Searching for a Target in a Random Arrangement of Names: An Eye Fixation Analysis*

RICHARD J. PHILLIPS
University of Nottingham

ABSTRACT

Four experiments investigated the eye fixations used in searching for names in map-like displays. A typical display was a random arrangement of 20 names, all of which were in the same type style and point size. Compared with data from searching for symbols, two differences emerged. Firstly, there was little or no tendency to fixate names which resembled the target. When subjects moved their eyes, they simply fixated one of the nearest names which had not been fixated before, often following a search path characteristic of the individual. Secondly, fixation times were not constant, but were consistently longer on names which resembled the target; for example, fixations on names with the same initial as the target were considerably longer than on names with a different initial. Fixation times were also longer on displays with names set in a small type size. Peripheral vision is important in placing fixations but, from tachistoscopic evidence, it is clear that information which is potentially available in peripheral vision is not always used when searching. The strategies available to the searcher are discussed, and practical implications for map design are considered.

RÉSUMÉ

Compte-rendu de quatre études relatives aux fixations oculaires observées dans une situation de repérage de noms. Dans chacune des expériences, le dispositif expérimental est constitué de vingt noms imprimés en un même caractère et répartis au hasard comme sur une carte géographique. Comparativement à ce qui a déjà été observé dans des situations de repérage de symboles, les résultats obtenus diffèrent sur deux points. Premièrement, il n'existe à peu près pas de tendance à fixer les noms qui ressemblent au mot-cible; les seules fixations observées portent sur les noms les plus rapprochés de ceux qui n'ont pas encore été fixés, suivant le plus souvent un mode de recherche propre à chaque sujet. Deuxièmement, même si les temps de fixation ne sont pas constants, ils sont plus longs pour les noms qui ressemblent au mot-cible; c'est le cas, par exemple, des temps de fixation sur les noms dont la première lettre est identique à celle du mot-cible qui sont considérablement plus longs. Les temps de fixation sont également plus longs quand le dispositif présente des noms imprimés en petit caractère. Enfin, d'après les données obtenues à l'aide du tachistoscope, le rôle de la vision périphérique semble important mais l'information disponible n'est pas toujours utilisée. La discussion porte sur les différentes stratégies dont disposent les sujets de même que sur les conséquences pratiques pour l'élaboration des cartes géographiques.

Printed words are nearly always presented to the reader in some tidy arrangement, such as the lines on this page or the columns which make up lists and tables. If one disregards the anarchistic typography of the Dada school and similar experiments, the only common exception to this tidy presentation is the arrangement of names on a map. This paper reports experiments which use eye movement recording to study the task of searching a random arrangement of names, such as is found on a map.

When we read a book or a newspaper, our eyes move along the lines of print, frequently coming to rest. These fixations gather the information, and it is unlikely that anything can be taken in while the eyes are moving. When people are searching for

*Requests for reprints should be sent to Dr. Richard J. Phillips, Shell Centre for Mathematical Education, The University, Nottingham NG7 2RD, England. I would like to thank Liza Noyes for her help and advice, the technical staff of the Psychology Department, University College London, for modifying the eye movement apparatus, and Dr. C. Day for making available his program PARADIGM. The greater part of this work was conducted at University College London. The preparation of this paper forms part of the United Kingdom Social Science Research Council project HR2917/1.

a name on a map, the task differs in several ways. There is no predetermined path for the eyes to follow, the space between words is rather larger than on a page of text, the names are generally less familiar than the words in a book, and there is often much irrelevant visual detail in the background. A study of eye movement behaviour should aid our understanding of this task and may provide useful information on the design of maps.

This study aims to answer several questions. Firstly, does the searcher take in several names at each fixation or must each name be fixated separately? In normal reading, it is sometimes possible to process two words in one fixation (see, for example, Taylor, 1957; Rayner, 1975), but with the greater separation of names on a map, this is less likely.

Secondly, although it may be necessary to fixate names individually, is it possible to bypass names which differ substantially from the target? When one name is being fixated, peripheral vision must be in use to decide where to place the eyes next. Does the brain simply select the nearest name, or is it more selective? Names may be selected which have the same initial letter as the target, or are the same length as the target, or have the same word shape as the target. Williams (1967) has recorded the eye movements of people searching for symbols on map-like displays, and he found that peripheral vision was frequently used to fixate symbols of the same color or the same size as the target; however, the shape of the target was a relatively poor cue. If this also applies to searching for names, the eye may fixate only those names which are about the same length as the target.

Thirdly, are fixation times constant, or do they vary according to the similarity of the fixated name to the target name? Williams (1973) assumed a constant fixation time in his equation to predict median search time. Luria and Strauss (1975), using a task where subjects searched for dials, found that fixation time was 'an inconsistent measure' and that the number of fixations was far more important in determining performance. However, Gould and Dill (1969) found that fixation time increased when difficult pattern discriminations were required in a counting task, and Rayner (1978) describes other evidence for fixation duration reflecting cognitive processing.

The last question to be considered is probably of greatest practical interest: What factors influence the total time taken to find a name? It can sometimes take over a minute to locate a name on a city street map (Phillips & Noyes, 1977), and any means of reducing search time would be of great utility. The search path chosen by the subject is clearly of interest here. Previous studies of searching for names on maps (Bartz, 1970; Foster & Kirkland, 1971; Phillips, Noyes, & Audley, 1977) have all used the total search time as a means of estimating search speed; but because of chance factors, the total time fluctuates widely, making it difficult to study how variations in map design affect search speed, unless a large number of subjects are employed. A study of eye movements should make it possible to study directly the factors determining search speed: the placing of fixations and fixation time.

EXPERIMENT I

METHOD

Eye Movement Apparatus

A Polymetric V-1164-3 Eye Movement Recorder linked to a PDP-12 computer was used to record subjects' eye fixations. The apparatus is similar to that described by Mackworth and Mackworth (1958), and uses a corneal reflection monitored by a television camera. The television picture is divided into a grid of 15 by 15 cells, and the computer samples the position of the corneal reflection in this grid every 20 msec. The position of fixations can be measured to an accuracy of about one degree of visual angle in both the horizontal and vertical directions.

