Visibility Laboratory
University of California
Scripps Institution of Oceanography
San Diego, California 92152

VISUAL SEARCH IN COMPLEX FIELDS
PROGRESS REPORT

by

J. C. Bailey

June 1966
SIO Ref. 66-13

TABLE OF CONTENTS

VISUAL SEARCH IN COMPLEX FIELDS

PROGRESS REPORT

by

J. C. Bailey

1.0 INTRODUCTION

The science of Visibility deals with the prediction of human performance in the accomplishment of specified visual tasks.[1] One important aspect of this science is the case in which the observer does not have á priori knowledge as to the location of the desired object and must, therefore, perform search in order to achieve detection. Many individuals, including staff members of the Visibility Laboratory, have contributed to the evolution of techniques by which predictions of visual search performance can be calculated.[2] Successful results have been achieved in predicting visual search performance for the case of objects located on uniform backgrounds.[3] Many practical problems involve search of extremely cluttered natural or man-made backgrounds. The state of the art of Visibility Engineering is not sufficiently advanced to permit adequate visual search performance prediction for the complex background case.

An experimental study has been initiated in an attempt to advance the state of the art with respect to prediction of visual search performance in a cluttered background. Two fundamental premises underlie the experimental study:

(1) The first premise is that any successful analytic handling of this problem must involve realistic assumptions as to the search procedures, i.e., the location and

duration of fixations which an observer actually employs in the process of searching a complex field. Since adequate information on this subject does not exist, it is necessary to gather experimental evidence by the recording of visual fixations during search of complex fields.

(2) The second premise is that any successful analytic handling of this problem must involve the ability to define the clutter adequately in terms of the specific search task.

Based upon present thinking, the hypothesis is advanced that clutter should be defined in terms of the extent to which the background resembles the object for which the search is being conducted. Mathematically this hypothesis suggests that the complex background should be studied in terms of its correlation to the object. Therefore, a later step in the research will be to transform complex scenes into two-dimensional correlation maps which define, for each point in object space, the correlation between the immediate surround of that point and the object for which the search is conducted. If this hypothesis should prove to be true, it should be possible, at least in part, to explain the pattern of fixations used by the observer in terms of such correlation maps.

The study is still in its preliminary stages, and the present report describes the work to date. This has consisted of (1) acquiring a large number of aerial photographs of representative backgrounds varying greatly in complexity, (2) the artificial insertion of an "object" into each of these scenes, and (3) photographic recording of eye movements made by observers in the process of searching these pictures. Quantitative data reduction to date has been limited to calculation of the probability distribution of the time duration of the fixations made by the observer. It is interesting that the mean duration of the fixations has been found to be about 1/3 second, consonant with the results of White.[4] The report contains photographs of some of the scenes with the observer fixation points superimposed.

2.0 GENERATION OF BACKGROUNDS AND OBJECTS

2.1 Aerial Photography

Aerial photographs were taken of a wide variety of cluttered natural backgrounds. These black-and-white photographs were taken with a Nikon 35 mm camera at aircraft altitudes of from 750 to 1,000 feet. The majority of the photographs were taken with a 135 mm focal length lens, and exposure times were short enough to prevent any appreciable loss of resolution due to image motion. Each of the background scenes was transformed into a 35 mm slide for projection on to a white screen.

2.2 Insertion of Artificial Objects

The choice of an object and its positioning within the scene were dictated by a number of considerations. The purpose of the investigation is to study backgrounds, not objects. It is necessary, however, to have a well defined, easily identified object, in order to be able to accomplish the long-term goal of mapping the background as a correlation function. In many practical cases of visual search in a complex field such as that performed by a trained photo-interpreter, the observer initiates the search task on the basis of subtle and complicated á priori information as to probable object locations. Automobiles, for example, are not frequently found in tree tops. The probable location of a person in the scene is highly dependent on whether the person wants to be seen, wants not to be seen, or doesn't care whether or not he is seen. There are marked differences in individual abilities with respect to the efficient use of á priori information, and it would also be expected that training and experience would produce marked improvements in performance.

Since the observers available for this experiment are not trained in the sense of á priori information utilization, it was felt that the present experiment should be designed to minimize the importance of á priori information. A second consideration is that in the latter phases of the investigation, correlation computations will be made, and an appropriate choice for the object can minimize the labor of these computations.

