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REPORT

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THE EFFECT OF INSTANTANEOUS FIELD OF VIEW ON SEARCH RATE FOR SINGLE TARGETS OVER A WIDE FIELD

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The effect of the instantaneous field-of-view in searching a complex, wide-angle field viewed at fixed resolution was examined by simulation. The results show a decelerated improvement with instantaneous field-of-view over the range 6.9° to 55° for a 55° search field. This improvement was attributable to increased slewing rate of the search window.

CONTENTS

THE EFFECT OF INSTANTANEOUS FIELD OF VIEW ON SEARCH RATE FOR SINGLE TARGETS OVER A WIDE FIELD

1. INTRODUCTION

In many visual search tasks an observer must mechanically slew a surveillance instrument in order to cover a given search field. The design of such instruments raises the problem of balancing the requirements for high resolution with width of the field of view so as to optimise the search rate. Actual instruments covering different fields of view already represent a compromise, with resolution decreasing as the field of view increases for instruments of comparable cost. Hence to assess the effect of the instantaneous field of view, independent of the quality of the image viewed by the observer, it is unwise to use existing systems.

Here we describe a simple simulation procedure using a tripod-mounted cylinder with an eyehole at the observer's end and a field aperture at the search-field end. This was used to study the effect of different instantaneous fields of view in search for human targets in projected black-and-white slides. The field aperture was varied to give a range of instantaneous fields of view of constant vertical subtense but with the horizontal subtense ranging from 6.9° to 55° (full field).

Each subject carried out six search sessions over a period of five weeks. The first two sessions provided familiarisation and training of the subjects. The third and fourth sessions were used to gain data on the difficulty of each slide, as well as to give further practice in the task. Sessions five and six provided the experimental data.

2. SUBJECTS

Subjects were volunteer males, with ages ranging from 23 to 55 years, and having no previous experience of such a search task. Fifteen subjects carried out all six sessions, and the analysis is confined entirely to these subjects.

3. MATERIALS

Black and white slides were taken in which a man (the target) was located at either 100 m or 200 m range across an open space in front of a tree line. The target wore light coloured clothes (except for a dark tie, which was resolvable in the projected slides and used by some observers to confirm target recognition). In some locations the target was obscured below knee or mid-thigh height, but never above this body level. Both target background, and target location in the viewing field for a given background, were varied, so that no item was replicated. For each target/background combination five field locations of the target were used, these being approximately equally spaced across the total field, and obtained by rotation of the recording camera. At each range twenty six different target/background combinations were used, giving 130 test slides at each range.

The slides were arranged into two sets for sessions one to four, such that each set had either two or three slides from each target/background combination for the two ranges, and also had the same number of slides in each of the five field sectors. One set was then used as search materials for seven of the subjects over sessions one to four, while the other set was used for the remaining eight subjects.

From the analysis of search times in sessions three and four the 200-m range slides were then reduced to two sets of 20 slides. For each of the five field sectors in which the single target could be located four slides were selected, subject to the following constraints:-

a. two are to be from the set familiar to one half of the subjects, the other two from the other set;

b. for each pair in (a) above, one is to be of low difficulty for that location, the other to be moderately hard;

c. where a number of items equally well satisfy conditions (a) and (b) above, for a given field location, that item which shows the smallest difference in mean detection time between sessions three and four is chosen.

Applying these constraints in the selection of search items provides a set with no item bias, based on familiarity, which could interact with field location or item difficulty in either sessions five or six.

4. APPARATUS

The subject sat on a swivel chair whose height he adjusted to allow comfortable scanning of the search field. Figure 1 shows the search instrument, consisting of a 150-mm diameter tube with a circular 10-mm aperture at the eye end, and a rectangular aperture at the search end. The tube was surrounded by a baffle which prevented the observer from directly viewing the scene. Attached to the baffle were two handles - one on either side of the tube - to allow the subject to slew the instrument across the search field. The observer used a thumb switch, close to the right-hand handle, to indicate that a target had been found.

The images to be viewed were projected from Pradovit C2000 slide projectors over the head of the observer onto a flat screen located 1.6 m from the observer's eye. All observers viewed the search scenes from the same distance. One of the projectors presented the search scenes, the other a location grid. A shutter driven from a stepping-motor ensured that only one of the images was seen at a time. This mechanism was electrically connected to the switch on the search instrument, to a set of switches available to the experimenter, and to a parallel input port of a North Star Advantage microcomputer.

Prior to a scene presentation the location grid was shown. The experimenter then triggered the shutter movement which obscured the location grid and simultaneously displayed the search scene. The observer searched until he found the single target, at which stage he triggered the shutter to the initial state by pressing the thumb switch. To verify target location the subject specified the target's horizontal grid coordinate. An accuracy of 3^{o} was required for acceptance as correct. The experimenter recorded each response as correct or incorrect, and verbally informed the observer of the result. The signals used to trigger shutter movements - ON or OFF - were also used for timing purposes via the microcomputer. A maximum search time of 40 s was allowed, termination of search being electronically controlled. These timing methods ensured that the only significant error in determining search time was that due to the thumb-switch response.

5. PROCEDURE

The data of central interest come from sessions 5 and 6. Prior to these each subject had searched for over 500 targets. Both sessions followed the same design, differing only in the set of 20 slides presented, and the set of aperture sizes used. The following is a description of the procedure for session 5.

The set of slides was divided into two subsets of ten each. Four different apertures for the search were used, these being 6.9^{o}, 10.2^{o}, 17.1^{o}, and 55^{o}. Treatment orders both within and between subjects were completely counterbalanced to eliminate any effect due to a linear rate of learning. Table 1 below shows how this was achieved:-

Subject	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4
	Slide Set							
a	4	2	3	1	2	4	1	3
b	2	4	1	3	4	2	3	1
c	1	3	2	4	3	1	4	2
d	3	1	4	2	1	3	2	4

TABLE 1. Presentation order of search conditions for a group of four subjects. Slide sets A_i, B_i, i = 1,2,3,4 consist of the same slides with different orders. $A_i \cup B_i$ is the full set of 20 slides. The numbers 1,2,3,4 refer to the different apertures used.

Thus, subjects were presented with a set of 10 slides for a particular aperture, each presentation being as described in the Apparatus section. There was then a break of approximately 90s while the aperture was changed, followed by presentation of another block of 10 slides. Prior to the actual data collection period of a session subjects had approximately 15 trials, at speed, to refamiliarise themselves with the task and ensure comfort with the equipment.