Displays

Subjects searched for names on map-like dis-

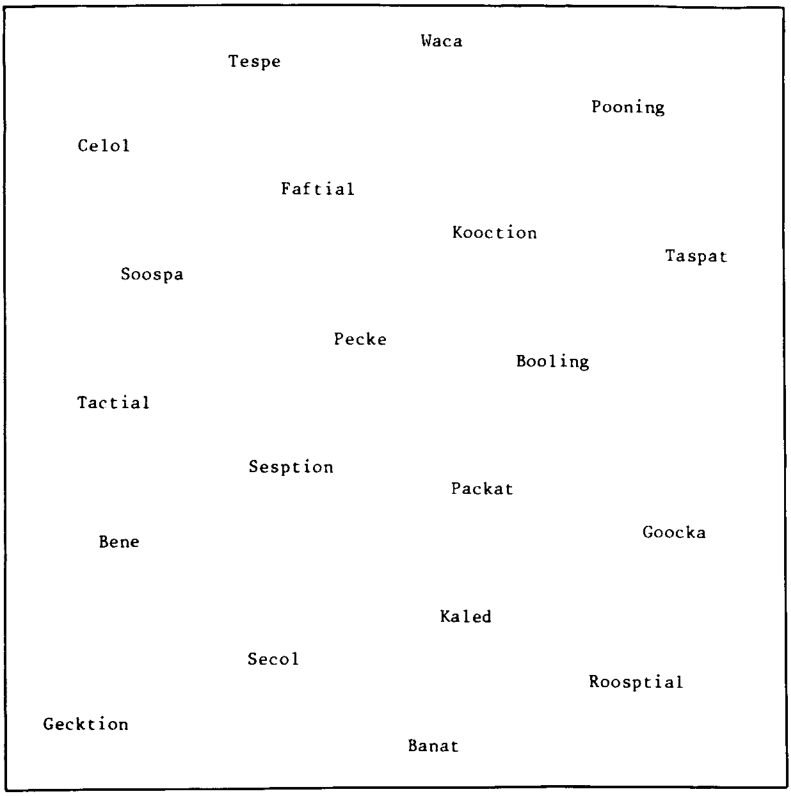

FIGURE 1 One of the displays used in Experiment I.

plays presented as back-projected slides at a distance of 450 mm. Each display subtended a visual angle of about 18° square, and included 20 names in lower case typewriter script with an initial capital. The separation between names was about 3.5° of visual angle and a typical six-letter name was 1.5° in length. The names were in black against a light blue background, with nothing else in the display. An example is shown in Figure 1.

For half the displays all the names had the same initial letter, namely S, while the other half had names beginning with a number of different letters. A third of the displays had names with identical word shapes – they were all six letters long with ascending and descending letters occurring in the same positions (e.g., Goatug, Keetay). Another third of the displays used only six letter words, but of varying word shape. The remaining third had words which varied in length from four to nine letters, with an average length of about six. Two versions of each of the six types of displays were prepared, making 12 displays in all.

As it was clearly impossible to find enough real place names fulfilling these conditions, names were made up according to carefully constructed rules. It was important that all the names should be easily pronounceable and that the more constrained sets of names (same initial letter and same shape) should not be so similar as to be difficult to remember. A computer program generated lists of names. A typical rule was:

First letter: S.
Second letter: c or m or n or v or w.
Third letter: a or e or o or u.
Fourth letter: b or d or f or t or k or l.
Fifth letter: a or e or o or u.
Sixth letter: g or p or y.
Examples: Smulug, Snuday, Scolup.

Every set of names was drawn from a theoretical population of 1440.

Target names were also presented on slides and were in the same type style as names on the search displays, but were about five times larger.

Subjects and Design

Six male and five female university students acted as subjects. Data from one subject was discarded because he made frequent head movements, upsetting the eye movement recording.

Each subject searched for 24 names, two on each display. The order of the displays was randomized separately for each subject, with each display being used once in the first and second blocks of 12 searches. Target names occurred in one of six positions (although subjects were not told this) and the position of the target was varied systematically.

Procedure

Some care was taken to seat subjects comfortably in the apparatus, to minimize body movements, and to give them time to adapt to the viewing conditions. An eyesight test checked that they would be able to read the names on the displays without difficulty. A calibration slide was projected showing 12 small spots arranged in a circle (diameter 11°), and with a 13th spot in the centre of the circle. Each spot contained a randomly chosen two-digit number. Subjects were instructed to read these numbers silently, starting in the centre, then working all the way around the circle, and finally returning to the centre. This generated an eye movement record which was used to check the correct operation of the apparatus, and to provide a guide for scoring subsequent records.

The procedure was the same for each search. The subject looked at the centre of a calibration slide and any necessary adjustment was made to the apparatus. A second slide was then projected with the name of the target. As soon as subjects had read and remembered this, they shut their eyes. The display slide was then projected and subjects started to search. As soon as they had found the target they closed their eyes again.

Although computer programs were used extensively in analysing the data, the job of matching fixations to particular locations in the display was carried out manually. Unintelligible eye movement records were discarded. This usually occurred when a subject made a head movement, sometimes taking the corneal reflection outside the 15 by 15 grid being monitored by the computer. Independent scoring by two judges of a sample of eye movement records showed good agreement between scorers. For the purposes of scoring, movements within the 15 by 15 grid from one square to an adjacent square either horizontally, vertically or diagonally, were regarded as part of the same fixation. All larger movements were regarded as saccades. In counting the frequency and duration of eye fixations, the scorers included only fixations from approximately 400 msec after the eyes were opened until the last fixation before the target name was found. Fixations on the target itself were considered to be unrepresentative, and eye movements in the first 400 msec were difficult to analyse (see *A Typical Search* below). The design of the apparatus makes it impossible to separate the duration of an eye fixation from the duration of the saccade which follows it. However, the latter is relatively short and the effect is that all fixation times are overestimated by a time between about 20 msec and 60 msec with an average of approximately 30 msec (Yarbus, 1967).

The apparatus has a spatial resolution of about one degree and a temporal resolution of 20 msec. Checks on accuracy came from the calibration slide records, from independent scoring, and from frequent checks on the apparatus using simulated eye movements of known characteristics. The computer provided an independent check of the 20 msec time base generated by the eye movement apparatus.

RESULTS

Lost Data

When subjects made a head movement just before, or during, a search the eye movement record could not be analysed. Approximately 10% of searches were lost this way.

