two-dimensional Fourier analysis to determine unique power spectra most strongly related to performance (Pantle, 1974).

Tinker Test

This reading test seems to be an accurate and sensitive metric for performance on visual displays for several reasons:

(1) It is possible to refine the measure by subtracting the baseline time per passage to eliminate most of the inherent between-subjects differences;

(2) Subjects are familiar with the reading type task and there are no learning effects or other difficulties which might result from a more exotic measure; and

(3) Such a reading task is very realistic in terms of future wide scale applications of computer-generated visual displays, such as in training systems and computer I/O.

The major disadvantage seems to be that subjects became bored during the 25 min (approximately) of each form of the reading test. From the results gathered in this research, it was concluded that a 5-10 min reading test of 10-20 passages would probably have been just as valid and reliable as was this 50 passage test. Several subjects stated, after the experiment, that they could anticipate slightly the target word's location. Because of the small number of subjects reporting this, the probably random distribution of the subjects, and the apparent *post hoc* insignificance of such an effect, it was not considered in the data analysis.

Random Search Task

This task produced desirable results but was not as selective as was the Tinker reading task. Two or three subjects stated that they knew the target would appear in each area only once. Again, this random and apparently insignificant effect could only be ignored in data analyses. It is desirable, however, to debrief subjects to learn of such possible complications.

Menu Search Task

This measure was not as sensitive as the Tinker test or the random search task, probably because it was too simple. As several subjects commented, it was possible to observe and be able to recognize only the first two or three characters of each pseudoword to perform well on this task since it was not likely that more than one or two pseudowords in each trial began with the same first character. The range of the cell means reflected this effect because the menu search had a much smaller range (4.17-7.93 s) than did either the random search task (4.36-21.53 s) or the Tinker reading test (4.33-15.32 s). The task could have been more sensitive if more pseudowords were used and each word consisted of two or three characters. Another solution would be to constrain the random number generator in such a way that the random pseudowords were more similar; ideally, such target pseudowords would have only one or two characters different from the other pseudowords.

Agreement with Previous Studies

These results agree with the pertinent results of Taylor (1975) and Albert (1975). They showed direct effects of luminance, character size and context which are generally the same as the trends shown by the ambient illuminance, size-spacing and reading *vs.* search task results of this study.

Design Recommendations

Element size. There was some difference between the reading and the search tasks. The smaller dots (and smaller characters) were more favorable to quick scanning with redundant cues, as in the reading task, while simple detectability was enhanced in the search tasks by using the larger elements (and larger characters). This difference must be taken into consideration when designing such displays.

Element shape. The square shape was the best in all cases.

Interelement spacing ratio. Againing, scanning rate seemed to be critical for the reading task so the smallest space was the best.

Ambient illuminance. The enhanced contrast ratio resulting from the low illuminance level (5.4 lx) was superior to the lower contrast ratio obtained with the higher illuminance level.

Of probably the most importance from the designer's viewpoint is the finding that the best condition for all three tasks was the medium sized (1.14 mm), square element with the small interelement spacing ratio (0.5). That is, for best performance, dots should be square and approximately 1.14 mm wide; edge-to-edge spacing should be no greater than 0.57 mm; and the displayed element/background contrast ratio should be at least 8.5:1. Increases in element size and decreases in interelement spacing, the combination of which yields greater percent active area, lead generally to improved performance.

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APPENDIX A.

SAMPLE READING TEST PASSAGES

ON HIS WAY TO WORK ONE MORNING, MR. SMITH SLIPPED ON THE ICE AND BROKE HIS LEG. SEVERAL MONTH WENT BY BEFORE HE WAS COMPLETELY WELL AND COULD SEE AGAIN.

JOHN DELIVERED HIS NEWSPAPERS PROMPTLY THROUGHOUT THE COLD WINTER MONTHS NO MATTER HOW COLD IT WAS OR HOW DEEP THE SNOWDRIFTS. FEW PEOPLE ARE AS LAZY AS THIS.

