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CONSPICUITY OF AIDS TO NAVIGATION:

EXTENDED LIGHT SOURCES

by

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SUMMARY

Conspicuity of point and extended sources was measured in field and laboratory experiments to assess the effects of signal size and background lighting density on a mariner's ability to find a navigation light. In the laboratory experiment, observers searched a computer display for a signal embedded in a background of point sources. The time required for observers to correctly locate the signal light was used as the measure of conspicuity. In the field experiment, observers searched the shoreline of New London Harbor in Connecticut for vertically oriented extended sources that had been installed for the experiment. The proportion of time each light was located in a fixed time period was used as the measure of conspicuity. Conspicuity increased with size of extended sources and decreased with density of background lighting. High density backgrounds caused less reduction in conspicuity of large signals than small signals. Flashing enhanced conspicuity of small targets more than large targets. Methods are provided for aiding design engineers in the sizing and selection of extended sources.

This is an electronic version of the paper presented to 12th IALA Conference in Holland in1990. Some of the figures/graphs have been difficult to reproduce!

1.0 INTRODUCTION

Visual signals used for navigation must be distinctive to insure that the signals can be located and interpreted rapidly. Road signs, channel lights or runway lights must be easy to distinguish from the background clutter, since time spent searching for a navigation signal may interfere with the demands of safely operating an automobile, ship or plane.

Conspicuity is a measure of the attention-getting quality of' a navigation signal. High conspicuity signals, or signals that attract the attention of an observer, are most desirable so that the likelihood of missing a critical signal is small.

Currently no standard methods exist for rating conspicuity of different signals. Designers of visual signals must rely on the traditional measure of intensity as a measure of signal effectiveness. High intensities are considered more effective since they can be detected at greater distances than low intensities. The intensity of a signal, however, does not reflect how well it can be located within a background. An intense, white navigation light, for example, may be quite difficult to find in a background of bright, white lights, while a dim red light may highly conspicuous.

A signal does not have an inherent conspicuity in the absence of a background, and thus any measure of conspicuity must take into account the background. High intensity signals may be effective when the background has low intensity lights. Red signals are conspicuous when the background has a high density of green lights. Flashing lights are conspicuous against backgrounds of fixed lights.

For mariners approaching harbors nighttime backgrounds generally consist of many point sources of light of different color and intensity (Worthey, 1988). Typical navigation lights are red, green and white point sources that flash in some characteristic way. Mariners often report great difficulty in determining which lights are relevant signal lights and which lights are the irrelevant background lights. In many situations the conspicuity of the signal lights is inadequate.

One approach for improving the conspicuity of navigation signals is to use signals that look physically different from the point sources that comprise the background. Extended sources, large lights that appear to have physical dimension at a distance, are one class of signal light that may have a higher conspicuity than point sources. A mariner searching a harbor for a navigation light can rapidly reject as not being a navigation light any light that is obviously a point source.

This report, the first in a series to deal with the issue of conspicuity, is an evaluation of the concept of using extended sources for aids to navigation. This report provides data of a laboratory and field experiment designed to understand the relationships between conspicuity, signal size and background lighting. The laboratory experiment used computer simulated backgrounds to study conspicuity while the field experiment involved the task of locating real extended sources in an industrial harbor.

This report provides extended source design guidelines for the engineer. The report addresses the conspicuity advantage expected from extended sources, describes the effects of signal size and background lighting on conspicuity, and provides guidelines to be used for developing extended source hardware.

2.0 BACKGROUND

Conspicuity of aids to navigation has become a problem in the past 50 or 60 years with the advent of cheap electricity and the development of the shoreline. A Committee on Vision Working Group of the National Academy of Sciences - National Research Council studied the conspicuity problem for the Coast Guard in 1971 and reported that background lighting was a severe problem (NAS-NRC, 1971). The Working Group recommended that a permanent solution be obtained through regulation of lighting along the shoreline. The Group observed that many of the developments for aids to navigation, such as flashing/rotating lamps and flashtubes have been copied by bars and restaurants along the shoreline, adding to the Coast Guard's difficulty in improving conspicuity.

In 1983 the Signal Effectiveness Project was begun to investigate methods of improving navigation safety through improvements in aids to navigation. The idea of using extended sources became realistic with the development of a light from TIR Systems Limited that required only a single, standard lamp to illuminate a large area.

3.0 METHODS

3.1 LABORATORY EXPERIMENT

3.1.1 Apparatus and Stimuli

Signal and background lights were generated on the face of a high resolution (1024 x 768 pixels) color display controlled by a Hewlett-Packard Series 9000 Model 320 computer. Each pixel of the display subtended approximately 1.75 min arc at the 61 cm viewing distance. Signals were all horizontally oriented extended sources with a width of 1.75 min arc and a length that varied between 5.25 and 28 min arc. Some signals flashed with a flash rate of 1.0 flash/sec and a duty cycle of 0.3. Background lights were square and varied in size from 1.75 min arc per side to 3.5 min arc per side. Background lights were always fixed on.

Observers searched the display for a single signal light that was placed randomly within a 35 cm wide x 9 cm, high (30 x 8 deg) search area. The signal light was always larger than the background lights. When the signal light was found observers pressed a response button. The computer recorded the time required to locate the signal.

The display was divided into five equal-size areas. Observers reported the area in which the signal was found by pressing one of five response buttons. The computer delivered a tone when an incorrect button was pressed.

Background lights were randomly placed on the screen such that each light was at least 10.5 min arc (6 pixels) from its nearest neighbor(See ref. 1) . Signal lights were also randomly placed with the constraint that they be no closer than 10. 5 min arc to any background light. In the absence of signal and background lights the screen had a luminance of approximately 0.01 ft-L, equivalent to a clear night with full moon. A drawing of the stimulus display is provided as Figure 1.

If signals were all of equal luminance, the larger signals would tend to appear brighter than the smaller signals. Conspicuity would then be a function of both signal size and brightness. To ensure that the measure of size conspicuity was not confounded with the brightness of the signal, all signals were adjusted to be a constant multiplier above threshold. Thresholds, minimum luminance required to just detect a light, were measured for all sizes of lights. Average thresholds of eight observers, shown in Table 1, were used as the base luminances. All signals were adjusted to be 15 times their respective thresholds. Luminance of background lights was randomly selected for each light to be between 10 and 20 times threshold.