A Typical Search

In order to present the data it is useful to describe a typical search. After the eyes are opened, the first 200-400 msec appear to be spent in focussing the eyes and adapting to the brightness of the display; no name is being fixated and the eyes appear to drift. There follows a sequence of rapid fixations, nearly all of which fall on or close to names on the display. Finally, the target name is fixated and the eyes are shut. Very occasionally subjects fixate a position which is not near a name; this usually follows a long saccade when the eyes come to rest some distance from a name, and a second correcting movement is made. On about a quarter of the searches, subjects fixated the target, fixated another name and then returned to the target. Subjects differed considerably in their frequency of doing

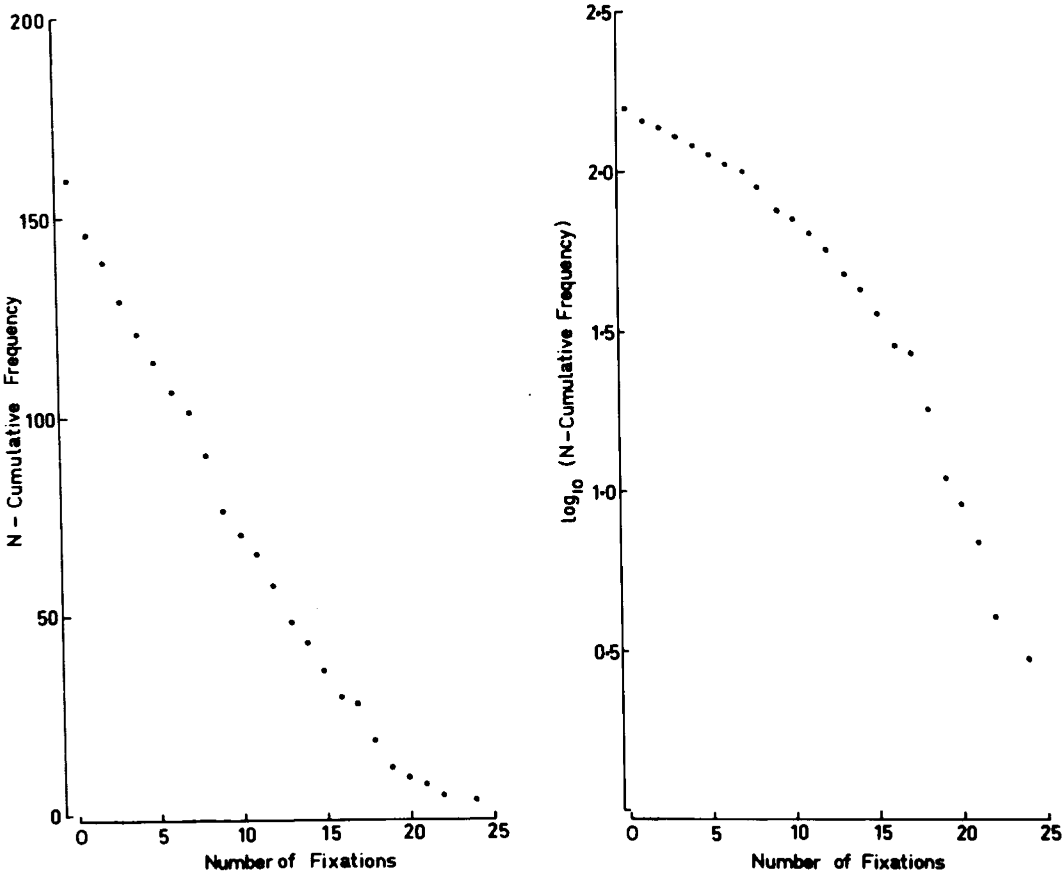

FIGURE 2 Appendix A shows that for a search without replacement the probability that *s* or more fixations are made before fixating the target is linearly related to *s*, but for search with replacement it is the logarithm of this probability which is linearly related to *s*. These cumulative frequency plots of the number of fixations show that the data support search without replacement. *N*, the number of searches, is 160.

this, and it might suggest that the target could not be identified fast enough to stop a further eye movement from occurring. It is also possible that subjects did not always have the target name firmly in memory, and this too could have resulted in some delay in identifying the target.

Number of Fixations

Pooling data from all conditions, the mean number of fixations before the target was fixated is 9.1. If subjects fixate completely at random, with one target and 19 distractors, the mean would be 19 (see Appendix A). But a random search, in which subjects do not fixate a name more than once, would have a mean of 9.5 (again, see Appendix A). However, if subjects are more selective and only fixate names which resemble the target in some way, the mean should be less than 9.5. The actual mean of 9.1 suggests subjects show little or no discrimination in choosing names to fixate.

Further evidence for a random search without replacement comes from the distribution of the number of fixations (see Figure 2).

Between Displays

The data are analysed in several different ways. The *between displays* analysis compares differences between the six types of dis-

TABLE I
Experiment I mean scores for the different types of display

	Total search time (sec)	Mean fixation time (msec)[a]	Number of fixations
Same shape	4.47	333*	9.1
Same length	4.98	342	10.3
Different length	4.13	309	9.5
Same initial	5.25**	341*	10.6
Different initial	3.79	315	8.6
Interactions		Initial* × Order	

[a]Fixation times include the time of the following saccade and so are overestimated by about 30 msec.
$*p < .05$; $**p < .01$

plays using three dependent variables: the total search time, the number of eye fixations before the target is fixated, and the mean fixation time. Each subject made four searches on each type of display, but only the last two of these have been used in the analyses of variance; in cases where data are missing, earlier searches have been substituted.

Each analysis of variance has a 3 by 2 by 2 design, corresponding respectively to word shape (same shape, same length, different length), initial letter (same or different) and presentation order (third or fourth). Table I shows means and significance levels.

The number of fixations show no significant main effects or interactions, and so appears to be unaffected by the type of display. However, mean fixation time shows two significant main effects and an interaction. Fixation times appear to be shorter when searching names of differing length and differing initial letter, but word shape as distinct from word length does not seem to affect fixation time. The interaction suggests the effect of initial letters is enhanced with practice. Total search time is clearly dependent on both mean fixation time and number of fixations; thus, it might be expected to echo any significant effects upon the other variables. In practice, it shows only a significant effect of initial letter.

These results suggest that changes in the display affect fixation time but not the number of fixations. However, mean fixation time may have less variance than the number of fixations because in any particular search, the former is based on several scores while the latter is only measured once. Therefore, small differences in the mean number of fixations may have gone undetected.

In any row of Table I, if the number of fixations is multiplied by the mean fixation time, the product is about 1.3 sec less than the total search time. The apparent discrepancy is due to the fact that total search time was measured from subjects' first opening their eyes to closing them when the target was found. In addition to the scored fixations, this time includes fixations which were not upon a name, fixations which fell partly or wholly in the first 400 msec, fixations on the target, and fixations which occurred after the target was first fixated but before the eyes were shut. Blinks also account for a small amount of the time.