For the reasons indicated above, the object was chosen to be a simple cross, as shown in Fig. 1. This object has the advantage of being a geometric pattern having no intended real-world interpretability in terms of the background scene, and also has the advantage of minimizing the labor of correlation computation. The location of the objects within the scenes was determined by selecting six digits from a random number table[3], using the first three to locate a horizontal distance (to three significant figures) in the projected scene and the second three to locate a vertical position.

A second projector was used to superimpose the cross on the projected background scene at the randomly selected position. The flux in the cross projector was varied to obtain a contrast level such that the cross was just distinguishable when viewed directly. Under these conditions the object becomes undetectable rapidly as the point of fixation is moved away from the cross. The settings were made subjectively but documented by measurement with a telephotometer masked to cover an area slightly larger than the cross as shown in Fig. 1. Readings were taken with the cross projector at the selected level and with it turned off.

After the operation of positioning the cross and adjusting its flux level, the composite scene was rephotographed and 35 mm slides made of the composite scene. The projection of these slides constituted the scene viewed by the observers. When projected, the background scene subtended a horizontal angle of approximately 17° from the observer position and approximately 11.5° in the vertical direction. The cross subtended 42 minutes of arc in the long dimension from the observer position and approximately 2.2 minutes of arc in the smallest dimension. At this angular subtense, the object is easily resolved as a cross. The Carrousel projector which was used produced a screen luminance of approximately 25 foot lamberts with no film inserted. For the slides used, the range of scene luminances was on the order of 1 to 10 foot lamberts.

3.0 EYE MOVEMENT RECORDING

Eye movements have been recorded by many investigators utilizing photography of the corneal reflection from a small light source. A relatively crude set-up was made for applying this technique. The geometry is shown in Fig. 2. The observer's head was immobilized by means of a biteboard and a headrest.

A test chart was made consisting of a uniform field with the numerals 1 through 20 evenly spaced as shown in Fig. 3. The observer was instructed to fixate on each of the numerals in sequence, spending two seconds on each numeral. Corneal reflection movies were made as the observer performed the task. After appropriate magnification, the movie strip was projected back onto the test chart, and the outline of the corneal reflection was traced. These tracings are shown in Fig. 3. A slight modification in the positioning of the light source and movie camera produced the results shown in Fig. 4. These two figures indicate the level of precision associated with the location of fixation.

4.0 EXPERIMENTAL RESULTS

A selection of scenes with superimposed observer search procedure are shown in Figs. 5 through 10. The instructions to the observer were:

> "This is a study of locating targets in cluttered backgrounds. Scenes of meadows, trees, buildings, or other natural backgrounds will be projected on the screen. In each of these scenes is a small white cross (+) which measures 38 x 38 x 2 mm; the cross is located on the scene by use of random number tables, so there is no order in its location. The target's contrast with the area immediately surrounding it is very low and, generally speaking, will require a direct foveal detection; you must look at the target to find it."

A brief study of the statistics of the time of fixations was made. The results which are shown in Fig. 11 combined data from all scenes and hence do not reflect differences in fixation which may exist as a function of the complexity of the scene.

5.0 CONCLUSIONS

The experimental work to date is considered to be exploratory in nature. Few, if any, concrete conclusions can be drawn for this reason. From the preliminary studies much information of value has been derived relative to various practical problems associated with the experimental set-up and to the precision of eye movement achievable with the rather crude techniques utilized.

Based on the preliminary data it would appear that the observer makes a greater number of fixations in areas of high clutter than in areas of low clutter, a result which is not surprising. One interesting observation is that quite frequently the fixation just prior to detection was of short duration and in some cases more remote from the just previous fixation. Since experimental evidence in the literature indicates that detection thresholds are markedly increased during the time in which the eye is in motion between fixations, this observation may imply something about a time delay associated with brain processing of the message from the eye. No conclusions are justified based on the data to date, but this would seem to be an interesting item to be included in future investigations.

REFERENCES

1. S. Q. Duntley et al, "Visibility," Applied Optics 3, 549 (1964).

2. ________________, Proceedings of Symposium of Armed Forces-NRC Committee on Vision (Publ. 712, Natl. Acad. Sci.-Natl. Res. Council, Washington, D.C.) (1963)

3. J. I. Gordon, "Predictions of Sighting Range Based upon Measurements of Target and Environmental Properties," SIO Ref. 63-23 (1963).