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The separation betweenlights minimized the effects of spatial summation. Spatial summation is the process where nearby lights sum their brightness to create an area brighter than that of the individual lights. Spatial summation at luminances similar to that of this experiment occurs over 3-4 min arc. The separations chosen for this experiment ensure that no areas of high brightness compete for the attention of the observer.

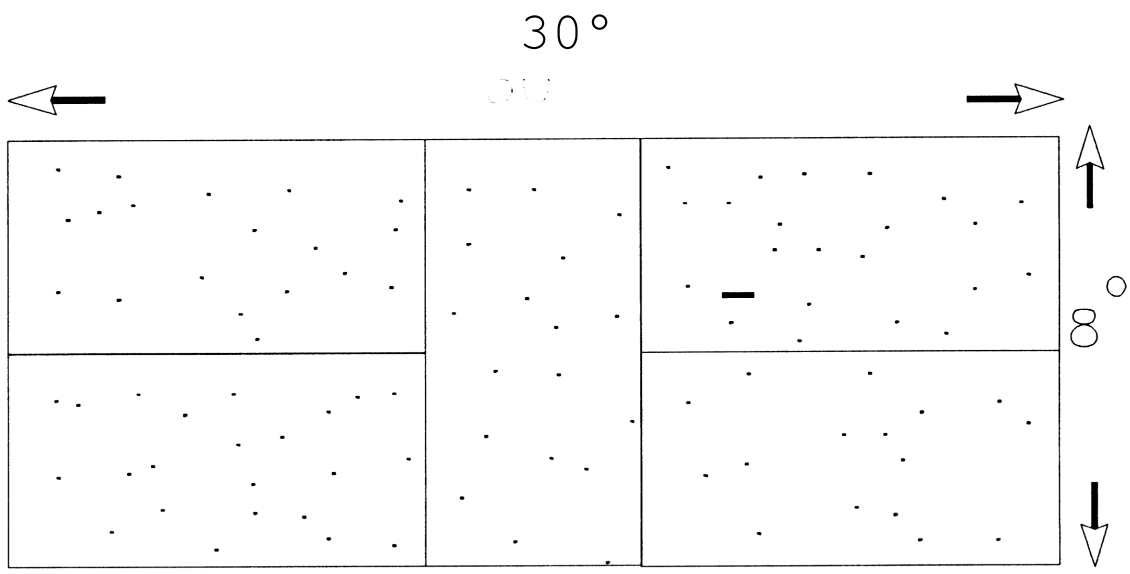

Figure 1

Observer view of display in lab experiment

TABLE 1

DETECTION THRESHOLDS FOR SIGNALS AND BACKGROUND LIGHTS

Size (min arc)	Threshold (ft-L)
1.8 X1.8	0.32
3.5 x1.8	0.22
5.3 x1.8	0.19
7.0 x1.8	0.17
8.8 x1.8	0.16
10.5 x1.8	0.16
14.0 x1.8	0.14
21.0 x1.8	0.14
28.0 x1.8	0.13
3.5 x3.5	0.16

3.1.2 Procedure

A session was composed of 300 trials plus a brief practice session. Thirty different experimental conditions (signal size, background density, flash/fixed) comprised a session with ten presentations of each experimental condition. Instructions for the experiment were provided on the computer display as observers adapted to the background luminance level. Thirty practice trials were provided to familiarize observers with the task.

A tone sounded to signal the start of each trial. The background lights and signal were illuminated simultaneously, and the observer began searching for the signal. When the signal was found, the observer pressed one of five buttons corresponding to the area in which it was found. If an incorrect button was pressed, the computer provided a tone to inform the observer and the experimental trial was discarded. If the signal was not found in 20 seconds, the trial was terminated and reaction time was recorded as 20 seconds.

An experimental session took between 35 and 60 minutes depending on the reaction times and length of rest periods taken by each observer.

3.1.3 Observers

Twenty people, all employees of the Research and Development Center and between the ages of 22 and 60, served as observers. A vision exam on a Titmus Vision Tester was used to screen all observers. All observers had vision corrected to 20/30 or better.

3.2 FIELD EXPERIMENT

3.2.1 Materials

Seven extended sources were installed along the waterfront in New London Harbor. Two of the sources were light pipes purchased from TIR Systems Ltd. of Burnaby, British Columbia, Canada. A schematic of this light source is shown in Figure 2. A 75 Watt flood lamp installed at the base of the light shines toward the mirror at the top of the light. Through the property of total internal reflection, the light is diffused uniformly across the surface of the light by reflecting from the plastic prismatic material. The prismatic material allows a portion of the light to "leak" out, providing a 50 ft-L, 10 foot long light source.

Five other extended sources were constructed at the Research and Development Center of off-the-shelf materials, including white, vinyl rain gutters, 60 1-Watt Christmas-type

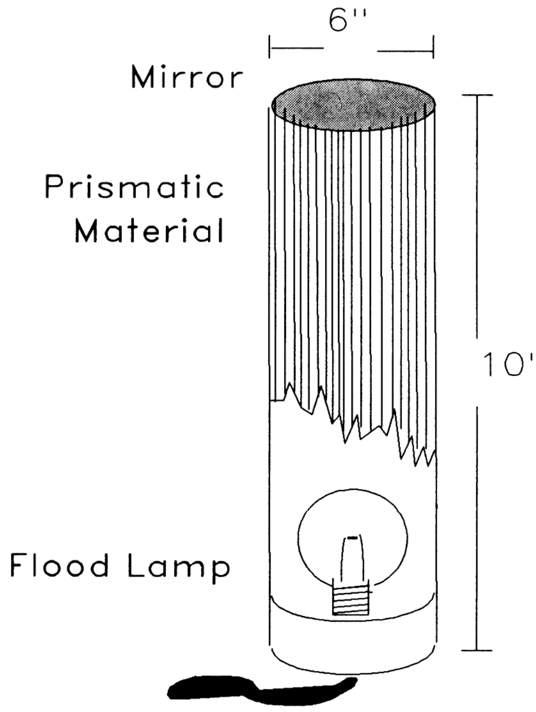

Figure 2

Schematic of TIR lamp

lamps equally spaced along the length of the rain gutter, and clear plastic diffusing material like that used for indoor lighting to diffuse fluorescent lamps. These lights, constructed in 10-foot sections, had a luminance of 40 ft-L.