In all cases subjects were asked to commence their search from the extreme left hand edge of the field, and - with all but the 55^{o} aperture case in session 6 - to have this edge in the centre of the viewing window. In the exceptional case subjects were asked to locate the centre of the full search field in the centre of the viewing field, which resulted in there being no need to slew the instrument to search the field. Some movement did, however, occur, suggesting that subjects require that the search field lie completely within the viewing field, by a few degrees.

6. RESULTS

Search times from the fifteen subjects were collapsed to give a mean search time for each slide. Table 2 presents these for all items in both sessions. Fewer than 1% of items were incorrectly located in these sessions, and in no case was there no response within the allotted time of search. Hence the times used are the time to response irrespective of whether that response was correct or not. Figures 2 to 9 show the mean time of search as a function of target position from the left of the search field for the different window sizes used.

SESSION	SLIDE No.	Position	WINDOW SIZE 6.9	10.2	17.1	20.0	35.0	55.0
5	1	1.3	1.80	1.49	1.81			1.47
	2	1.3	2.07	1.31	1.63			1.32
	3	1.3	1.87	1.97	1.73			1.84
	4	10.1	2.40	1.92	2.83			2.10
	5	16.1	2.78	2.58	4.23			1.92
	* 6	16.8	9.64	9.52	9.04			7.99
	* 7	17.4	4.77	3.44	5.41			6.30
	8	22.1	3.42	3.04	2.87			2.77
	9	23.5	3.32	3.53	3.49			2.59
	10	24.1	3.34	2.83	2.94			2.12
	11	26.8	3.28	4.93	6.24			2.66
	12	27.5	3.72	3.35	3.22			2.55
	13	35.5	4.88	4.42	4.18			5.66
	14	35.5	4.43	4.21	3.74			3.93
	15	36.2	4.71	4.04	3.90			3.02
	16	40.2	4.78	4.38	3.73			3.93
	17	44.9	4.97	4.33	4.36			3.39
	18	45.6	5.17	5.02	4.06			3.37
	19	49.0	5.68	4.78	4.87			3.79
	20	53.6	5.34	4.89	6.30			4.06
6	1	1.3		1.38		1.40	2.16	2.57
	2	4.0		1.24		1.76	1.23	1.42
	3	5.4		1.52		1.28	1.39	1.53
	* 4	10.7		3.69		5.31	4.67	5.41
	5	16.1		2.58		2.01	1.59	1.65
	6	17.4		2.29		1.98	3.84	1.62
	7	18.8		2.37		2.12	2.21	1.88
	8	18.8		2.50		2.13	2.21	2.24
	9	24.1		2.83		2.39	2.24	2.54
	10	26.8		2.85		2.57	2.22	2.31
	11	28.2		3.21		2.53	2.53	2.45
	12	32.2		4.34		3.53	3.02	2.95
	13	34.9		4.02		3.06	3.06	2.91
	14	40.2		4.54		4.10	3.58	3.28
	15	40.2		4.44		3.95	3.84	3.44
	16	40.2		3.85		3.31	3.07	2.44
	17	44.3		4.61		3.69	3.38	3.00
	18	49.6		4.83		4.14	3.74	3.36
	19	52.3		4.91		4.06	4.25	3.57
	20	53.6		5.11		3.99	3.94	4.19

TABLE 2. Mean search times for all items in sessions 5 and 6. Items in the table are ordered according to field location.

In both sessions there were one or two items in each window size condition which were markedly more difficult than most items. Excluding these items - indicated in Table 2 by asterisks - a linear least squares fit was made to the individual window data. Table 3 presents the resulting parameters for the various conditions, with the excluded items noted.

SESSION	WINDOW SIZE (degrees)	GRADIENT (sec/deg)	INTERCEPT (seconds)	R^2	NEGLECTED
5	6.9	0.0748	1.72	0.96	6,7
	10.2	0.0698	1.52	0.94	
	17.1	0.0581	1.78	0.85	
	55.0	0.0490	1.45	0.87	
6	10.2	0.0769	1.12	0.96	4
	20.0	0.0581	1.17	0.92	4
	35.0	0.0525	1.20	0.88	4
	55.0	0.0409	1.42	0.73	4

TABLE 3. Linear least-squares fitting to mean search times of $t = a\theta + b$ for different window sizes, where t = mean search time, θ = field location and R is the correlation coefficient. Items modified in each case had one of the fifteen observers taking more than 20 seconds to find the target. Such an observation was excluded in forming the mean.

The variation of the gradient with window size indicates that the slewing rate of the instrument is dependent on window size. This interaction between field location and window size makes it inappropriate to use analysis of covariance to extract the effect of field location on search times in order to find an effect due to window size which is not due to field location.

The gradient in Table 3 is the time of search per degree. Figure 10 shows a log(gradient) versus log(window size) plot, and a linear least-squares fitted line to this data. This fitted line has the equation

$$\frac{d\theta}{dt} = 8 \times w^{0.26}$$

where w is the window size in degrees. A similar analysis, using median, rather than the mean search time, gave results that were not significantly different (see Appendix).

7. DISCUSSION

The results given here come from a search situation in which the targets are of a known form and size, and also known to lie approximately on a fixed horizontal line - i.e. the search is one dimensional. Furthermore the target backgrounds were from a set of 26, all of which subjects had seen a number of times prior to sessions 5 and 6. The situation, then, is somewhat akin to perimeter or security surveillance, where the observer is familiar with the background against which a target may appear.

The main result is that the increase in search rate with instantaneous field of view, w, is monotonic, obeying a power law dependence on w, with exponent of 0.26. Noro [1] found a boundary effect in search tasks, this being a tendency to miss targets near the edge of the search field. Such an effect is suggested by the relatively raised times for the points on the extreme of the search field in session 6 using window 4, this being the case in which the window centre was initially coincident with the centre of the search field, so the extreme points were near the boundaries of the search window. However this effect would have to reduce the effective field by a factor of four in the horizontal dimension to explain the size of the exponent obtained here. Monk [2] found evidence of an approximately 50% longer time to acquisition of targets in the outer half of the search field, an effect which is only slightly affected by target conspicuity. This is obviously too small an effect to explain the result obtained here. Mocharnuk [3] has shown that the duration of fixations decreased when a speeded search task induced larger eye movements. If larger apertures were to induce larger eye movements, then reductions in search time with increasing aperture would be expected due to larger inter-fixational eye movements, reduced duration of fixations, and reduced edge effects.

8. CONCLUSION

Search rate was found to depend on window size, increasing with window size monotonically according to a power relation with exponent 0.26. This result was obtained for a search field whose resolution was independent of the size of the window of the search instrument. The result cannot be adequately explained in terms of known edge effects, and supports arguments by earlier authors for an increased rate of data acquisition from each fixation, assuming no data acquisition during eye movements.