4. C. T. White, "Ocular Behavior in Visual Search," Applied Optics 3, 569 (1964).

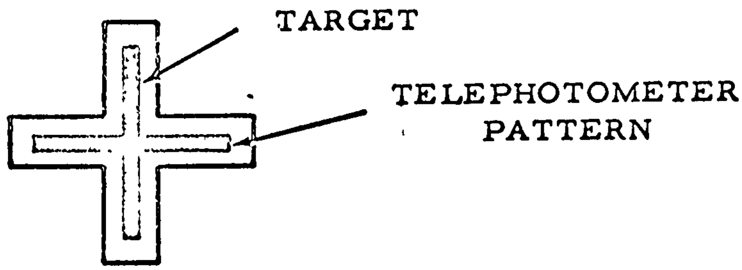


Figure 1. The inner cross is a superimposed target shown dark in this figure, but actually consisting of added light flux. The outer border shows the bounds of the telephotometer used to document the flux associated with the target.

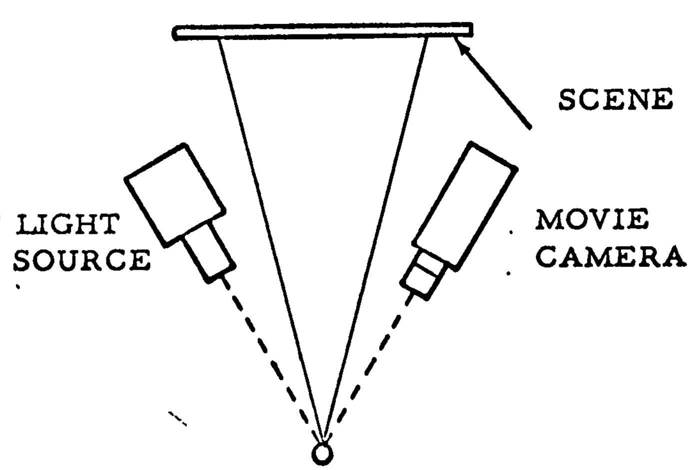


Figure 2. A rough sketch of the geometry of the set-up used for recording eye movements by corneal reflection.