Each light was outfitted with a servo motor attached to the power switch of the light source so the lights could be remotely controlled by radio signal. Ten-foot light sections were installed at four sites, and 20-ft sections (two stacked 10-ft sections) were installed at three sites. Figure 3 shows a photograph of a 10-foot tall extended source viewed from a distance of approximately one nautical mile.

<u>3.2.2 Procedure</u>

The experiment was conducted on five clear nights with calm seas in mid-September, 1988. The River Queen, a harbor tour boat with a capacity of 100 people, was rented for the experiment. Observers were taken to three different observation points within New London Harbor and instructed to locate all the extended sources that were illuminated. At any one time two to five

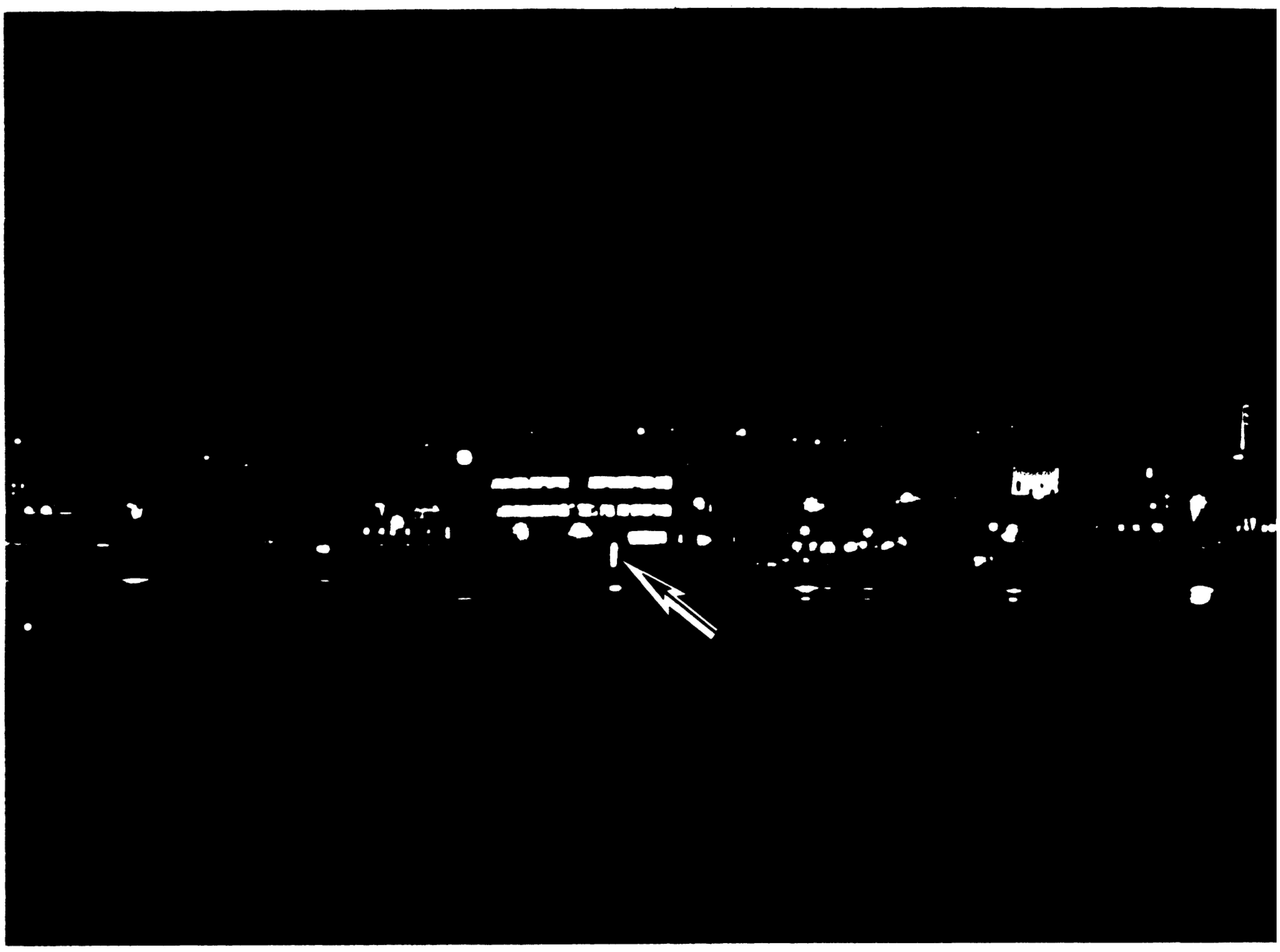

Figure 3. View of extended source in New London Harbor at a distance of 1.0 nautical miles

lights were illuminated. Observers were given either 30 or 45 seconds to search for the lights (depending on the number illuminated) and note the number found, but were not informed as to how many lights were illuminated. At the end of the search period they informed the experimenter of how many lights were found and pointed to the locations of the lights.

3.2.3 Observers

Fifty observers between the ages of 21 and 60 participated in the experiment. Most participants were Research and Development Center employees or spouses. All were assumed to have normal or near-normal vision. No vision screening was performed.

4.0 RESULTS

4.1 LABORATORY EXPERIMENT

Figure 4 shows average log (see ref. 2)reaction times as a function of number of background lights for seven signal sizes. Each symbol represents an average of 200 observations. Signal size is noted by each curve. The vertical bars about each symbol show plus and minus two standard errors of the mean.

Reaction times increase with increasing numbers of background lights; the amount of increase being dependent on signal size. In the absence of background lights reaction times for all signals are about 0.76 sec (-0.12 log sec). With a modest increase of 25 background lights, reaction times for the 5.3 and 7.0 min arc signals increased to 3.5 sec (0.55 log sec) and 2.1 sec (0.33 log sec), respectively. Reaction times for small signals (5.3 min arc) were affected more by background lighting than large signals (28 min arc).