Within Displays

A completely different kind of analysis is based on the variation in fixation time and the locus of fixation within each type of display. For example, half of the displays had names with different initial letters, but this does not mean that every name on

TABLE II
Variations in frequency of fixation and mean fixation times (msec) for the different types of display used in Experiment I

Similarity to target name	Total number of fixations[a]	Mean fixation time[b]	Mean time of next fixation[b]
Displays where names have different initial letters			
First letter different	693 (705.9)	313 ± 8	321 ± 10
First letter same	67 (54.1)	410 ± 56	322 ± 32
Displays where names have the same initial letter			
Second letter different	706 (718.5)	342 ± 10	358 ± 13
Second letter same	167 (154.5)	408 ± 32	377 ± 27
Displays where names are of the same length			
Last letter different	768 (779.9)	338 ± 10	346 ± 11
Last letter same	356 (344.2)	360 ± 18	352 ± 17
Displays where names are of different lengths			
Different length	383 (394.6)	324 ± 13	336 ± 14
Same length	126 (114.4)	335 ± 23	316 ± 28

[a]Numbers in parentheses show the expected number of fixations assuming that all names are fixated with an equal probability.
[b]Times are in msec. The first figure is the mean and the second is two standard errors of the mean. Fixation times are overestimated by about 30 msec as they include the time of the following saccade.

these displays had a different initial. Typically, eight initial letters were shared among the 20 names; thus, on most searches there were some nontargets with the same initial as the target name. The data were examined to answer three questions: (1) were names with the same initial as the target fixated more frequently than other names; (2) were their fixation times any longer; and (3) was the fixation time on the *next* fixation longer? These questions can be answered from the data in the first row of Table II.

The second row of Table II answers similar questions about the second letter of the name, where the initial letter is always the same. The third row concerns the last letter of the name, considering only cases where names were of fixed length. The fourth row is for displays with names of differing length, and shows whether subjects treated names which had the same length as the target any differently from those of different lengths.

Returning to the first row as an example, subjects made a total of 693 fixations on names beginning with a different letter from the target and 67 fixations on names with the same initial letter. Figures in parentheses show the expected frequencies if subjects had fixated at random; these do not differ significantly from the observed frequencies on a χ^2 test. This is also true of the other three comparisons: in no case is there any evidence for subjects selecting names to fixate which resemble the target. A test on the four comparisons taken together is also nonsignificant (χ^2 (4) = 6.7, $p > .1$).

Subjects show no tendency to fixate names which are the same length as the target, nor is there a more general tendency to fixate long names when the target is long, or short names when the target is short (Jonckheere, 1954, trend test, $p > .1$, Kendall's $\tau_b = .04$).

In considering mean fixation time, the interest is whether subjects dwelt longer on names resembling the target than on others. From the first row of Table II, it is clear that there is a mean fixation time of 410 msec when names had the same initial as the target, but only 313 msec with a different initial. Two standard errors of the mean give approximate 95% confidence limits and these suggest that the difference is unlikely to have occurred by chance. There is a similar but slightly smaller difference for the second letter of the name. In the other two comparisons, there is also a larger mean when a name resembles the target, but in these cases the difference may have occurred by chance.

It is possible that processing the names may lag behind the eye movements used to scan them. This is suggested, for example, by the frequency with which subjects fixate the target, fixate another name and then return to the target. Therefore, it is possible that similarities between a name and the target may affect the time of the *next* fixation. This is tested in the last column of Table II, but no effect is evident.

Fixation Time and Practice

It is possible that fixation times become shorter as subjects become more practised. However, presentation order was not a significant main effect in any of the analyses of variance summarised in Table I, but there is still the possibility that times decrease within a single search. This was tested by examining a sample of 44 searches where 10 or more fixations were made before the target was found. The mean durations of the first 10 fixations are 332, 362, 334, 320, 316, 356, 349, 330, 344 and 353 msec, respectively, and so there is no clear tendency for times to increase or decrease.

Search Paths and Other Individual Differences

There were no striking consistencies in the way people searched the display, although everyone usually started their search in the upper half. Three subjects frequently started with a circular scan of the display, two went clockwise and one counterclockwise. Six others often followed a zig-zag path working down the display, not unlike the movements used in reading, except that some subjects made fixations in scanning from right to left as well as from left to right. The remaining subject showed no consistent pattern. Long saccades were rare and the majority of fixations occurred on names which were physically close to the previous fixation. No relationship was obvious between the type of search path used and the subjects' mean search time.

Product moment correlations were calculated between subjects' mean search time, their mean number of fixations and their mean fixation time. The correlation between total time and fixation time is significantly positive ($r = .759$, $p < .01$), but that between total time and number of fixations is much smaller ($r = .267$). Number of fixations and fixation time seem to be independent ($r = .027$). Although a sample of 10 subjects is clearly inadequate for statements about individual differences, the results suggest that what distinguishes a fast from a slow searcher is not the search path followed, nor the number of fixations made, but simply the mean fixation time.

DISCUSSION

In several ways, the results confirm what one might expect: subjects place nearly all of their eye fixations on names, and in choosing the next name to fixate frequently choose the nearest name which has not been fixated before.

In other respects the results are perhaps more surprising. Neither the *between displays* nor the *within displays* analysis show any evidence for subjects selecting names to fixate which resemble the target. However, both types of analysis show that fixation times are affected by the similarity between a name and the target: there is an especially strong effect due to the initial letter of a name. In displays where initial letters varied, fixation times were, on average, 97 msec longer when a name had the same initial as the target. When all the names on a display had the same initial, the data suggest that subjects learned to ignore the first letter; thus, there is a similar but smaller difference with the second letter.

The failure to find any significant effects influencing the number of fixations does not, of course, prove that no effects exist. However, it is unlikely that any very strong effect is present, certainly not as strong as that found on colour coded displays; for example, Williams (1967) found 61% of fixations fell on the target colour compared to 20% expected by chance.

EXPERIMENT II

Experiment I failed to find any evidence for subjects selecting names to fixate on the basis of their similarity to the target. However, it is possible that this was due to insufficiently sensitive techniques. In the analysis of variance shown in Table I, the initial letter variable comes close to having a significant effect upon the number of fixations ($.05 < p < .06$) and a more sensitive method may demonstrate an effect. Experiment II employed displays where half the names had one initial letter and half another. The similarity of these initial letters was varied as well as the brightness of the background.

METHOD

The apparatus, displays and procedure were similar to Experiment I. Six different displays were used each with 20 names, six letters long. Ten had one initial and 10 another. In the three *easy* displays the initial letters were J or B, K or S, and Y or D. In the *difficult* displays they were R or P, V or W, and C or G. Each of these was viewed against a *light*, *medium* and *dark* background. *Medium* was a blue background similar to that used in Experiment I, *dark* was a darker blue, and *light* was a clear white background.

Unlike Experiment I, subjects were not asked to open and close their eyes. Instead, they started to search as soon as the search display was projected, and pressed a button when they had found the target to remove the slide from view and to stop the recording of eye movements.

Seven male and five female university students acted as subjects. Each began with two practice searches, followed by three blocks of six searches each. The effect of background was blocked and its order was determined by Williams' (1949) squares. The order of the six displays within a block was randomized for each subject.

RESULTS

A count was made of the number of fixations which fell on names with the same initial letter as the target, and the number on those with a different initial. Fixations were included from approximately 400 msec after the slide appeared to the last fixation before finding the target. As in Experiment I, a small number of search records were lost on account of head movements.