MARCELLA TOOK HER MISCHIEVOUS AND NOISY LITTLE BROTHER TO THE THEATER WITH HER THEN WAS ASHAMED OF HIM, FOR HE WAS SO QUIET SHE HAD TO TAKE HIM HOME.

THE LIGHT BULB IN THE LIVING ROOM BURNED OUT, AND AS A PARTY WAS GOING ON, MR. HICKS CALLED THE JANITOR TO ASK HIM TO PUT A NEW FURNACE IN.

CHESTER ALWAYS ENVIES THE GROWN FOLKS BECAUSE THEY DRINK COFFEE AND HE MUST NOT, AND HE CAN HARDLY WAIT UNTIL HE HAS GROWN UP SO HE CAN DRINK MILK TOO.

WE OPENED ALL OF THE WINDOWS TO GET RID OF THE PAINT SMELL, BUT FOR A WEEK IT BOTHERED US FOR NEVER HAD WE SMELLED SUCH A STRONG ONION ODOR.

JERRY GOT A SLIVER IN HIS FINGER AND BECAUSE IT WAS NOT REMOVED, IT BECAME SO INFECTED THAT THE DOCTORS THOUGHT THEY MIGHT HAVE TO CUT OFF HIS WHOLE EAR.

WE MUST BE SURE TO TEACH ALL OF THE CHILDREN TO TURN OFF THE LIGHTS WHENEVER THEY ARE NOT USING THEM, BECAUSE NO ONE SHOULD WASTE WATER IN THESE TIMES.

MARK WANTED TO
BUILD A BIRDHOUSE
FOR THE ROBINS,
AND ASKED EARL TO
SHOW HIM HOW, BUT
EARL COULD NOT,
FOR HE HAD NEVER
LEARNED HOW A
CHAIR WAS MADE.

WE SAW A BIG NEST
IN THE TREETOPS
WHEN WE WERE WALK-
ING THROUGH THE
WOODS ON OUR WAY
HOME FROM THE
LAKE. WE KNEW A
BEAR MUST HAVE
BUILT IT.