A repeated measures analysis of variance (size x number of background lights) revealed highly significant effects of signal size and number of background lights, as well as a significant interaction between size and number of background lights.

The effect of flashing the signal can be seen in Figures 5a and 5b. These figures compare log reaction times of fixed and flashing lights as a function of signal size for backgrounds of 100 lights (Figure 5a) and 400 lights (Figure 5b).

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A logarithm (base 10) transformation makes the reaction time distributions closer to normal distributions, reducing the skewness and making variances homogeneous. Normal distribution and homogeneous variance are prerequisites for performing parametric statistics.

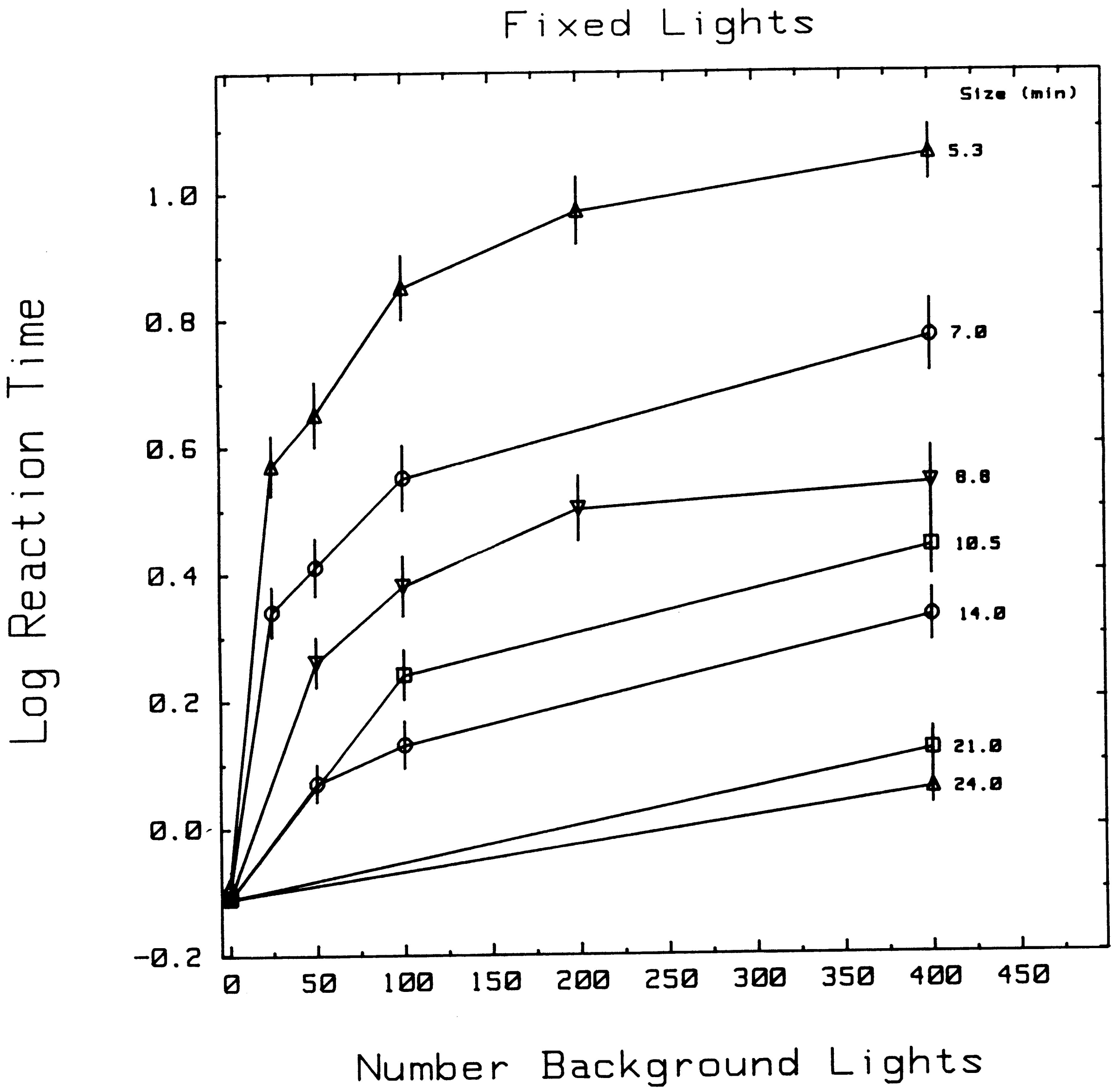

Figure 4. Average reaction times for fixed lights

Signal size is shown as the parameter of each curve. Vertical bars are +/-2 standard errors of the mean