On every search there was one target, nine names with the same initial and 10 names with a different initial. The mean number of fixations on names with the same initial was 3.95 with a standard error of .19; with a different initial the mean was 4.35 with a standard error of .23. The means are in the ratio .91 : 1, which is close to the frequency of the names themselves (9:10), suggesting that subjects selected names to fixate without regard to their initial letter.

The mean number of fixations on light, medium and dark displays is 7.8, 7.9 and 9.3, respectively; but this difference is not significant in an analysis of variance. Neither the effect of easy or difficult pairs of initial letters, nor the effect of same or different initial letters are significant as main effects, but there is a significant interaction between them ($F(1, 11) = 8.9$, $p < .05$). However, this offers no support for selection as the greater proportion of names with the same initial were fixated in the *difficult* condition. No other interactions are significant.

An analysis of fixation times shows evidence of longer fixations on names with the same initial letter as the target (mean 339 msec) than on those with a different initial (mean 299 msec). This is statistically significant in an analysis of variance ($F(1, 11) = 22.6, p < .001$). There is also a statistically significant interaction between this effect and the effect of easy or difficult letter pairs ($F(1, 11) = 5.8, p < .05$). When pairs were difficult (e.g., CG) the mean for names with the same initial letter is 327 msec and for different initials, 302 msec. But with easy pairs (e.g., KS) the difference is larger. For the same initial the mean is 351 msec, and for the different initial, 296 msec. The effect of background brightness was not significant.

DISCUSSION

Experiment II confirms the finding from Experiment I that subjects do not select names to fixate which have the same initial letter as the target. The influence of initial letter on mean fixation times is replicated, although the difference is smaller than that found in Experiment I. The effect appears to be stronger when initial letters are physically different (JB, KS, YD) than when they are similar (RP, VW, CG). In the former case the difference in means is 55 msec, and in the latter, 25 msec.

In the search tasks used in Experiments I and II, peripheral vision seems to be used solely for locating a name to fixate, regardless of its similarity to the target. In other types of search tasks peripheral vision undoubtedly has a much more active role (e.g., where stimuli can be discriminated by size or colour), and in a real map we would at least expect peripheral vision to be used in discriminating names from other types of information on the map. This is investigated in Experiment III.

EXPERIMENT III

Experiment III employs displays with 10 names and 10 other symbols which could be mistaken for names. The aim is to investigate people's efficiency in discriminating between the two when placing their eye fixations.

METHOD

The apparatus and procedure was the same as for Experiment II. Five displays were used. Four of these, illustrated in Figure 3, consisted of 10 names and 10 symbols likely to be mistaken for a name. The four types of symbols are called *Os*, *Dot Screens*, *Lines*, and *Punctuation*. The fifth display showed 20 names. Os and Punctuation appeared in the same typewriter script as the names. The size of Dot Screens and Lines was chosen to try to maximize confusion with names. After two practice searches, subjects searched for four targets on each type of display. These four searches were blocked together, and the order of the five displays was determined by a Williams (1949) square. The 10 university students who acted as subjects were six males and four females.

RESULTS

The data were scored in a similar way to Experiment II. As in the previous experiments, a small number of search records were lost on account of head movements. Table III shows the mean number of fixations made on names and on other symbols. Only 17.1% of fixations were made on Lines, so subjects were reasonably efficient in distinguishing them from names. Dot Screens were harder to distinguish with 25.3% of fixations. Punctuation came next with 39.2%, and Os were hardest of all with 45.2% – almost as many fixations as on the names themselves.

The mean fixation time on names was 312 msec, on Punctuation 312 msec, on Dot Screens 299 msec, and on both Os and Lines, 289 msec; however, an analysis of variance to compare the different types of display showed no significant effects.

Only one example of each type of display was used and this may limit the generality

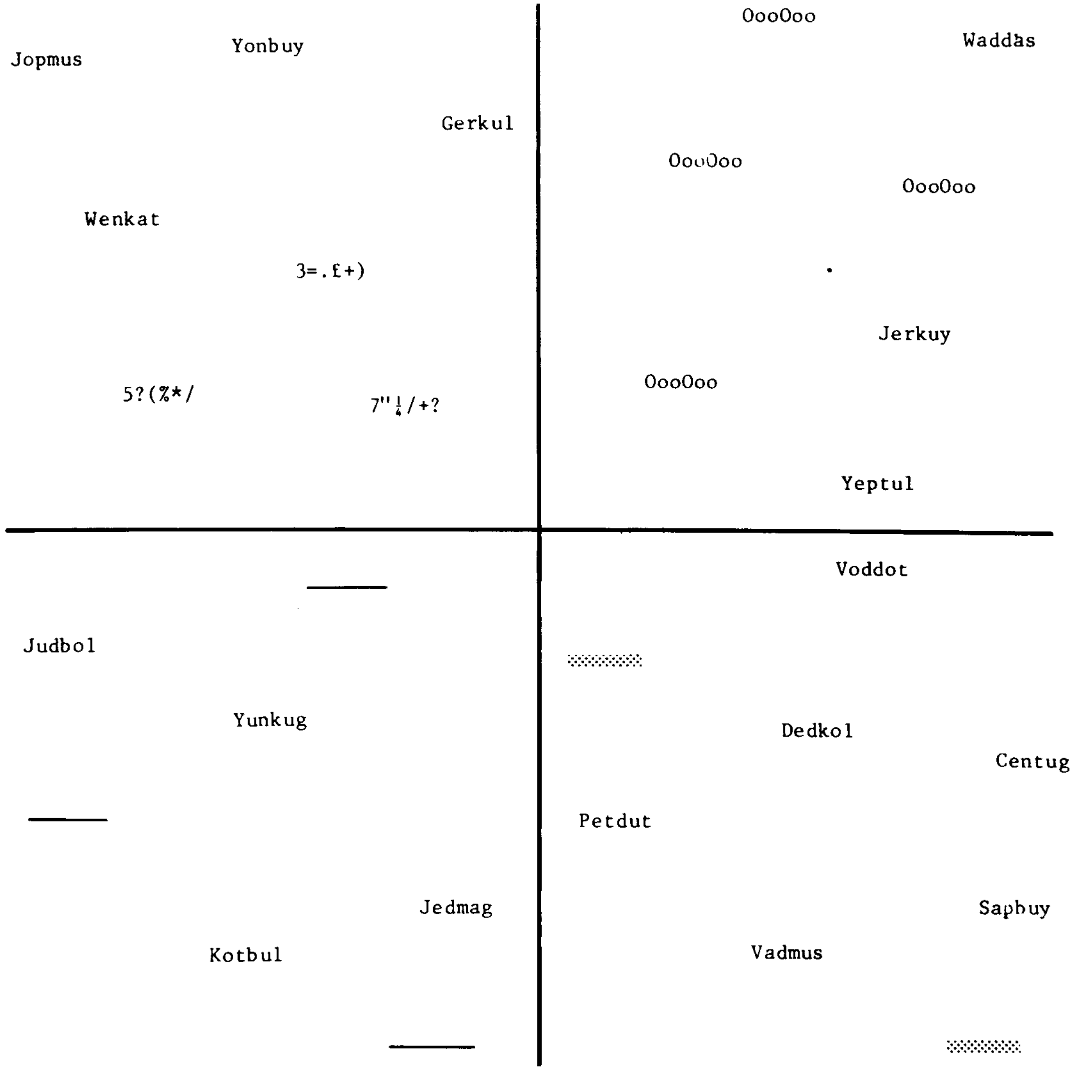

FIGURE 3 Sample areas from four of the displays used in Experiment III: Punctuation (top left), Os (top right), Lines (bottom left), and Dot Screens (bottom right).