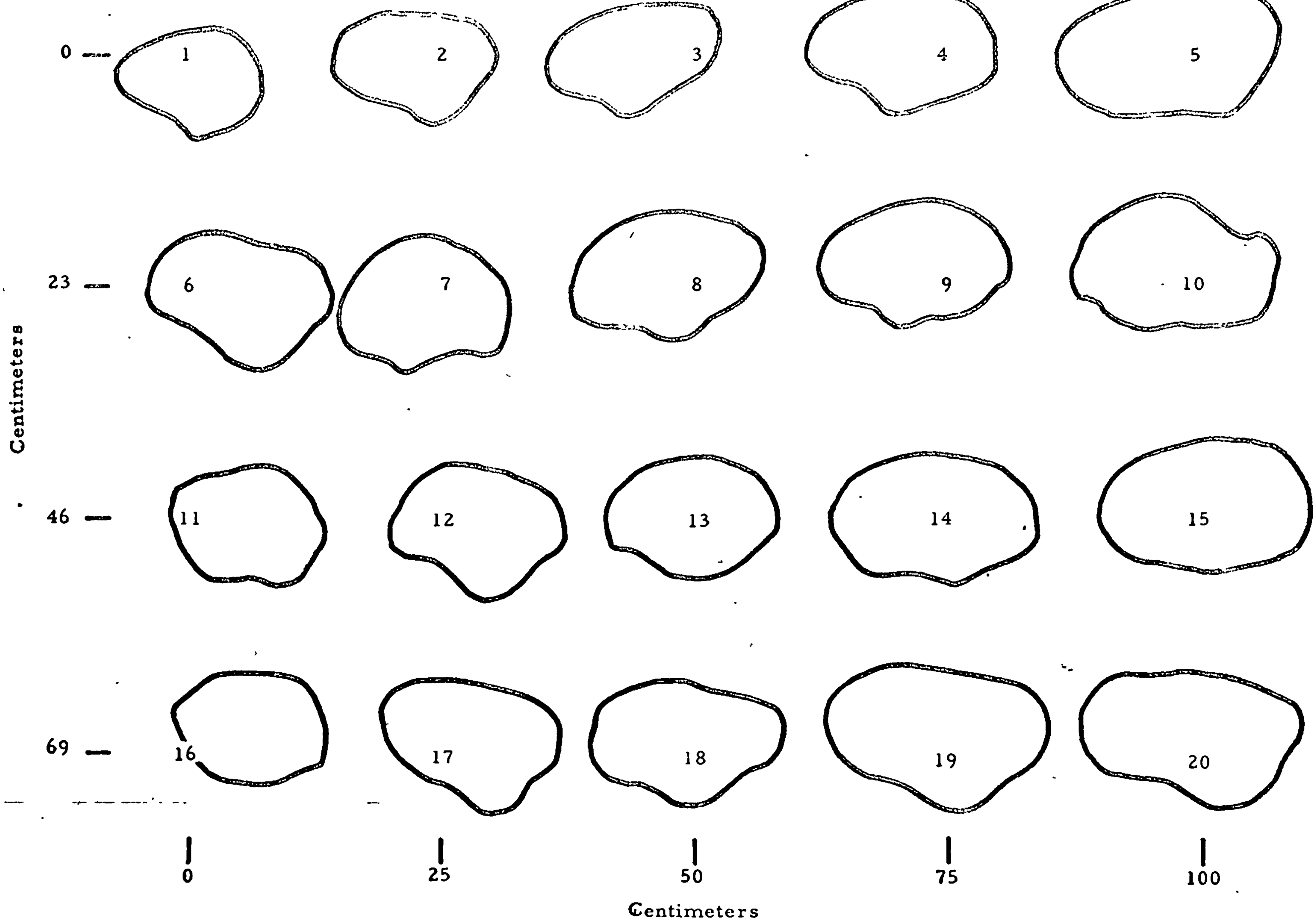


Figure 3. Tracings of the projected movie recordings of the corneal spot onto the test chart which the observer viewed during this calibration run.