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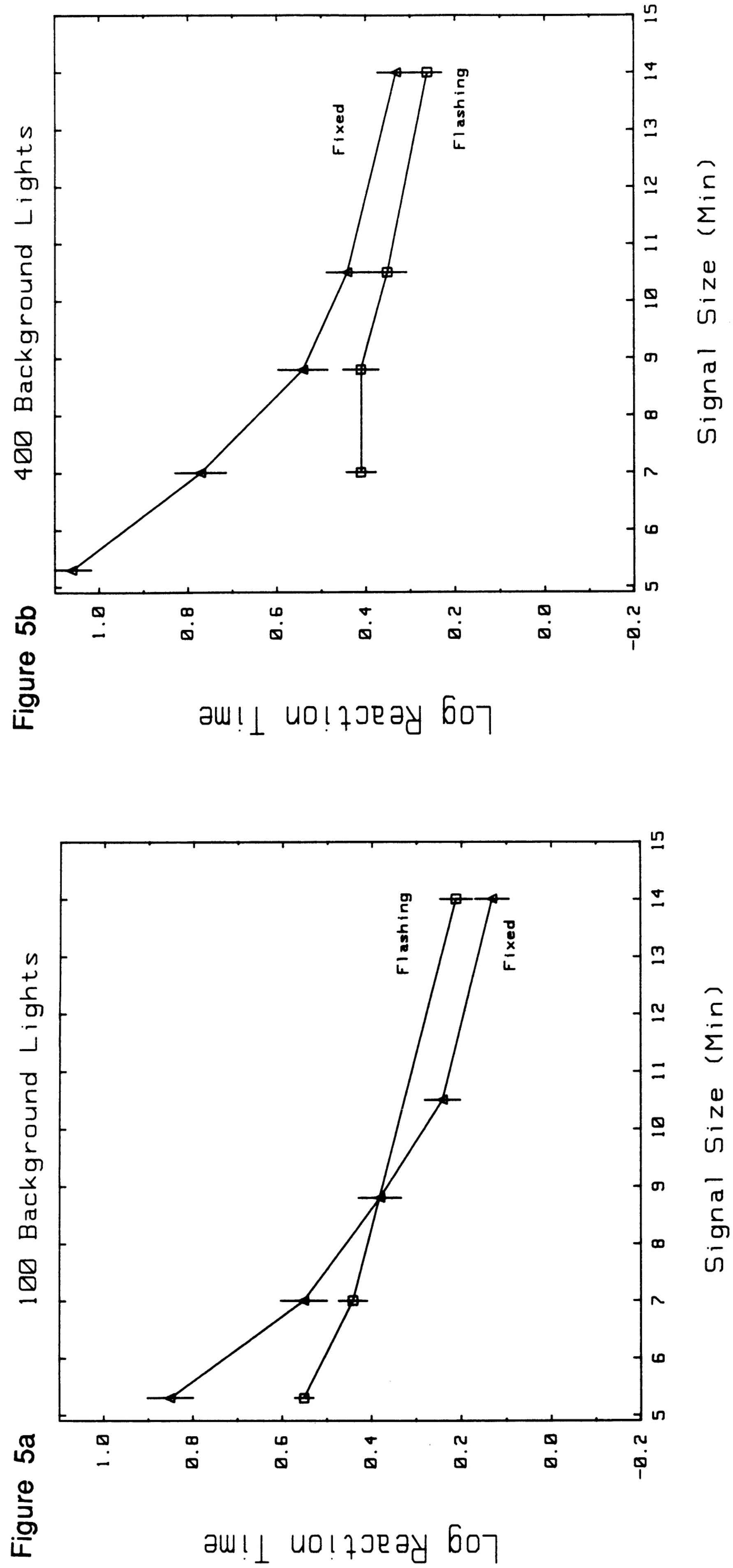

Figure 5. Average reaction times of fixed and flashing lights.

Figure 5a shows data for 100 background lights and 5b and 400 background lights. Vertical bars are +/-2 standard errors of the mean

When 100 background lights are present, flashing increases conspicuity (reduces reaction time) for small signals, but decreases conspicuity (increases reaction times) for large signals. When 400 background lights are present, flashing reduces reaction times for all signals measured.

It is interesting to note that the effect of background lighting on reaction time is much smaller when signals are flashing than when they are fixed. Figures 6a and 6b replot the data of Figure 5 to show this result. For the fixed lights (Figure 6a) a change from 100 to 400 background lights causes approximately a 50% increase in reaction time, while for the flashing lights (Figure 6b) the change in number of background lights has little effect.

A more complete representation of the data is shown in Figures 7 and 8. These figures show cumulative percent detected as a function of log reaction time for different signal sizes against various backgrounds. A single set of data represents 200 observations. Each symbol plots the percentage of times the signal was found within the time specified on the abscissa.

Note that all data sets appear reasonably linear over the range of 20% to 80%. Regression lines fit to each data set are shown as solid lines. Figure 7 shows data for fixed lights in the presence of 100 background lights (Figure 7a) and 400 background lights (Figure 7b). Figure 8 shows data for flashing lights in the presence of 100 background lights (Figure 8a) and 400 background lights (Figure 8b).

These plots are instructive in showing how: a) reaction time varies for a criterion detection probability; or b) detection probability varies for a criterion reaction time. The point at which a horizontal line at some criterion detection percentage, say 75%, intersects each regression line shows the time required to locate a signal 75% of the time. Similarly, the point at which a vertical dashed line at, say 0.3 log sec, intersects each regression line indicates the probability that a light of the given size will be located in 2 sec.

4.2 FIELD EXPERIMENT

Figure 9 shows the percentage of observers who detected a particular light as a function of the signal size of the light. The data are categorized by background lighting present when observations were taken. The open circles are for lights viewed against an area of low density background lighting. The open triangles are for lights in a background of many lights, or near a glare source. The filled symbols are data from the laboratory experiment that will be discussed below. On occasion the background for a particular light varied from night to night due