9. ACKNOWLEDGEMENTS

Design of the electronics and the timing system was by Dr P.J. Beckwith. Mr A. Leverett designed and built the shutter mechanism and the simulation search instrument. Mr J. Ward served as a target, as well as assisting with the photography. The Royal Military College of Science, Shrivenham, England, provided analysis facilities for the first author while on attachment to the College. We wish to thank all the foregoing, and also the fifteen volunteers from the Physics Division, Materials Research Laboratories.

10. REFERENCES

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2. Monk, T.H. (1981). "The interaction between the edge effect and target conspicuity in visual search", Human Factors, 23(5), 615-625.

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APPENDIX

By way of comparison, we have carried out the same analysis as described above except that median rather than mean values were used. The corresponding values to Table 3 are given in Table A1 and the relation between rate of slewing and window size is

$$\frac{d\theta}{dt} = 7.4 \times W^{0.25}$$

SESSION	WINDOW SIZE (degrees)	GRADIENT (deg/sec)	INTERCEPT (seconds)	R^2	NEGLECTED
5	6.9	0.0874	1.04	0.98	6,7
	10.2	0.0749	1.13	0.96	
	17.1	0.0658	1.15	0.95	
	55.0	0.0525	1.11	0.94	
6	10.2	0.0721	0.97	0.97	4
	20.0	0.0635	0.87	0.97	4
	35.0	0.0562	0.95	0.90	4
	55.0	0.0467	1.01	0.94	4

TABLE A.1 As for Table 3, except that median values rather than means have been used.

The great similarity of the result from the two methods is surprising - perhaps, even, fortuitous. However one must presume that dependence of search rate on a power of between 0.2 and 0.3 of the window size is established as a robust result.

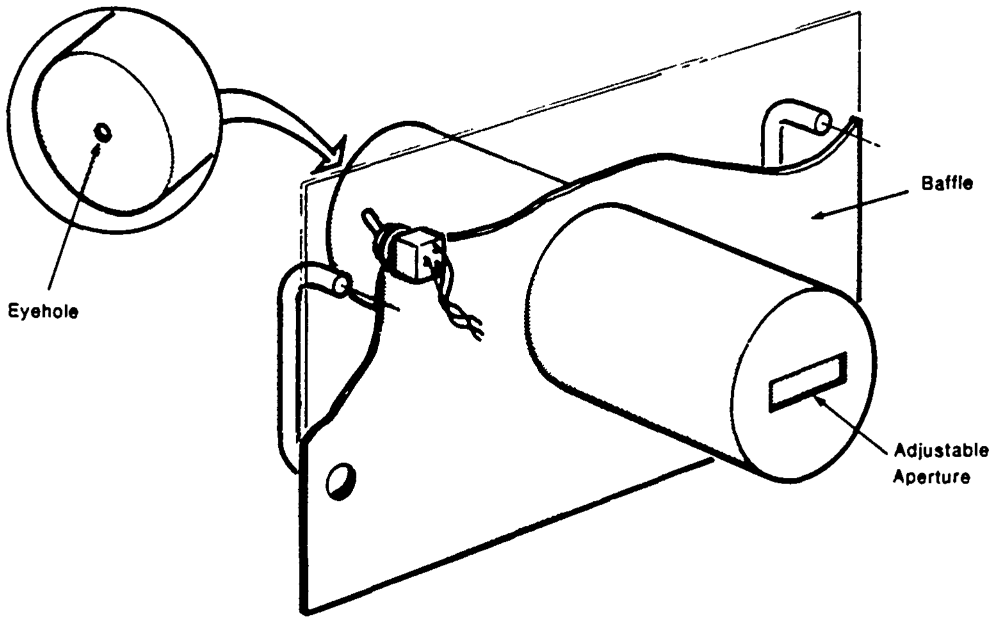

FIGURE 1 The search instrument used, showing the rectangular aperture whose horizontal angular subtense was varied by replacing the end-plate. This device was mounted on a tripod via a ball and socket joint. The large baffle prevented the observer from seeing the scene without looking through the instrument.