TABLE III
Mean number of fixations on names and non-names in searching for a name in Experiment III (± 2 standard errors of the mean)

	Os	Punctuation	Dot screens	Lines	All names
Names	3.6 ± 0.5	3.4 ± 0.9	3.3 ± 0.6	3.7 ± 0.9	9.4 ± 1.2
Non-names	3.0 ± 0.6	2.2 ± 0.8	1.1 ± 0.3	0.8 ± 0.3	—
Percentage non-names	45.2	39.2	25.3	17.1	—

of these results. However, the use of different targets and the natural variation in subjects' search paths partly overcomes this limitation.

DISCUSSION

In any search task, subjects can eliminate some stimuli which are not targets using peripheral vision, but others are fixated directly. In searching for geometric shapes, Williams (1967, 1973) has shown that size and colour are easy to distinguish peripherally, but shape is harder. When searching for names, it is likely that type size and colour can also be distinguished peripherally (see Bartz, 1970; Foster & Kirkland, 1971); but these cues were not available in Experiment III. Experiments I and II show that neither the individual letters of a name nor the pattern made by these letters seem to be used in selecting names to fixate. What then, were the cues operating in Experiment III? As Punctuation Symbols were fixated less often than real names, it must be possible to accomplish some discrimination from the shape of stimuli, as distinct from their size or colour. It will be argued that although some peripheral discrimination by shape is possible, it is optional and people frequently choose not to make use of all the information which is available to them through peripheral vision.

EXPERIMENT IV

The displays employed in Experiments I, II, and III contained arrangements of names which are similar to the random arrangements found on maps. However, the displays had none of the clutter which is characteristic of real maps. Experiment IV employs displays of the kind illustrated in Figure 4 which come much closer to the appearance of real maps.

The experiment sets out to discover how typographic variables such as point size and typeface affect the search task. It is predicted that, as in Experiments I and II, the independent variables will affect fixation time but will have little or no effect on the number of fixations.

METHOD

Design

The experiment had a 2 by 2 design with independent groups. The two independent variables were type size (6 point or 8 point) and typeface (Times or Univers). Each subject searched for 20 names with alternate searches on two different displays.

Materials

Two areas measuring 88 mm square were chosen from some experimental maps used in a previous study by Phillips et al. (1977). One area had 21 names and the other had 22. On these maps the names and a grid were printed in black while other map symbols appeared in orange and magenta (see Figure 4 for an example and for further details see Phillips et al., 1977). There were four versions of each area (6 point Univers, 6 point Times, 8 point Univers and 8 point Times) with the same names appearing in the same positions on each version. Both typefaces were of medium weight and all names were set in lower case with an initial capital. Times is a typeface with serifs and Univers is sans serif.

The displays were photographed and back projected so that each subtended a visual angle of 12° square. The screen was 56 cm from the subjects' eyes and the image was slightly magnified in comparison with the original maps. Visual angles in this projected display were equal to those in the original maps viewed at a distance of about 40 cm. A 6-point capital *H* subtended a visual angle of about .21° and an 8-point *H* subtened about .28°.

Target names, which were typewritten, were presented singly on slides which preceded each map display.

Subjects

Twelve male and 16 female university students acted as paid volunteers. Seven were randomly assigned to each of the four conditions. A preliminary test ascertained that all subjects would be able to read the names without difficulty.

Procedure

The search tasks and eye movement recording were conducted in an identical manner to Ex-

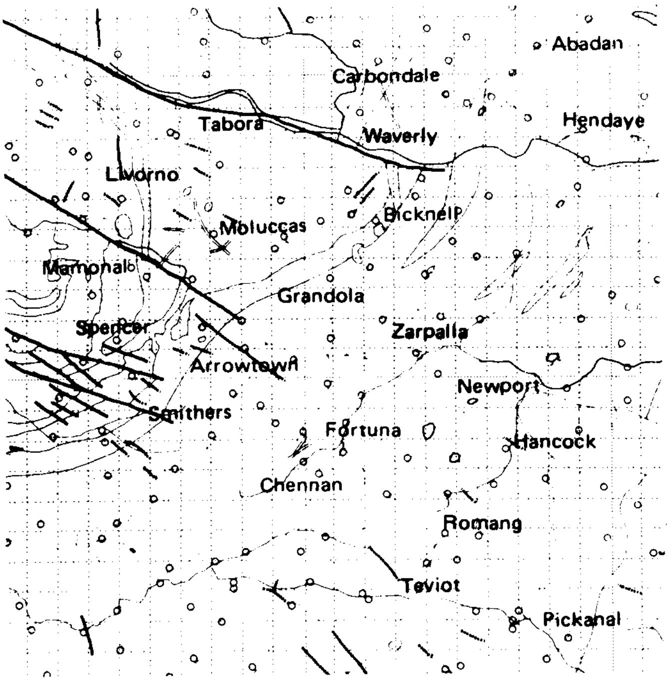

FIGURE 4 A monochrome reproduction of one of the search displays used in Experiment IV. The names and the grid were printed in black, the point and line symbols were magenta, and the layer tints, which are not visible here, were orange. In this display the names are set in 8 point Univers.

periments II and III. Each subject searched for 20 names; 10 searches were on the first area alternating with 10 searches on the second area.

RESULTS

Approximately 7% of search records were lost on account of head movements. The first 10 and second 10 searches were analysed separately to detect any effects of practice. The means are shown in Table IV. Analyses of variance showed a significant effect of point size on fixation time in both the first and second 10 searches ($F(1, 24) = 4.8$ and 7.2 respectively, both $p < .05$), but there was no significant effect on the number of fixations. There were also no significant effects due to the typeface, nor to the interaction of typeface with point size.