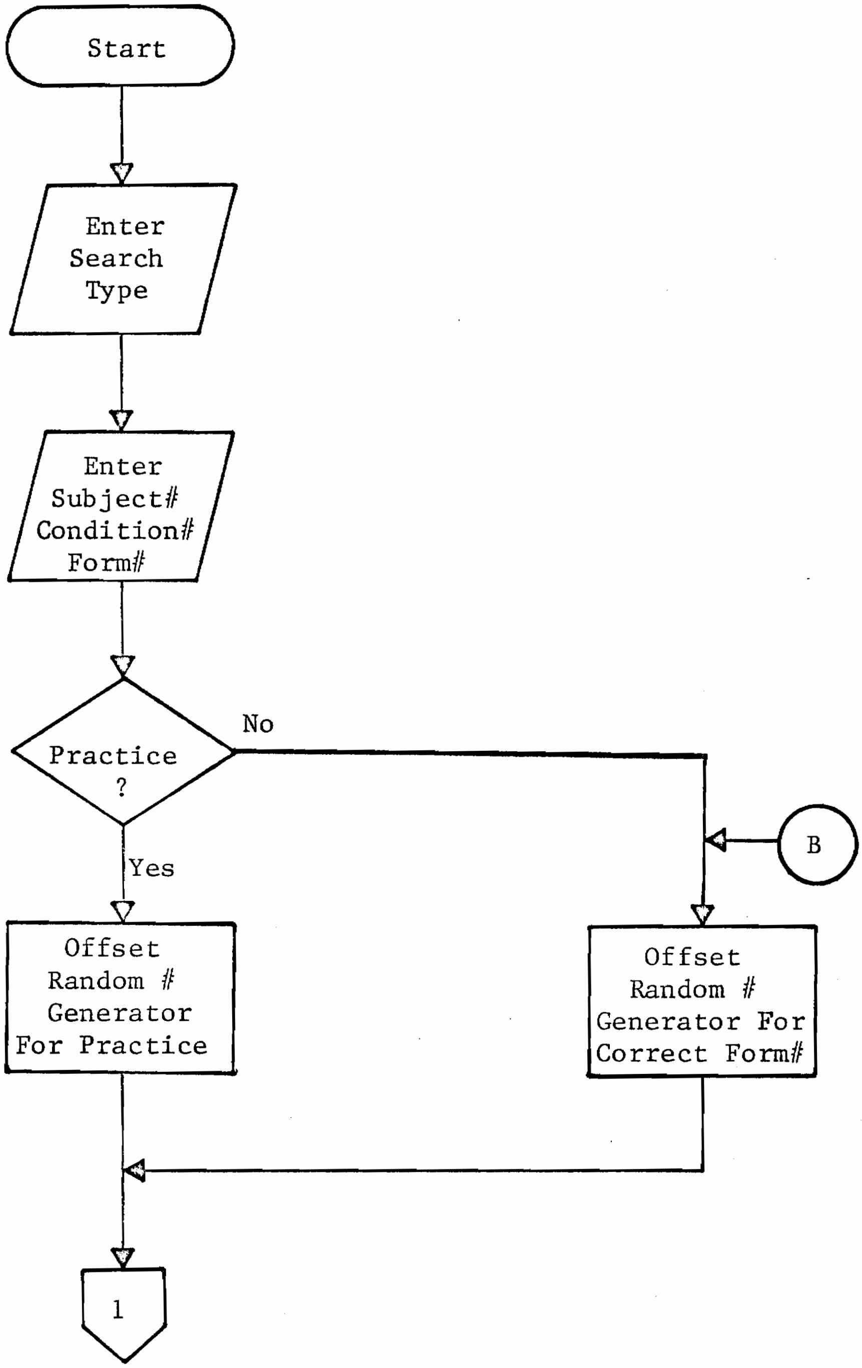
IF YOU WANT TO
BORROW COSTUMES
FOR THE PARTY, YOU
WILL HAVE TO ASK
MY SISTER AS SHE
USED THEM LAST AND
REMEMBERS WHERE
THE DISHES HAVE
BEEN PACKED AWAY.