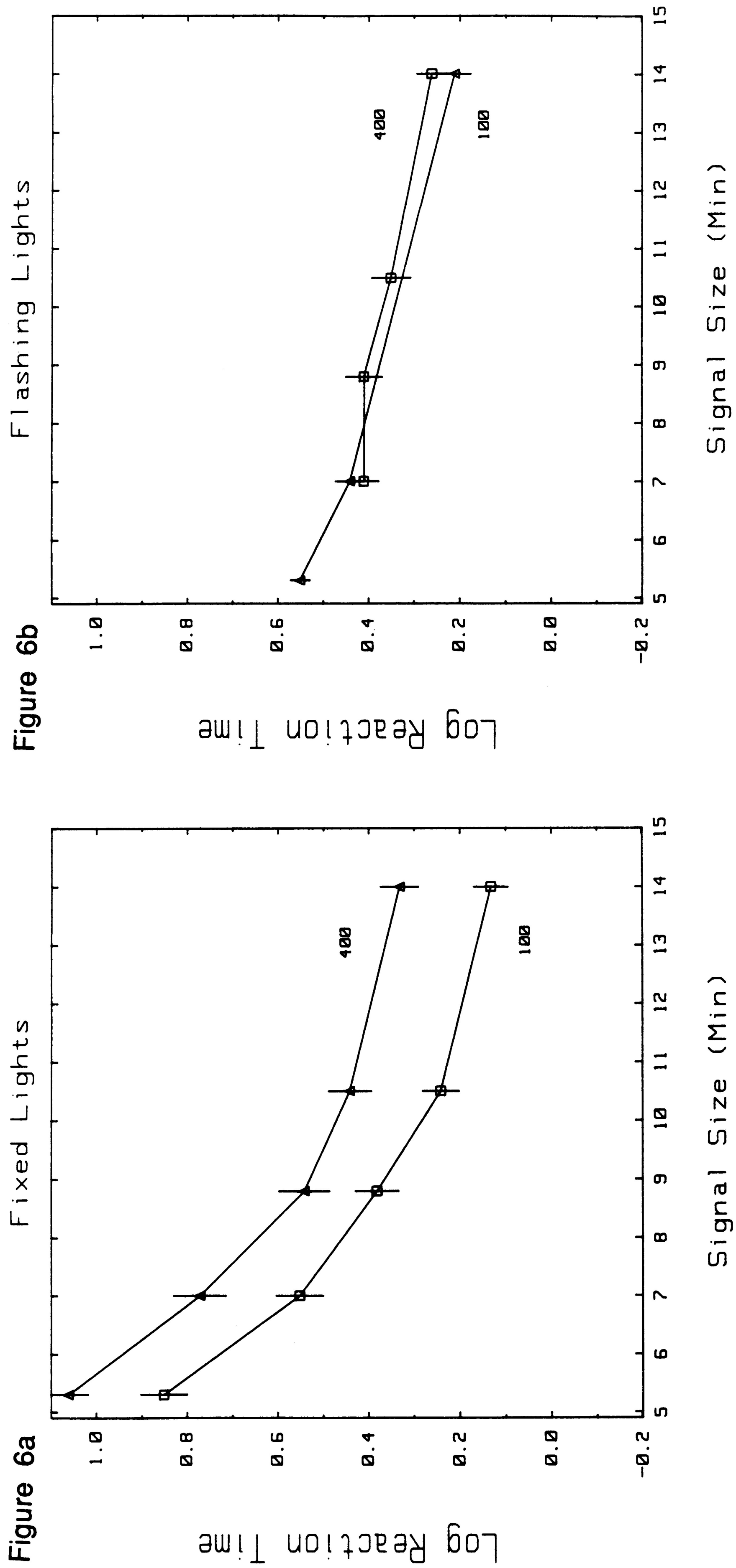

Figure 6. Effect of background lights on fixed and flashing lights

Figure 6a is for fixed lights and 6b for flashing lights. Number of background lights is given as the parameter of each curve. Vertical bars are +/-2 standard errors of the mean.

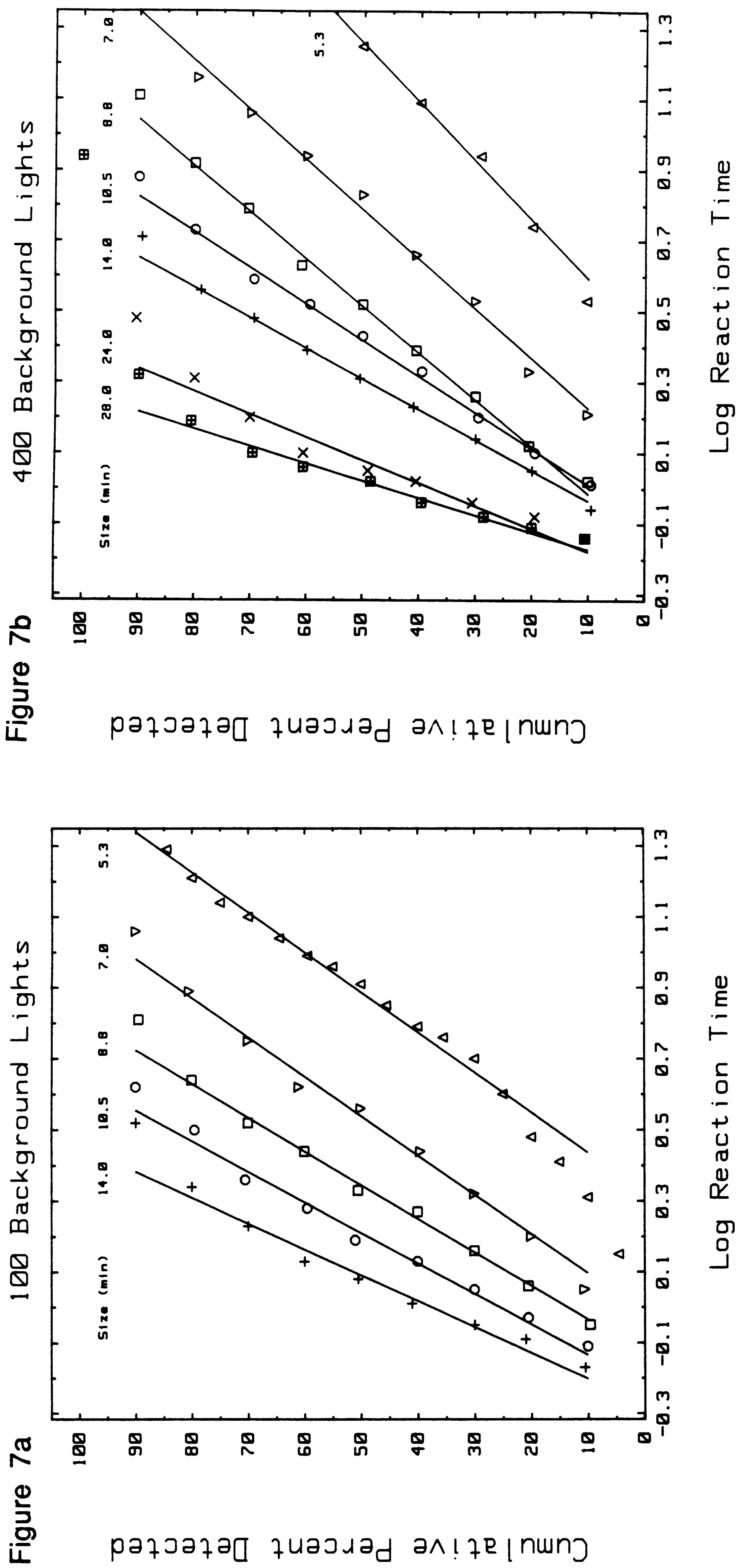

Figure 7. Cumulative percent detected for fixed lights

Figure 7a is for 100 background lights and 7b for 400 background lights. Signal size is given as the parameter of each curve. Lines are least-square fits to the data between 20% and 80%.