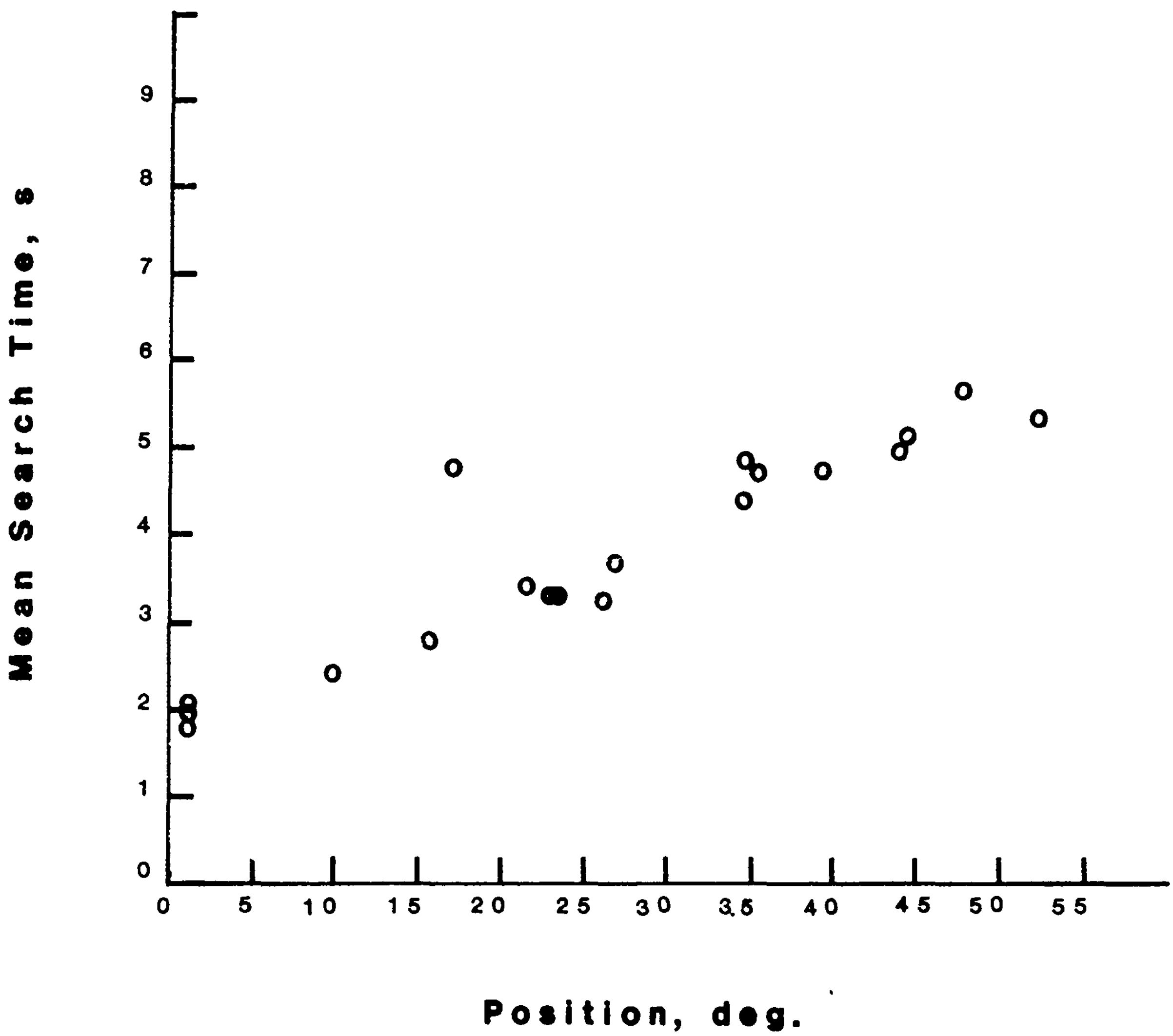

FIGURE 2 Mean search times for each target in session 5 with a search aperture of 6.9^{o}.

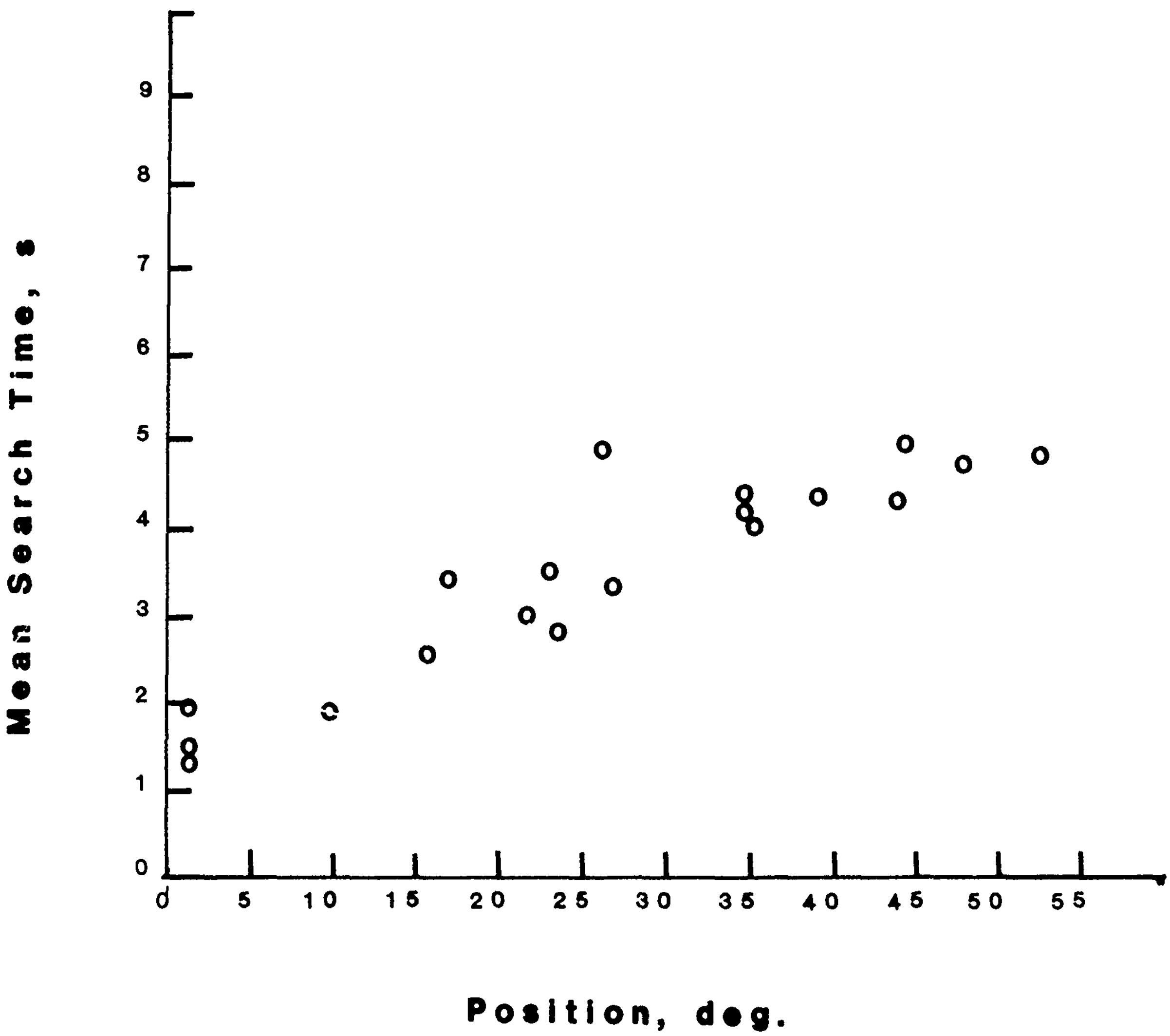

FIGURE 3 Mean search times for each target in session 5 with a search aperture of 10.2°.