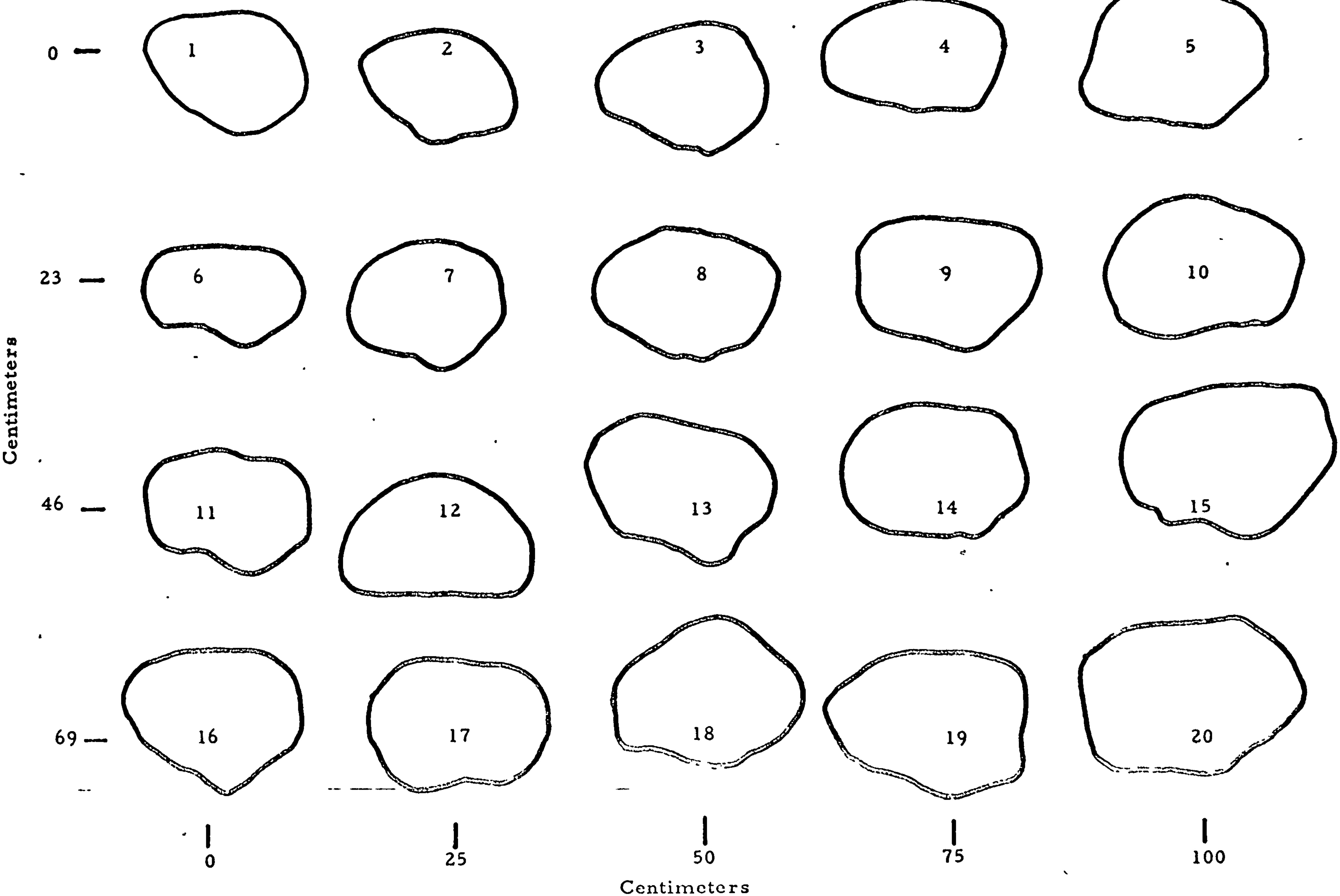


Figure 4. Tracings of the projected movie recordings of the corneal spot onto the test chart which the observer viewed during this calibration run.

FIGURES 5 THROUGH 10

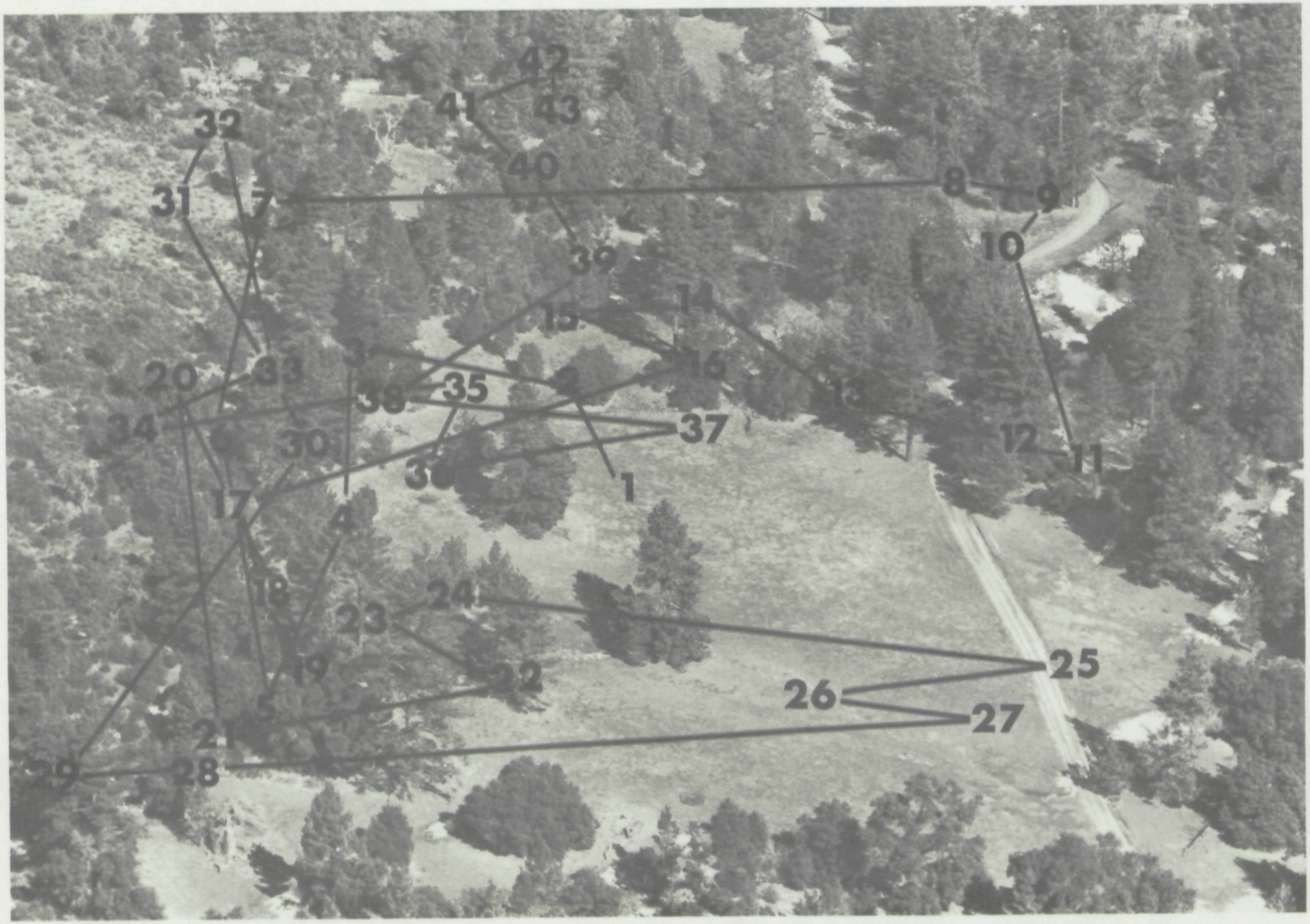
The following five photographs with superimposed overlays illustrate observer search procedures with successive fixations.