The mean fixation times from Experiment IV are consistent with the results of the study by Phillips et al. (1977) which measured search speed without recording eye movements. In both experiments, point size shows a significant difference but typeface does not. In order to compare the data from the two experiments more closely,

TABLE IV
Mean fixation times and mean number of fixations for the typographical variables studied in Experiment IV

	Mean Fixation Time[a]		Mean Number of Fixations	
	First 10	Second 10	First 10	Second 10
6 point	303*	298*	8.2	8.5
8 point	285	276	8.3	7.6
Times	298	283	7.8	7.2
Univers	290	290	8.7	8.9

[a]Fixation times which are in msec include the time of the following saccade and so are overestimated by approximately 30 msec.
*$p < .05$.

it is helpful to express the effect of the typographical variables as percentage differences of the grand mean, and to place 95% confidence limits on these differences. In the experiment by Phillips et al. search was 7.3 ± 5.4% faster for 8-point type than for 6-point, and 3.9 ± 5.4% faster for Times than for Univers. The comparable figures for Experiment IV are 6.9 ± 5.3% for point size and −0.1 ± 5.3% for typeface.

DISCUSSION

Experiments I and II demonstrated that the resemblance of names to the target name affects fixation time but has little or no effect upon the number of fixations. Data from Experiment IV suggest that typographic variables act in a similar way. An increase in the point size of the names reduced the mean fixation time; but there was no significant effect on the number of fixations, although it is possible that a more sensitive experiment would demonstrate an effect.

The results of Experiment IV are consistent with those of Phillips et al. (1977) and are of similar accuracy as indicated by the confidence limits. Whereas Phillips et al. tested 256 subjects, Experiment IV required only 28. It is clear that eye movement recording may provide a useful method of evaluating map typography without the need to employ large numbers of subjects. Since only fixation time needs to be measured, relatively simple eye movement techniques such as electro-oculography (see Young & Sheena, 1975) could be used.

Experiment IV employs displays where all the names are of the same point size; but on many maps, names appear in different sizes which vary with the size or importance of the place being named. Although there is no direct evidence, it is likely from an experiment by Bartz (1970) that map readers tend to fixate names of the size in which they expect the target to appear. So, for example, someone looking for a small village will tend to fixate names in the smallest point size on the map. This use of size as a typographic code clearly raises different questions from the problems of typographic legibility discussed here, and it is an area where eye movement recording also promises to be useful.

GENERAL DISCUSSION

Here are the main findings of the experiments:

(1) Under the conditions studied here, there is little or no tendency to fixate names which resemble the target. For example, a name beginning with the same letter as the target name seems no more likely to be fixated than a name with a different initial.

(2) Fixation times are affected by the similarity of the fixated name to the target name, and by the legibility of the fixated name. Thus, fixation times are longer on names with the same initial letter as the target, and on displays with names set in a small point size.

(3) When displays contain a mixture of names and other objects which are of a similar size and colour to names, the non-names are generally fixated less often than the names, unless the resemblance is very close.

When searching for symbols, independent variables usually affect the number of fixations but not the mean fixation time (e.g., Engel, 1977), but here the reverse was found. Gordon and Amos (1974) report an experiment on checking pairs of letter strings where string length affected both number of fixations and fixation time. It is possible that fixation time effects are more likely to occur with alphanumeric stimuli. In Experiment I the similarity of the initial letter of a name to that of the target produced the largest effect on fixation time. This suggests that initial letters are important for eliminating nontargets. This is consistent with Noyes' (1980) finding from a similar search task that visual clutter is most disruptive when close to the initial letter of a name.

None of the experiments demonstrated a tendency to selectively fixate names which resembled the target name, although it is possible that more sensitive experiments would show an effect. It is quite clear that the strong tendency for selective fixation found with colour coded displays (e.g., Williams, 1967; Luria & Strauss, 1975) does not occur for names. If there is no selective fixation, the average number of fixations should equal half the number of nontargets. The fact that the average was slightly less on all experiments could be taken to suggest a slight tendency for selective fixation, but an alternative explanation is possible. In all experiments, no eye fixations made during the first 400 msec of viewing were analysed. Although movements during this period often seemed uncoordinated and fixations frequently fell between names, it is possible that some names were eliminated during this initial period.

The placing of eye fixations must depend on information extracted from peripheral vision during previous fixations. But it would appear that not all the information which is potentially available in peripheral vision is actually used. The names in Experiment I varied in length from four to nine letters but there was no tendency to fixate names of a similar length to the target.

In order to discover whether length could be extracted from peripheral vision, pairs of names from Experiment I were briefly exposed (200 msec) in a tachistoscope on opposite sides of a fixation point with a separation of 10° of visual angle between their centres. Subjects were asked which of the pair was longer, and although the difference was only a single letter space, accuracy was better than 95%. These are more stringent conditions than in Experiment I, and it must be concluded that information that is available in peripheral vision is not always used while searching.

One possibility is that it would have taken too long to process information about word length. That is, information from peripheral vision is used if it can be processed fast enough not to make fixation times unduly long.

However, this may not be the whole story. It is clear from Table III that we can achieve quite subtle discriminations between names and other objects in the visual field. For example, the difference between names and punctuation symbols would seem to be a finer difference than that between short and long names. Perhaps the way information from peripheral vision controls the locus of fixation may depend on a search strategy. The choice of an appropriate strategy might be affected by the time necessary to process information from peripheral vision, but other factors could be important too, such as well established habits and the way information is subsequently processed when it is brought into central vision.

Williams (1967) drew attention to two ways of interpreting the control of eye fixations in a search task – either as similar to a choice response task, or as a perceptual structuring of the visual field. According to the choice model, there are always several objects in the visual field to which the eyes can move next. While the eyes are fixating one object, the brain chooses between several other objects on the basis of which have previously been fixated, how far away they are, and how closely they resemble the target. Kahneman (1973, p. 60) was clearly advocating a similar process when he suggested that 'the locus of fixation is determined by an assessment of the probabilities that relevant information will be acquired'. One problem with the choice model is the shortness of fixation times. Although fixations last typically for 300 msec, some of this time must be taken up by the motor control of the following eye saccade and so it is doubtful whether sufficient time is available for this kind of decision.

Williams' alternative is that we can structure our percept of the visual field to emphasize relevant stimuli. If we are seeking a red object, it may be possible to perceive a configuration of red objects in the field which stand out from other colours. These red objects are fixated in turn in a simple sequence, and there is no problem of choosing between red objects and other objects in the field. This model seems more parsimonious than the choice model and more consistent with the speed with which search operates. However, it does assume the existence of a mechanism for very rapid processing of large areas of the visual field according to physical dimensions such as size or colour. It may be relevant that size and colour can also be used to cue the partial recall of information from immediate visual memory (Von Wright, 1968), where there is a similar demand to process large areas of the visual field rapidly.