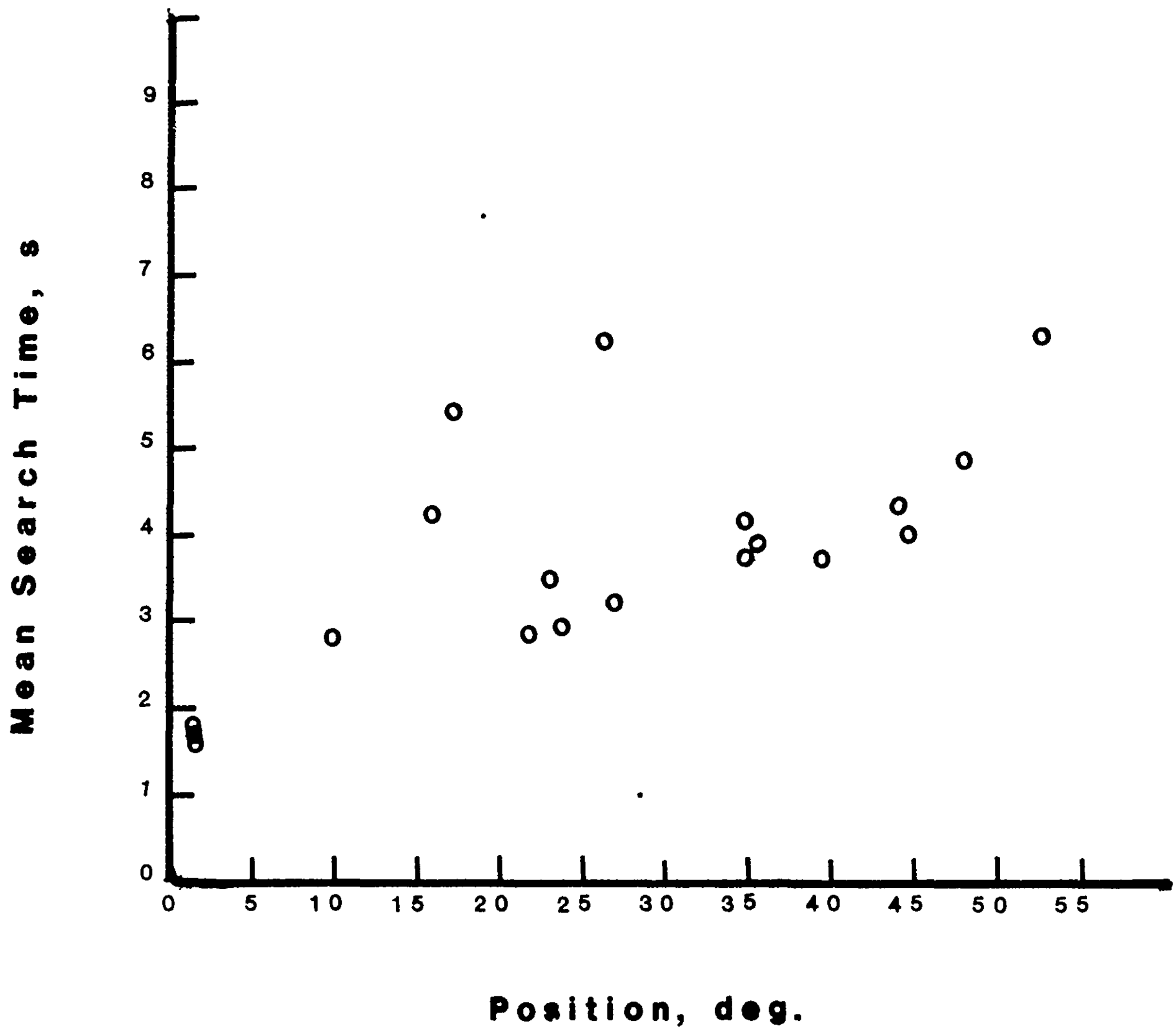

FIGURE 4 Mean search times for each target in session 5 with a search aperture of 17.1^{o}.

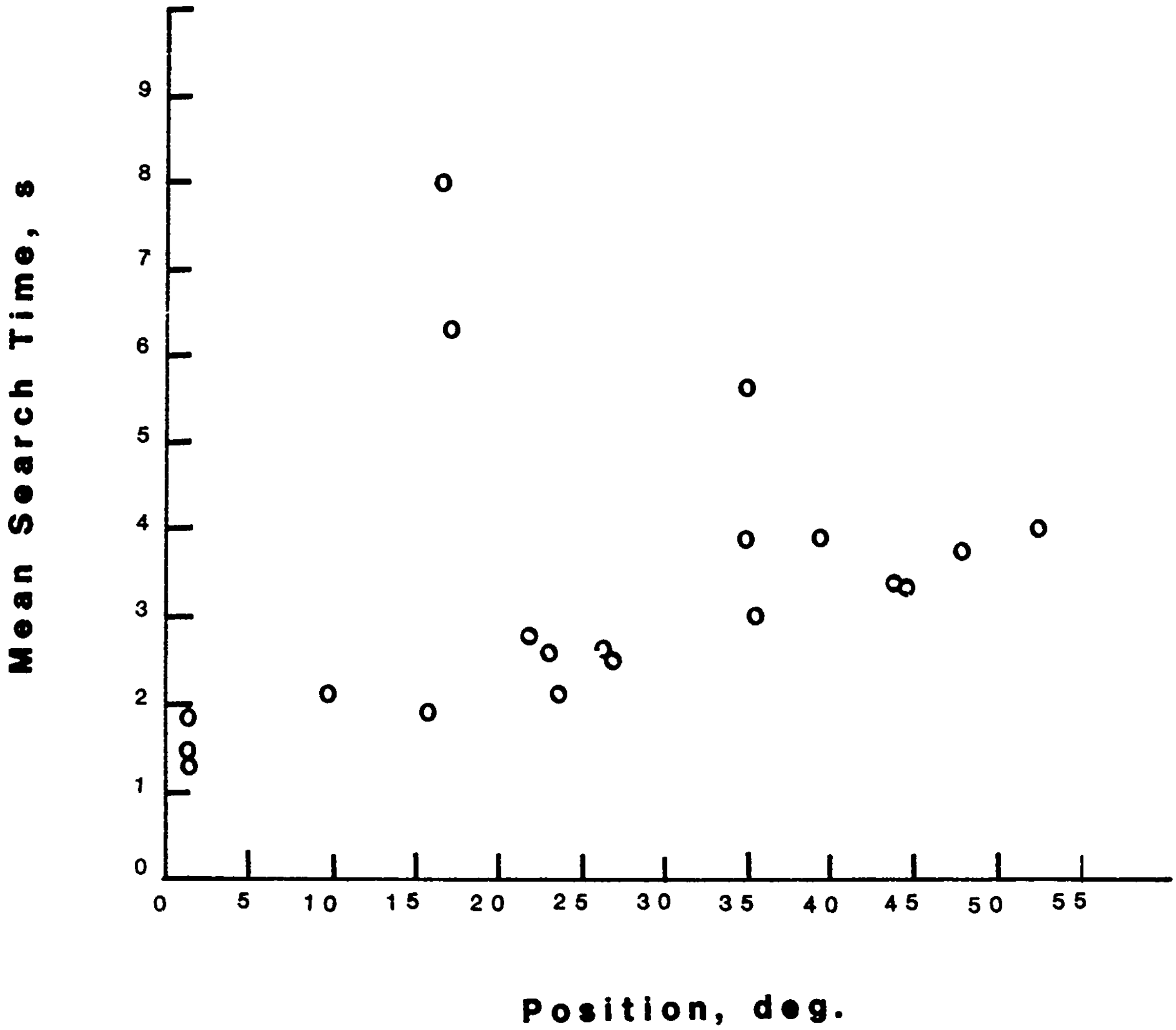

FIGURE 5 Mean search times for each target in session 5 with a search aperture of 55.0°.