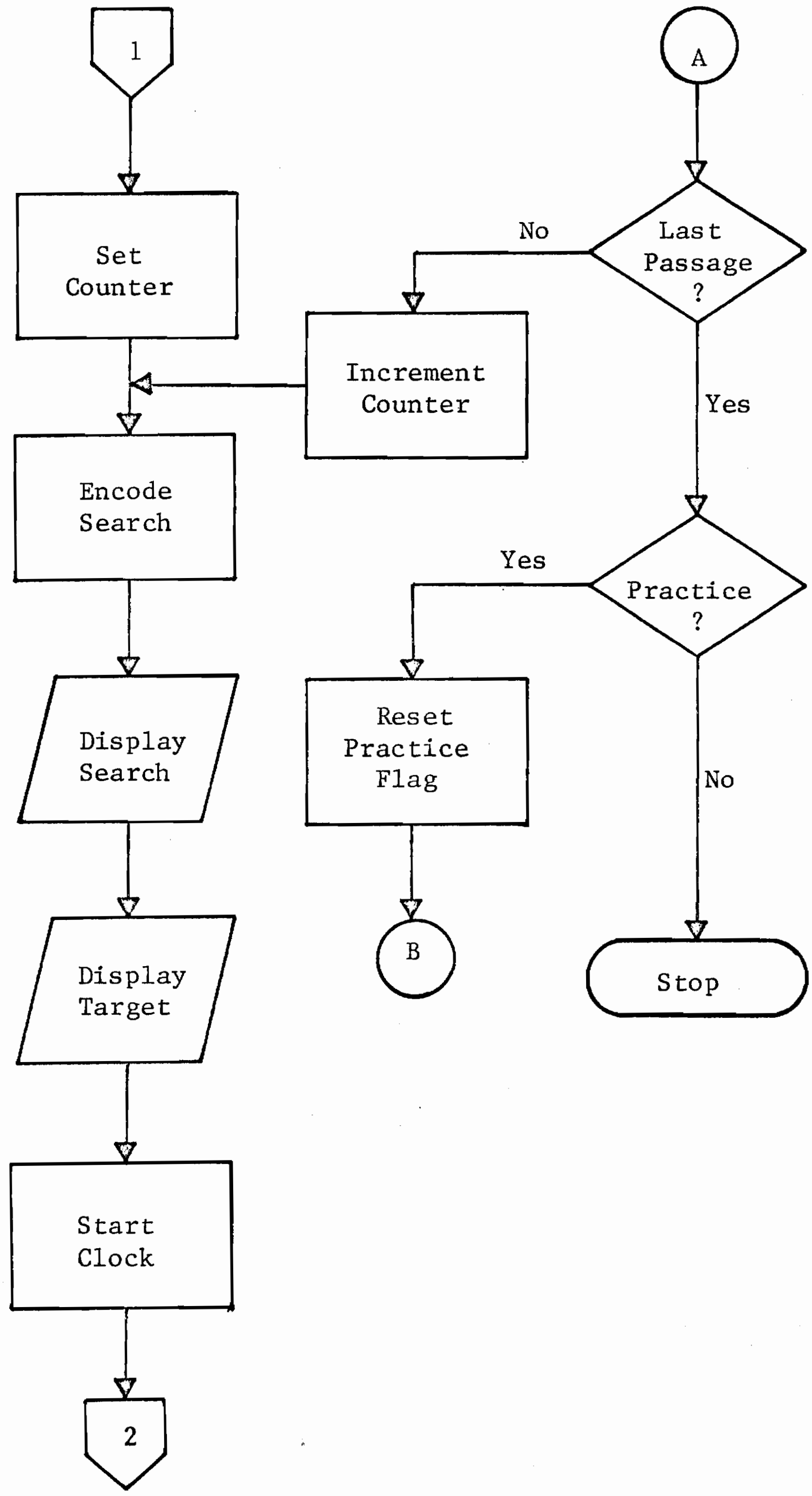
FREIGHT BOATS CAR-
RY COAL FROM THE
MINES TO DISTANT
PORTS WHERE IT IS
LOADED ONTO TRAINS
AND CARRIED TO ALL
WESTERN CITIES SO
YOU AND I CAN
PAINT OUR HOMES.