It is possible that search could be controlled by either process. Perhaps when simple physical cues such as size or colour are available in peripheral vision, these can be used to structure perception of the whole field; but with more complicated cues, such as those based on shape, each saccade is the result of a choice between several objects in the visual field. However, it is clear from the experiments reported here that the use of information from peripheral vision is optional, and there may be a wide range of strategies available to the searcher depending on what information in the periphery is used and how it is processed.

APPENDIX A

MEAN NUMBER OF FIXATIONS

In a search task there is one target and $k - 1$ distractors. If there is an equal probability of fixating either the target or any of the distractors, what is the mean number of distractors fixated before the target is found? This is calculated, firstly, for the case where a distractor may be fixated more than once (search with replacement) and, secondly, for the case where a distractor is not returned to once it has been fixated (search without replacement).

Let the number of fixations before fixating the target $= r$.

With Replacement

The probability that the target is fixated first is $1/k$. The probability that the target is found on the second fixation equals the probability that it is *not* found on the first fixation $(1 - 1/k)$ multiplied by the probability that it is found on the second fixation $(1/k)$. By extending this reasoning we can express the probability of finding the target after any number of fixations.

Prob. $(r = 0) = 1/k$.

Prob. $(r = 1) = (1 - 1/k)(1/k)$.

Prob. $(r = 2) = (1 - 1/k)^2 (1/k)$.

And, in general, Prob. $(r) = (1 - 1/k)^r(1/k)$.

If we multiply each probability by r, and add them up we get the mean value of r. As a search with replacement can, in theory, go on indefinitely we must sum from zero to infinity.

$$\text{Mean } r = \sum_{r=0}^{\infty} r(1 - 1/k)^r(1/k).$$

This can be simplified using the Binomial Theorem result

$$1/(1-x)^2 = 1 + 2x + 3x^2 + 4x^3 \dots = \sum_{n=0}^{\infty} nx^{n-1}.$$

First it is necessary to rewrite the expression for mean r, and then to substitute $(1 - 1/k)$ for x in the Binomial Theorem result.

$$\text{Mean } r = (1/k)(1 - 1/k) \sum_{r=0}^{\infty} r(1 - 1/k)^{r-1}$$
$$= (1/k)(1 - 1/k)(k^2) = k - 1.$$

Without Replacement

Similar reasoning can be used to find mean r when replacement does not occur. In this case r cannot be greater than $(k - 1)$ because the kth fixation must fall on the target as all nontargets have been eliminated.

Prob. $(r = 0) = 1/k$.

Prob. $(r = 1) = (1 - 1/k)[1/(k - 1)] = 1/k$.

Prob. $(r = 2) = (1 - 1/k)[1 - 1/(k - 1)][1/(k - 2)] = 1/k$.

And in general Prob. $(r) = 1/k$.

$$\text{Mean } r = (1/k) \sum_{r=0}^{k-1} r = (k - 1)/2.$$

CUMULATIVE FREQUENCY

What is the probability that s or more fixations are made before the target is fixated?

With Replacement

$$\text{Prob. } (r \geq s) = \sum_{r=s}^{\infty} (1 - 1/k)^r(1/k)$$

$$= (1- 1/k)^s(1/k) \sum_{r=0}^{\infty} (1 - 1/k)^r.$$

Using the Binomial Theorem result

$$1/(1 - x) = 1 + x + x^2 + x^3 .... = \sum_{n=0}^{\infty} x^n,$$

and substituting $(1 - 1/k)$ for x, it can be shown that

Prob. $(r \geqslant s) = (1 - 1/k)^s$.

Therefore, s is linearly related to log Prob. $(r \geqslant s)$.

Without Replacement

$$\text{Prob. } (r \geqslant s) = \sum_{r=s}^{k-1} 1/k = 1 - (s/k).$$

In this case, s is linearly related to Prob. $(r \geqslant s)$.

REFERENCES

BARTZ, B.S. Experimental use of the search task in an analysis of type legibility in cartography. *Cartographic Journal*, 1970, **7**, 103–112

ENGEL, F.L. Visual conspicuity, visual search and fixation tendencies of the eye. *Vision Research*, 1977, **17**, 95–108

FOSTER, J.J., & KIRKLAND, W. Experimental studies of map typography. *Bulletin of the Society of University Cartographers*, 1971, **6**, 40–45

GORDON, I.E., & AMOS, M. Checking groups of letters. *Journal of Applied Psychology*, 1974, **59**, 354–357

GOULD, J.D., & DILL, A.B. Eye-movement parameters and pattern discrimination. *Perception and Psychophysics*, 1969, **6**, 311–320

JONCKHEERE, A.R. A distribution-free *k* sample test against ordered alternatives. *Biometrika*, 1954, **41**, 133

LURIA, S.M., & STRAUSS, M.S. Eye movements during search for coded and uncoded targets. *Perception and Psychophysics*, 1975, **17**, 303–308

KAHNEMAN, D. *Attention and effort.* New Jersey: Prentice-Hall, 1973

MACKWORTH, N.H., & MACKWORTH, J.F. Eye fixations recorded on changing visual scenes by the television eye-marker. *Journal of the Optical Society of America*, 1958, **48**, 439–445

NOYES, L. The positioning of type on maps: The effect of surrounding material on word recognition time. *Human Factors*, 1980, **22**, 353–360

PHILLIPS, R.J., & NOYES, L. Searching for names in two city street maps. *Applied Ergonomics*, 1977, **8**, 73–77

PHILLIPS, R.J., NOYES, L., & AUDLEY, R.J. The legibility of type on maps. *Ergonomics*, 1977, **20**, 671–682

RAYNER, K. The perceptual span and peripheral cues in reading. *Cognitive Psychology*, 1975, **7**, 65–81

RAYNER, K. Eye movements in reading and information processing. *Psychological Bulletin*, 1978, **85**, 618–660

TAYLOR, E.A. The spans: Perception, apprehension and recognition as related to reading and speed reading. *American Journal of Opthalmology*, 1957, **44**, 501–507

VON WRIGHT, J.M. Selection in visual immediate memory. *Quarterly Journal of Experimental Psychology*, 1968, **20**, 62–68

WILLIAMS, E.J. Experimental designs balanced for the estimation of residual effects of treatments. *Australian Journal of Scientific Research*, 1949, **2**, 149–168

WILLIAMS, L.G. The effects of target specification on objects fixated during visual search. *Acta Psychologica*, 1967, **27**, 355–360

WILLIAMS, L.G. Studies of extrafoveal discrimination and detection. In W. BENSON and M.A. WHITCOMB (Eds.), *Visual search.* Washington, D. C.: National Academy of Sciences, 1973

YARBUS, A.L. *Eye movements and vision.* (B. Haigh, trans.). New York: Plenum, 1967

YOUNG, L.R., & SHEENA, D. Survey of eye movement recording methods. *Behavior Research Methods and Instrumentation*, 1975, **7**, 397–429

(Date accepted 13 February 1981)