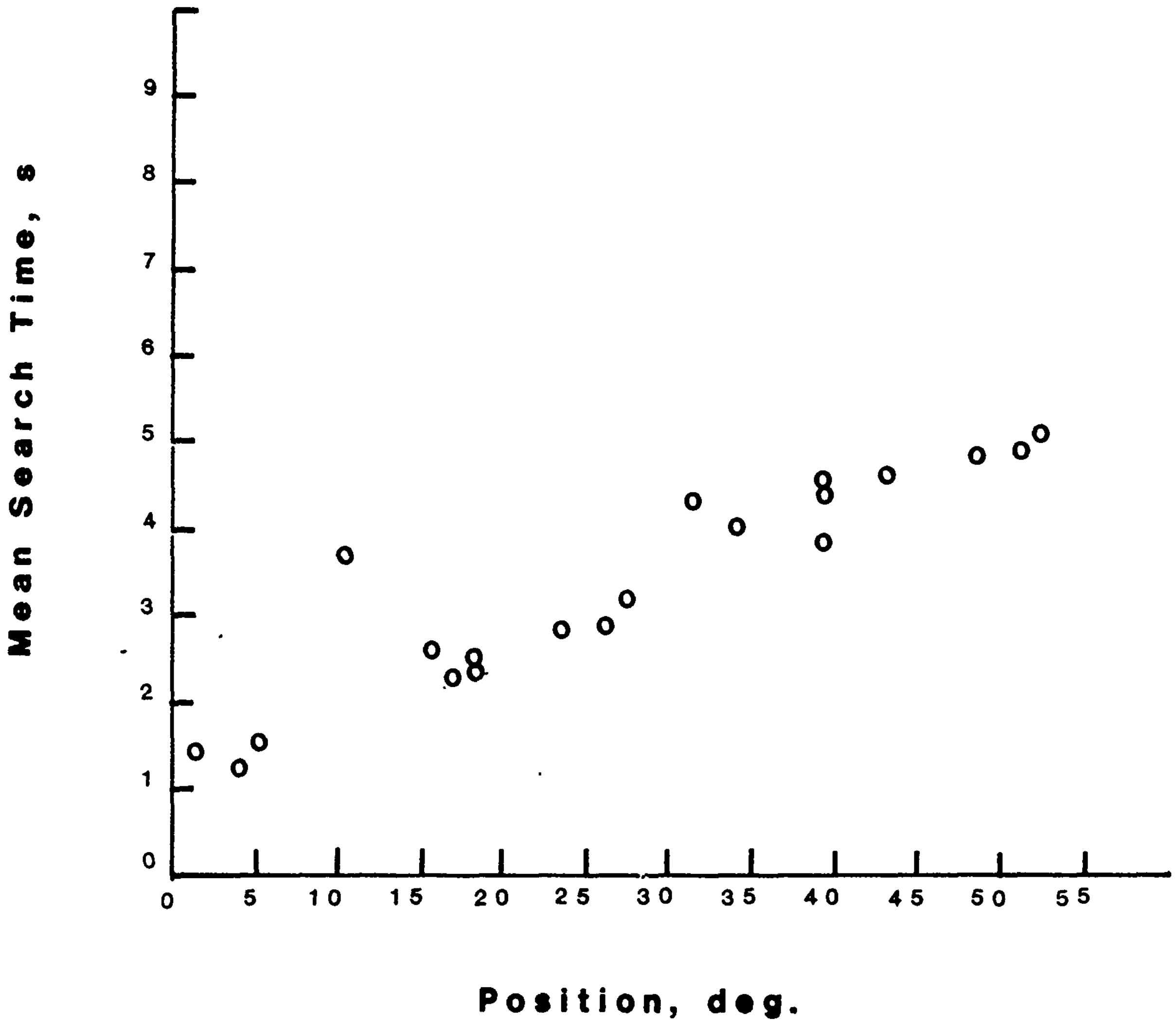

FIGURE 6 Mean search times for each target in session 6 with a search aperture of 10.2°.