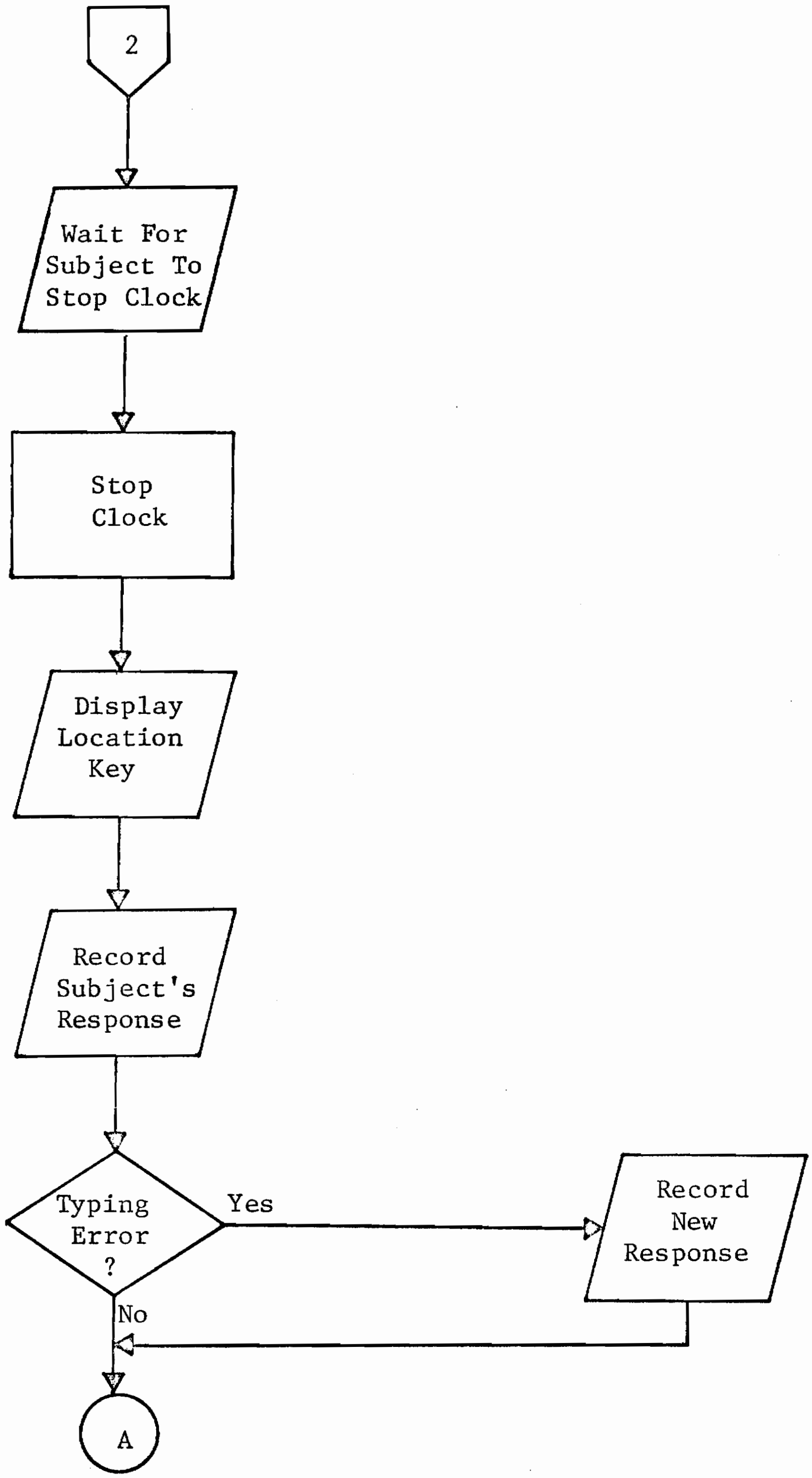
APPENDIX B

COMPUTER PROGRAMS FLOW CHARTS

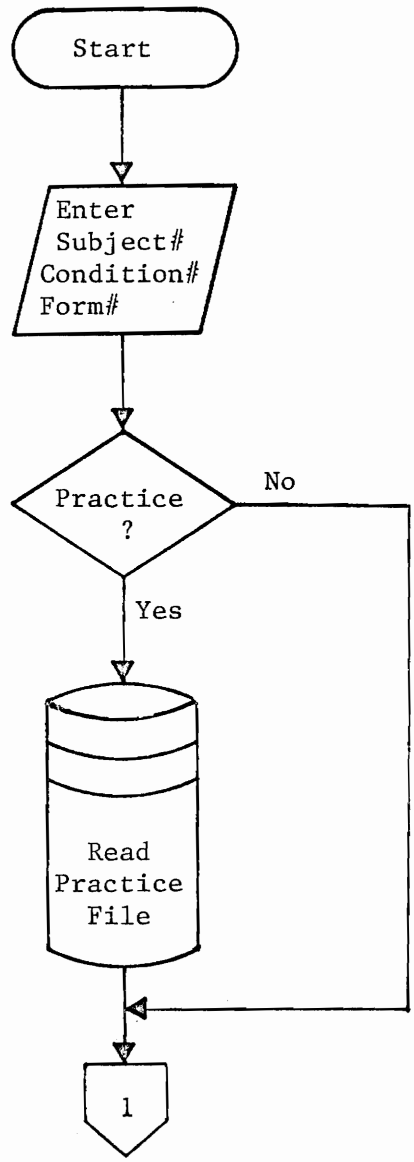
Search Tasks

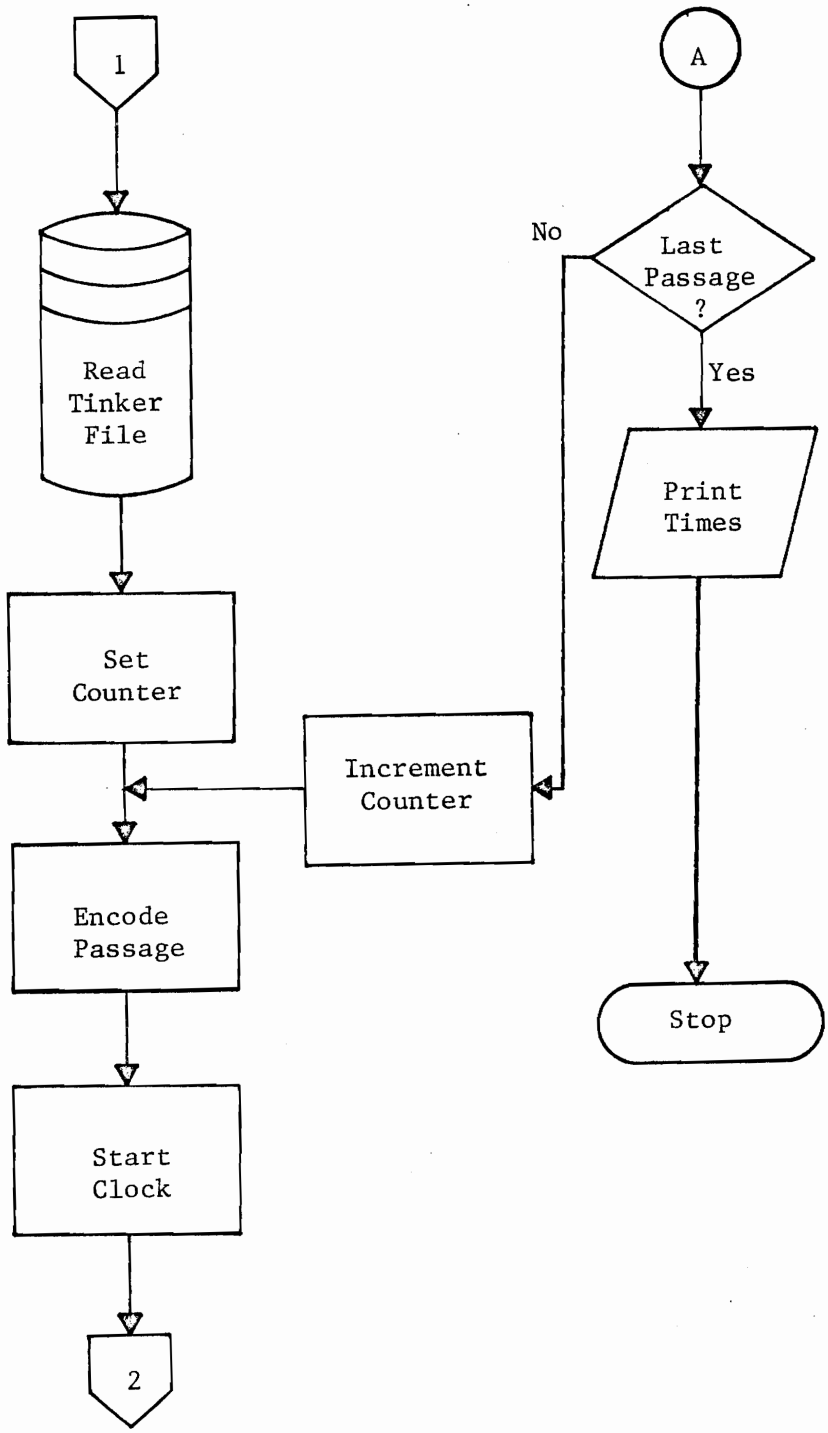


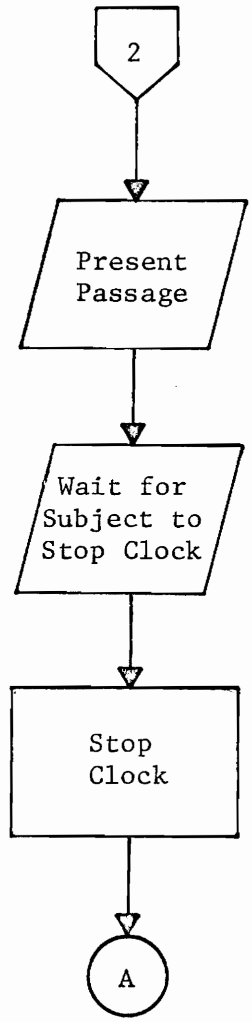

1
Set Counter
Increment Counter
Encode Search
Display Search
Display Target
Start Clock
2
A
Last Passage ?
No
Yes
Practice ?
Yes
No
Reset Practice Flag
B
Stop


2
Wait For Subject To Stop Clock
Stop Clock
Display Location Key
Record Subject's Response
Typing Error ?
Yes
Record New Response
No
A

Tinker Reading Test




1
Read
Tinker
File
Set
Counter
Encode
Passage
Start
Clock
2
A
Last
Passage
?
No
Yes
Increment
Counter
Print
Times
Stop


2
Present Passage
Wait for Subject to Stop Clock
Stop Clock
A

APPENDIX C.

EXPERIMENTAL PROCEDURE

Chronological order and description of activity	Approximate Time (min)