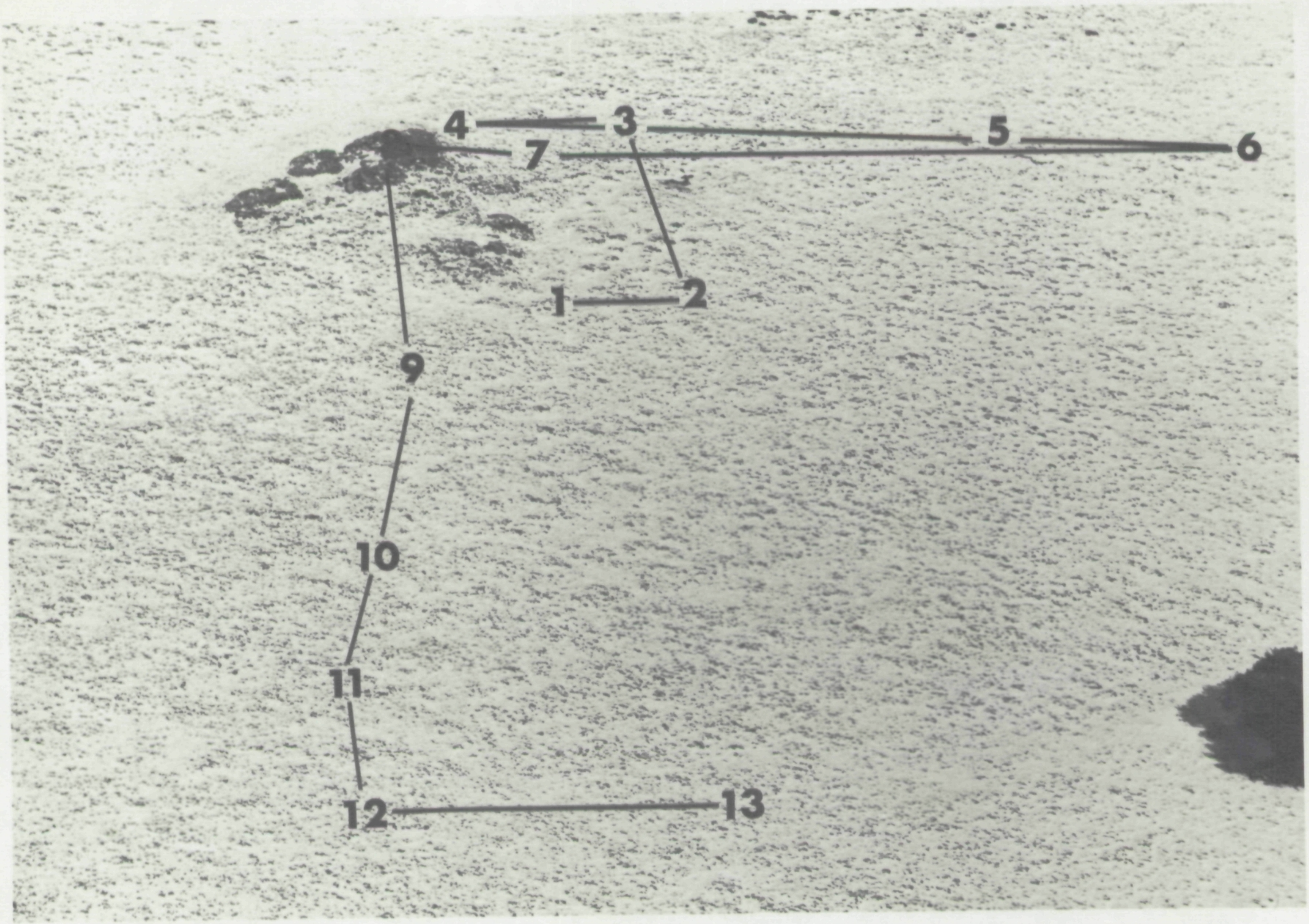
In these photographs the last fixation number falls over the target which, because of its low contrast to background, cannot be seen.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