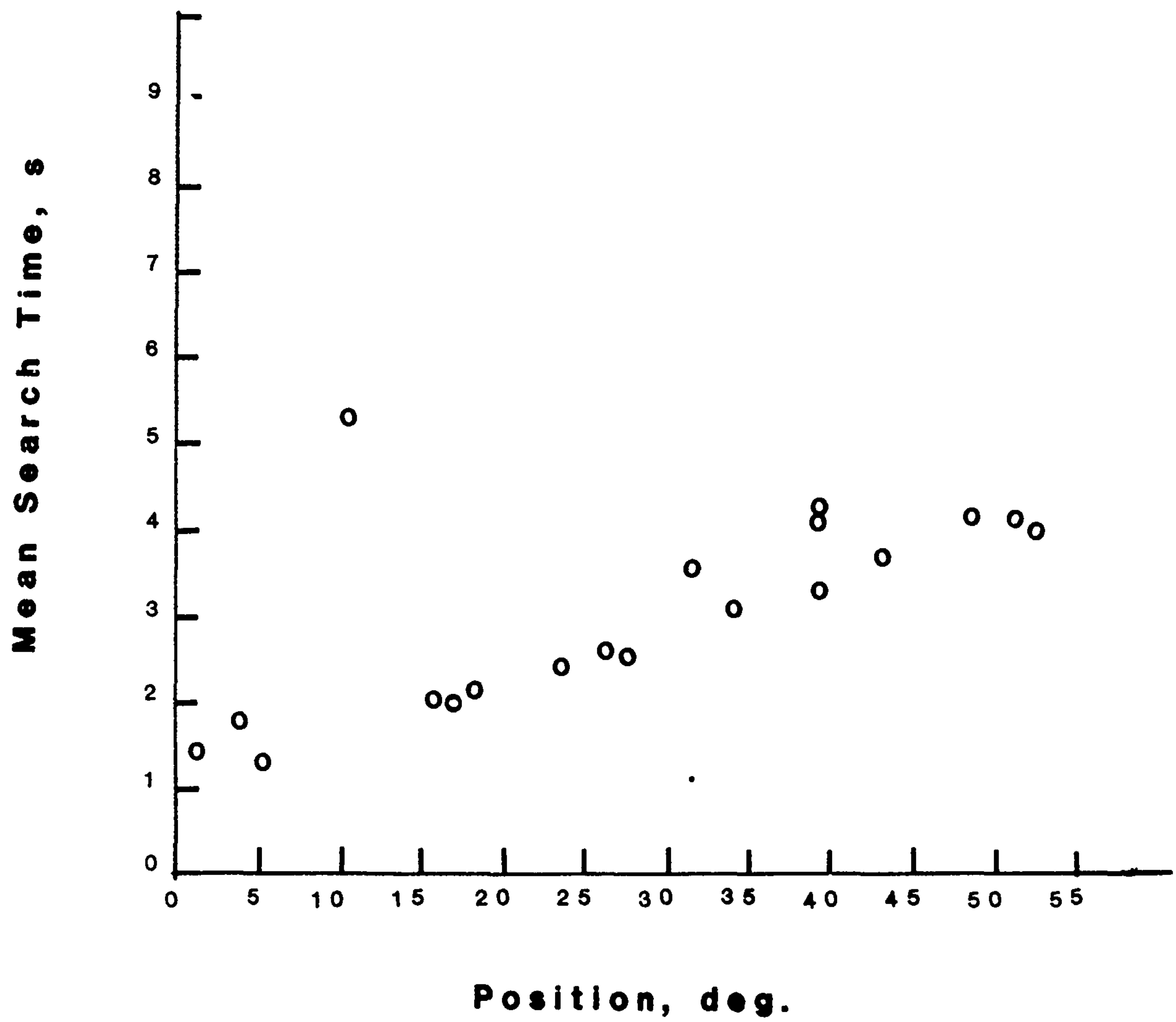

FIGURE 7 Mean search times for each target in session 6 with a search aperture of 20.0°.

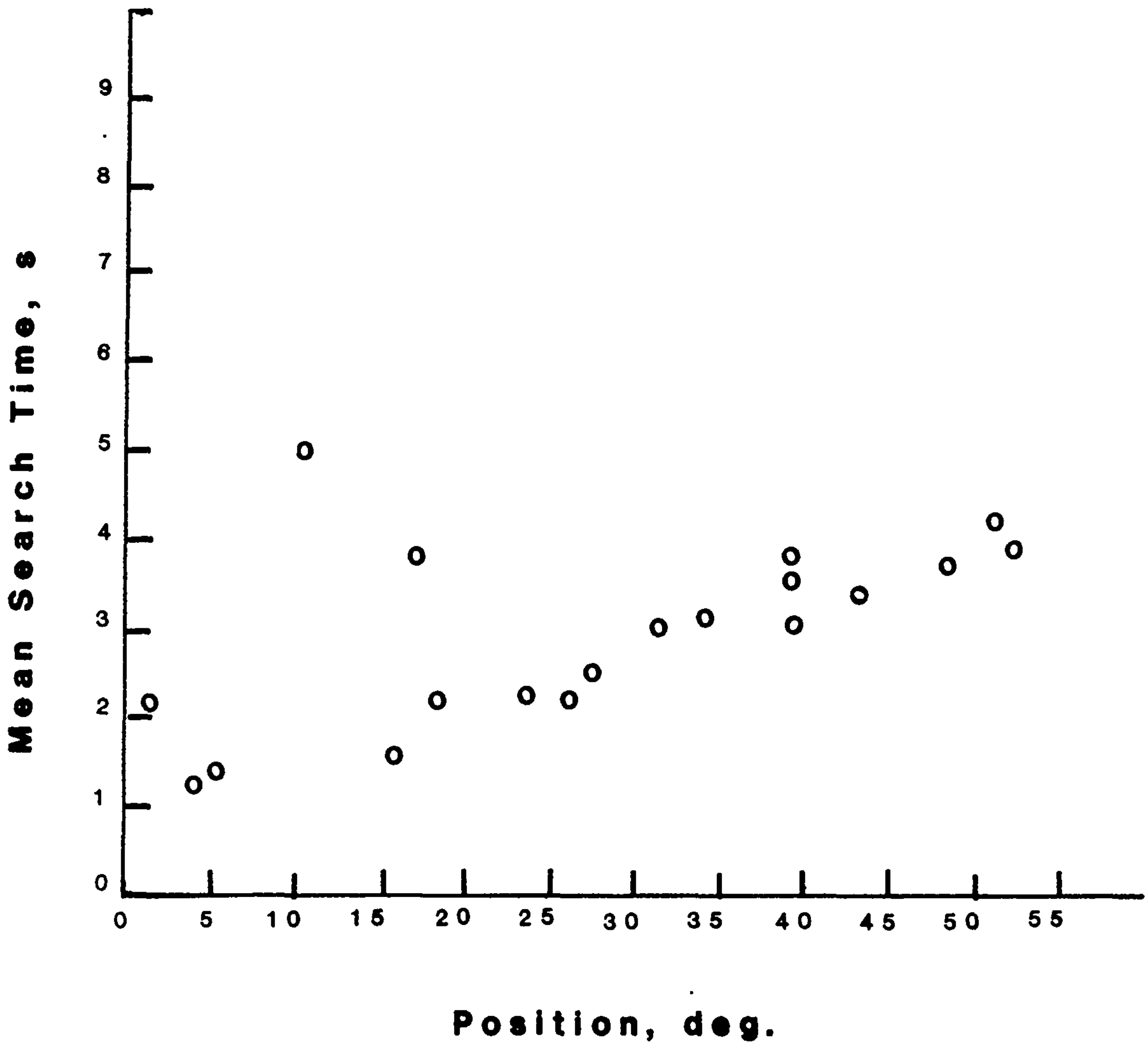

FIGURE 8 Mean search times for each target in session 6 with a search aperture of 35.0°.