Figure 8a

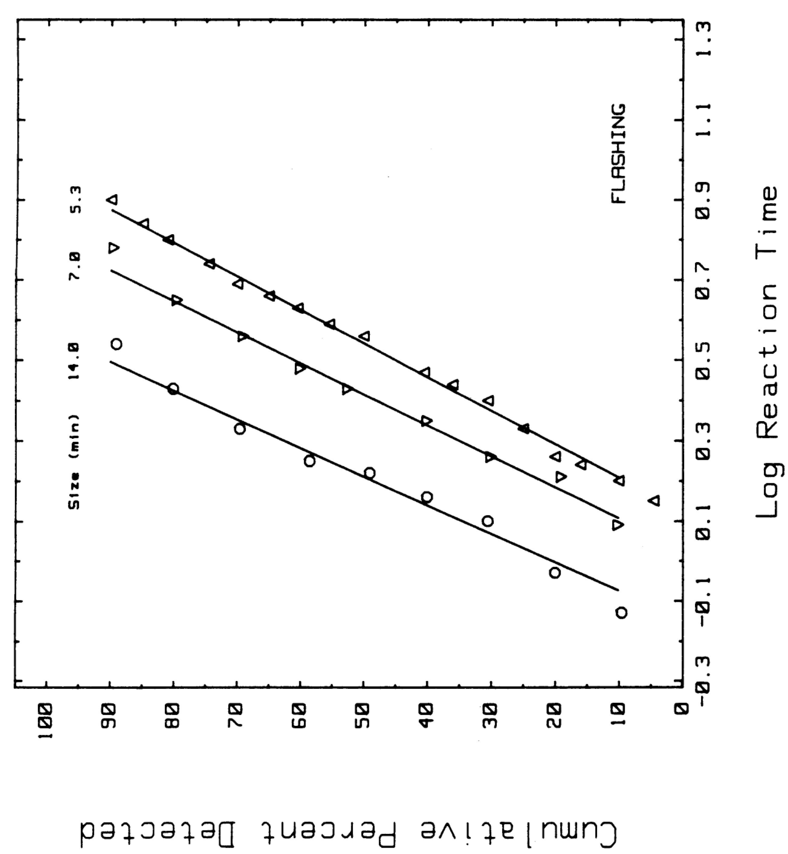

Figure 8b

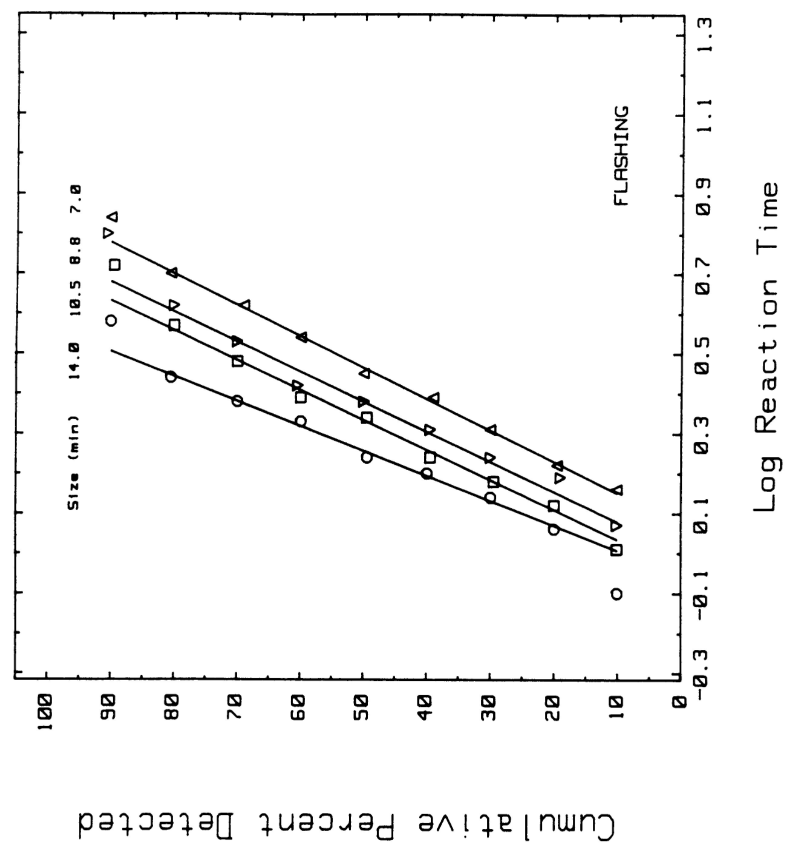

Figure 8. Cumulative percent detected for flashing lights

Figure 8a is for 100 background lights and 8b for 400 background lights. Signal size is given as the parameter of each curve. Lines are least-square fits to the data between 20% and 80%.