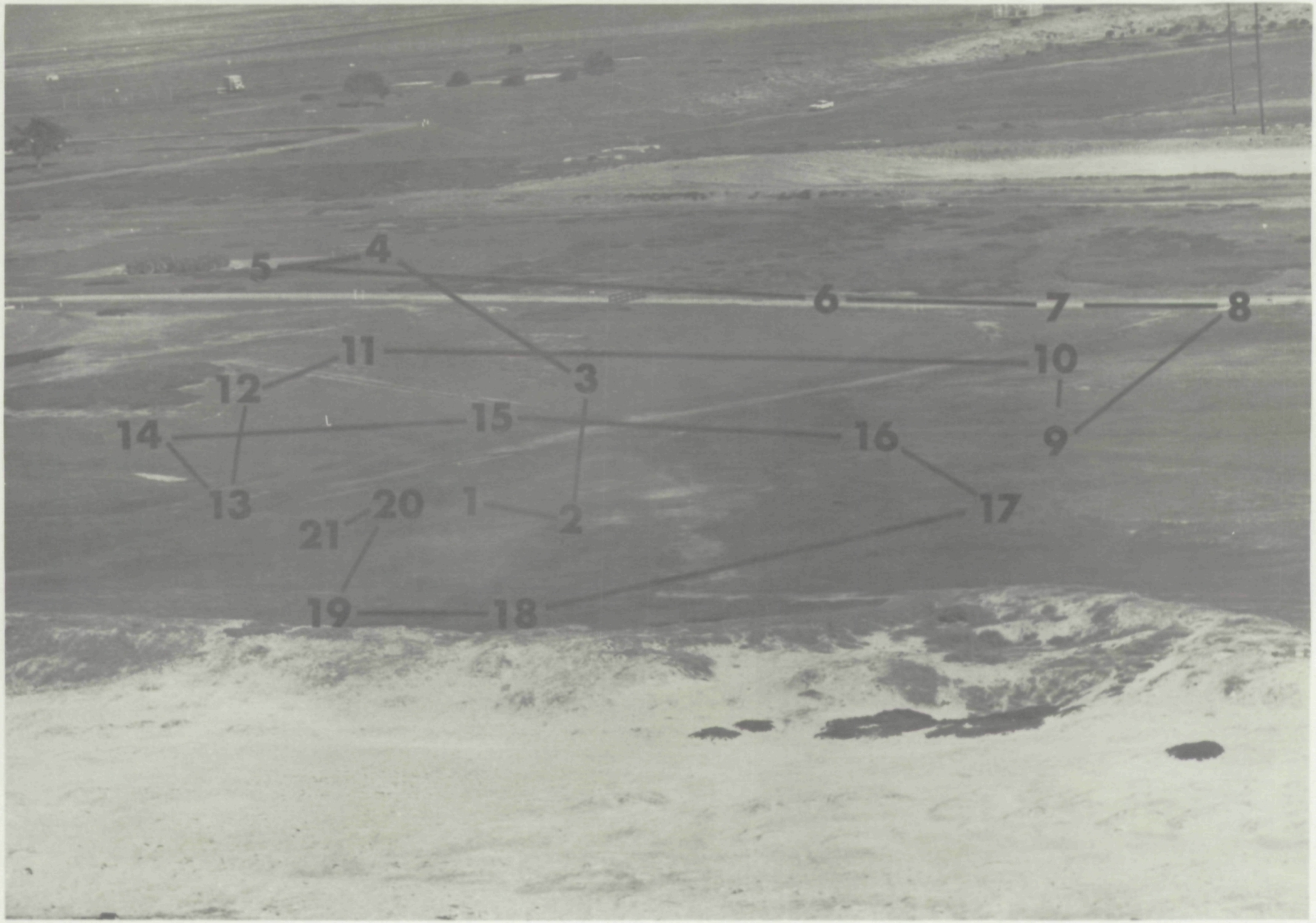

3
17
15
16
1
2
21
18
14
5
7
20
19
8
22
23
4
9
13
28
27
24
6
29
26
30
25
10
12
11


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22


42
41
43
32
40
8
31
7
9
10
39
14
15
3
16
20
33
2
35
38
13
34
37
6
30
12
11
36
1
17
4
18
24
23
25
19
22
26
5
27
21
29
28