Assign subject randomly to experimental conditions	--
Subject reads instructions and adapts to illuminance level A	10
Answer subject's questions on the experimental procedure	5
Give subject 10 practice reading passages followed	5
by 50 passages of the Tinker reading task-form A	25
Subject must: find the incongruous word and stop clock	
turn the microphone "ON"	
say the incongruous word	
turn the microphone "OFF"	
next passage is written automatically	
Give subject 5 practice trials from search task A followed	3
by 12 experimental trials of search A-form A	5
<u>Random search</u>	
Subject must: find the target character and stop clock	
find target's location number on grid	
type number and check for typing errors	
correct typing errors or depress "NEXT"	
next trial starts	
<u>Menu search</u>	
Subject must: find the target pseudoword and stop clock	
find target's location number in number list	
type number and check for typing errors	
correct typing errors or depress "NEXT"	
next trial starts	

Chronological order and description of activity	Approximate Time (min)
Give subject 5 practice trials from search task B followed	3
by 12 experimental trials of search task B-form A	5
Give subject a break while adapting to illuminance level B	10
Give subject 50 passages of Tinker test-form B	25
Give subject 12 trials of search task B-form B	5
Give subject 12 trials of search task A-form B	5
Give subject a break while adapting to high illuminance level for baseline reading task	5
Give subject 10 passages of baseline reading task	3
Debrief subject	--
Total	114

APPENDIX D.