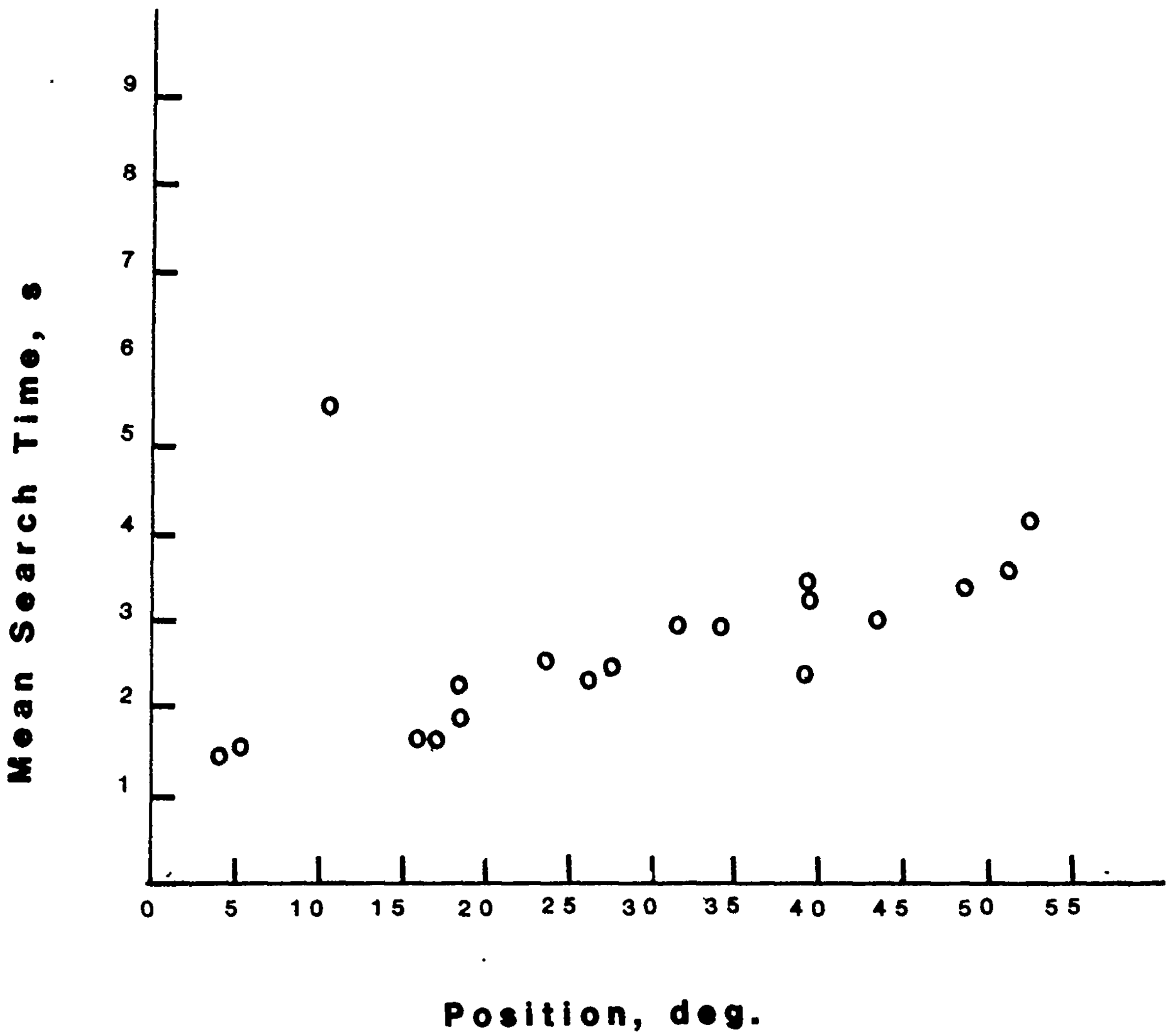

FIGURE 9 Mean search times for each target in session 9 with a search aperture of 55.0°.

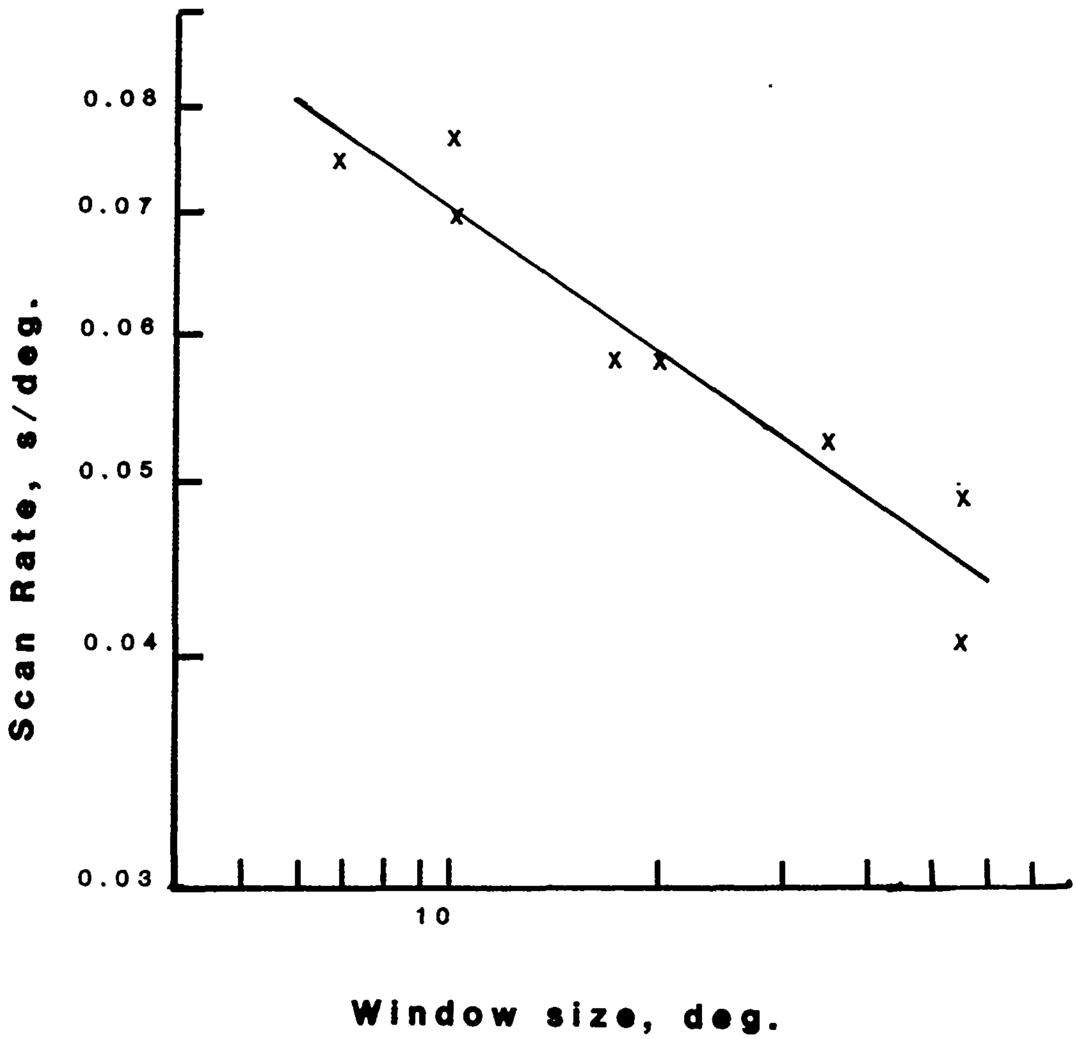

FIGURE 10 Logarithmic plots of search speed against search aperture for sessions 5 and 6.