4
3
5
6
7
1
2
9
10
11
12
13



4
5
6
7
8
11
10
12
3
15
14
16
9
13
20
1
17
21
2
19
18

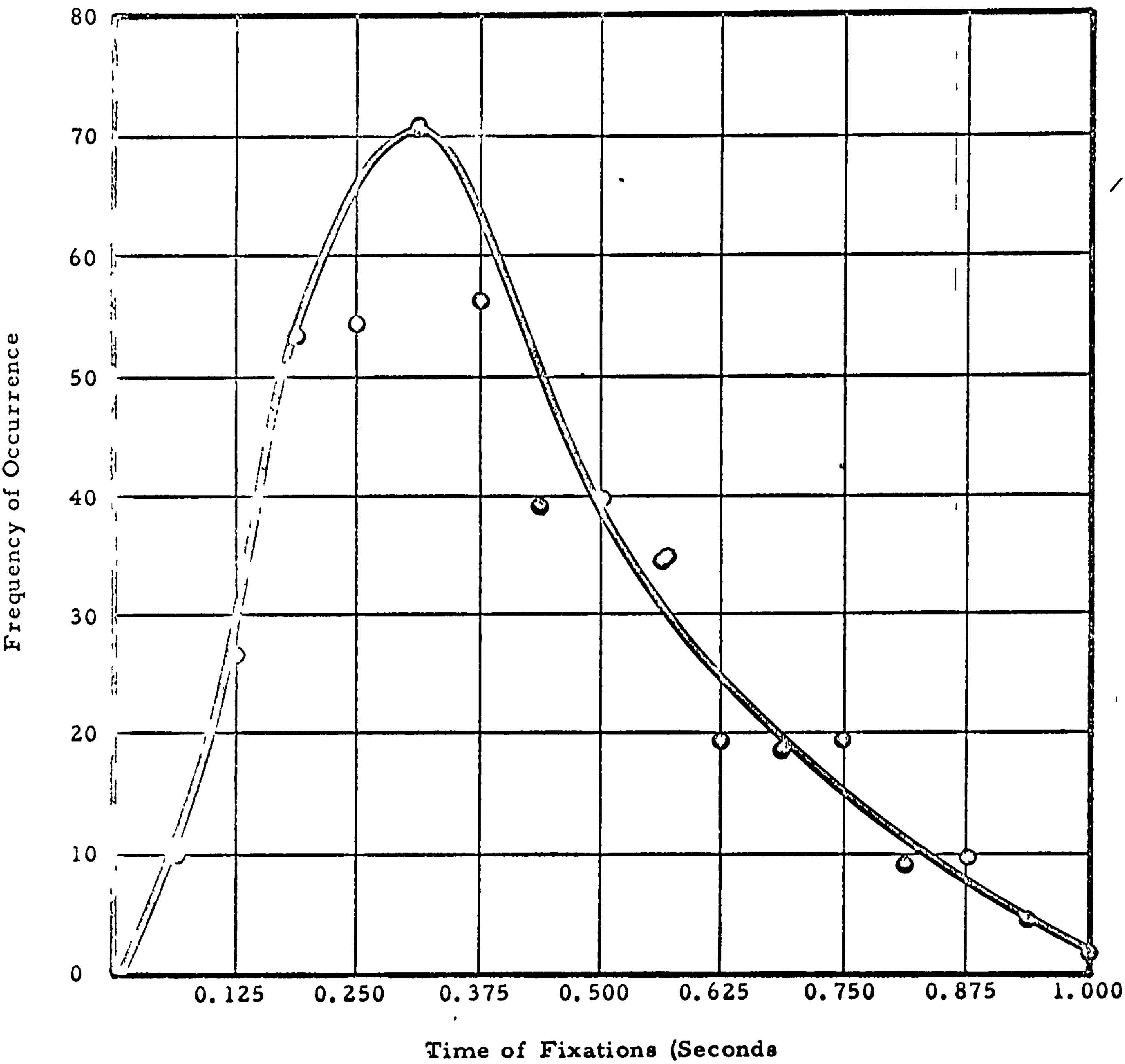


Figure 11. Experimentally determined probability distribution of the time of fixations.