CELL MEANS

5.4 lux

Element Size (mm)	Element Shape*	Interelement Spacing/Size Ratio	Reading Test (s)	Random Search (s)	Menu Search (s)
0.76	S	0.5	1.13	6.68	5.37
0.76	S	1.0	1.58	6.99	5.41
0.76	S	1.5	2.71	5.58	6.89
0.76	H	0.5	1.72	6.34	6.44
0.76	H	1.0	1.85	5.15	5.93
0.76	H	1.5	2.23	6.23	6.52
0.76	V	0.5	1.80	8.84	6.22
0.76	V	1.0	2.08	7.67	6.40
0.76	V	1.5	0.86	5.95	6.34
1.14	S	0.5	0.61	4.83	4.17
1.14	S	1.0	1.08	5.32	5.00
1.14	S	1.5	2.23	5.54	4.99
1.14	H	0.5	0.61	6.51	5.69
1.14	H	1.0	2.47	4.89	5.22
1.14	H	1.5	3.96	8.92	6.88
1.14	V	0.5	1.73	5.50	5.96
1.14	V	1.0	1.46	5.58	5.80
1.14	V	1.5	2.13	4.54	5.14
1.52	S	0.5	1.43	6.60	5.78
1.52	S	1.0	2.63	4.36	5.68
1.52	S	1.5	3.01	4.64	5.60
1.52	H	0.5	2.24	6.94	5.77
1.52	H	1.0	2.93	6.15	6.03
1.52	H	1.5	3.42	5.53	6.55
1.52	V	0.5	1.89	5.36	4.96
1.52	V	1.0	2.05	4.33	5.62
1.52	V	1.5	2.03	5.33	5.58

*S=square; H=horizontally elongated rectangle; V=vertically elongated rectangle.

700 lux

Element Size (mm)	Element Shape*	Interelement Spacing/Size Ratio	Reading Test (s)	Random Search (s)	Menu Search (s)
0.76	S	0.5	0.48	7.25	6.01
0.76	S	1.0	1.48	9.31	6.04
0.76	S	1.5	2.47	7.49	6.63
0.76	H	0.5	2.01	12.60	7.14
0.76	H	1.0	2.17	9.28	6.85
0.76	H	1.5	2.75	6.32	6.33
0.76	V	0.5	2.13	8.35	6.04
0.76	V	1.0	2.98	14.05	7.74
0.76	V	1.5	4.86	21.53	7.68
1.14	S	0.5	0.66	5.52	4.77
1.14	S	1.0	1.54	5.88	5.60
1.14	S	1.5	3.29	8.05	5.31
1.14	H	0.5	1.13	7.71	5.46
1.14	H	1.0	2.80	7.60	5.34
1.14	H	1.5	1.85	8.90	6.98
1.14	V	0.5	1.17	8.58	5.36
1.14	V	1.0	1.89	7.56	6.00
1.14	V	1.5	1.74	5.93	5.28
1.52	S	0.5	1.31	7.02	5.63
1.52	S	1.0	2.32	6.16	5.18
1.52	S	1.5	2.92	7.69	6.05
1.52	H	0.5	1.94	8.36	6.27
1.52	H	1.0	3.67	8.84	6.13
1.52	H	1.5	4.40	7.52	7.04
1.52	V	0.5	1.54	6.06	5.47
1.52	V	1.0	2.41	6.41	5.10
1.52	V	1.5	2.05	7.27	6.36

*S=square; H=horizontally elongated rectangle; V=vertically elongated rectangle.

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OPTIMAL ELEMENT SIZE-SHAPE-SPACING COMBINATIONS FOR A 5 X 7 DOT MATRIX VISUAL DISPLAY UNDER HIGH AND LOW AMBIENT ILLUMINANCE

by

James Tilson Burnette

(ABSTRACT)

A broad range of element size, element shape, and interelement spacing/element size ratio combinations at high and low ambient illuminance levels was used to determine optimal combinations for a 5 X 7 dot matrix visual display. Three tasks - a reading test, a random search task, and a structured (menu) search task - were used to enhance the utility of the research. All tasks were displayed on a CRT display 1.02 m from the subject.

There were different overall results for the reading and the search tasks, as shown by an analysis of variance. The smaller elements (0.76 and 1.14 mm) and the 0.5 space/size ratio produced the shortest reading times, while the shortest search times came from the larger elements (1.14 and 1.52 mm). The square shape and low illuminance level (5.4 lux) had the shortest times for all three tasks.

For a general purpose display, the combination of a square 1.14 mm dot, with 0.57 mm edge-to-edge spacing is recommended, to be used with the lowest practical ambient illuminance.