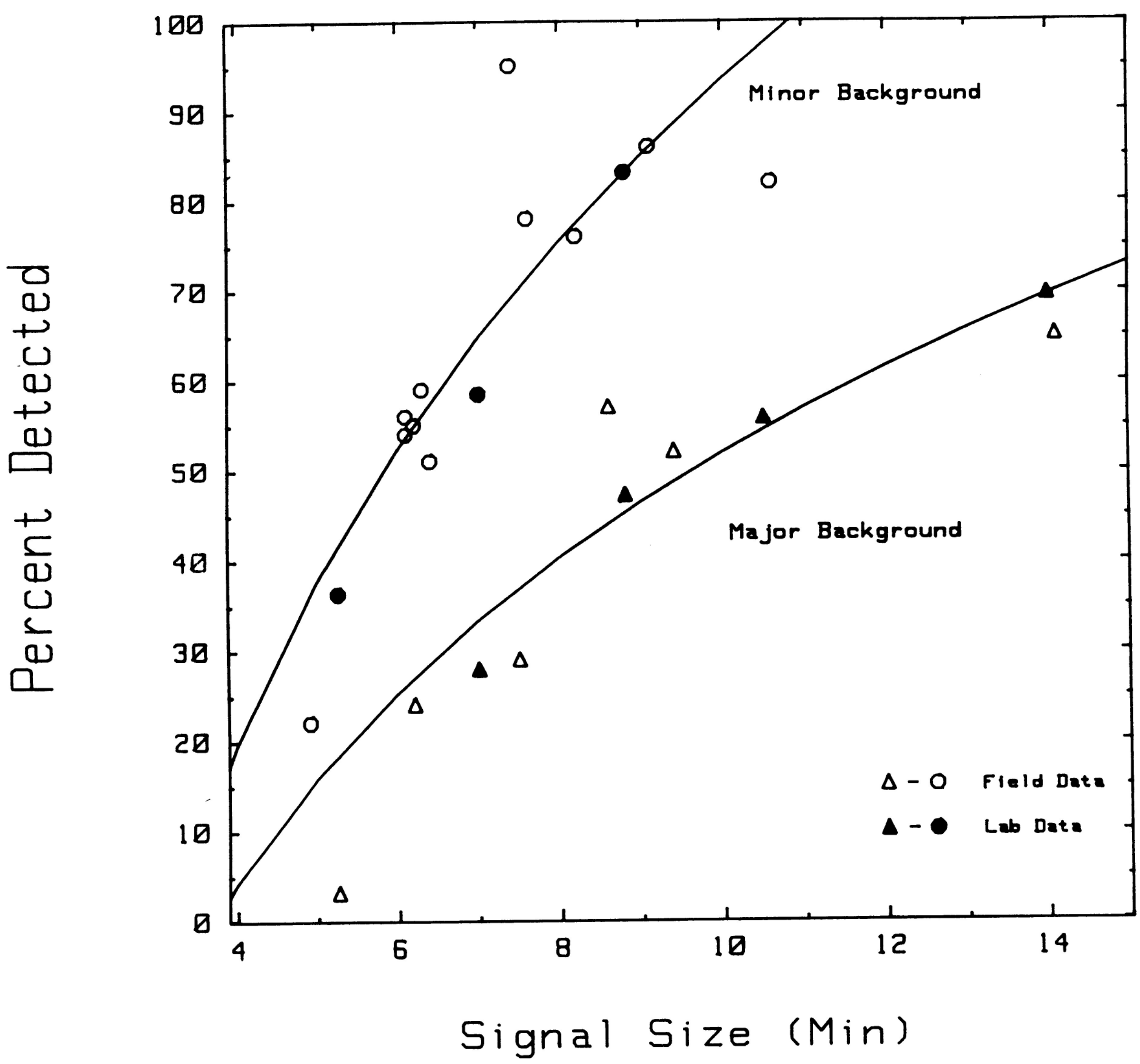

Figure 9. Percent detected for field experiment

Data divided into two background lighting conditions shown on the figure. Open symbols are from field experiment, filled symbols from lab. Experiment. Lines are least-square fits to the logarithm of signal size.

to factors beyond our control. For example, one night a ship tied up near one of the extended sources. The bright lighting on the deck of the ship caused sufficient glare to obscure the signal light. The data were sorted to reflect these variations in background lighting. Least-square fits to the logarithm of signal size are shown on linear axes for the two sets of data.

As signal size increased, the probability that the light was detected also increased. Moreover, lights viewed against low density backgrounds were detected more often than lights viewed against high density backgrounds. The largest signal, 14 min arc viewed against a high density background was detected only 65% of the time, compared to an 8 min arc signal that was detected 75% of the time in the presence of minor background lighting.

4.3 COMPARISON OF FIELD AND LABORATORY DATA

Though the laboratory and field experiments used different methodologies and were conducted under different experimental conditions, an attempt was made to find some commonality between the two sets of data. If the data from these two experiments accurately measured the relationship between detection, signal size and background lighting, it should be possible to superimpose the two data sets under the appropriate conditions.

The filled symbols in Figure 9 represent the percentage of signals detected within 3 seconds. These data were obtained from the curves in Figure 7 by taking a vertical "slice" through the data at a reaction time at 0.48 log sec (3.0 sec) and reading the percentages off the fitted curves. Three seconds detection time was chosen as it provided a good fit, by eye, to the field data. The minor and major background lighting data were taken from the data for 50 and 400 background lights, respectively.

5.0 DISCUSSION

5.1 CONSPICUITY INDEX

One of the goals of these experiments is to provide a method for rating conspicuity of different signals. A metric must be established that reflects the ease with which a signal can be found. Such a metric will be useful for selecting appropriate-size signals for a specific application.

Reaction time forms the basis of the conspicuity measure. A simple metric using the inverse of reaction time yields large numbers for signals found quickly and small numbers for signals that are difficult to find.

What reaction time should be used? We could use average reaction time, or a criterion like the reaction time at which 75% or 90% of lights are found. A criterion of 75° has the advantage that it provides a metric that varies between 0.0 and approximately 1.0. Table 2 shows this conspicuity metric (1/reaction time) for the 30 conditions of the laboratory experiment. Values in parentheses are for flashing lights.

TABLE 2

CONSPICUITY INDEX FOR EXTENDED SOURCES
(Detection Probability = 0.75)

Signal Size (min arc)	Number of Background Lights: 0	25	50	100	200	400
5.3	0.98	0.15	0.11	0.07 (0.18)	0.04	0.01
7.0	1.08	0.31	0.24	0.15 (0.25)		0.07 (0.22)
8.8			0.38	0.26	0.18	0.09 (0.27)
10.5				0.37		0.21 (0.30)
14.0	1.14		0.64	0.53 (0.41)		0.30 (0.39)
21.0						0.57
28.0						0.72

The most conspicuous signals, with conspicuity indexes near 1.0, are those signals that are viewed in the absence of a background. The 5.3 min arc flashing light, the signal most similar to a quick flash aid to navigation, has a conspicuity of 0.18 in a background of 100 lights. By increasing the size of the signal to 14.0 min arc the conspicuity increases by a factor of 2.27 to 0.41. This means that the larger signal can be found 2.27 times faster in the background than the smaller signal.

Figure 10 shows how the conspicuity index varies with target size and background lighting for fixed (Figure 10a) and

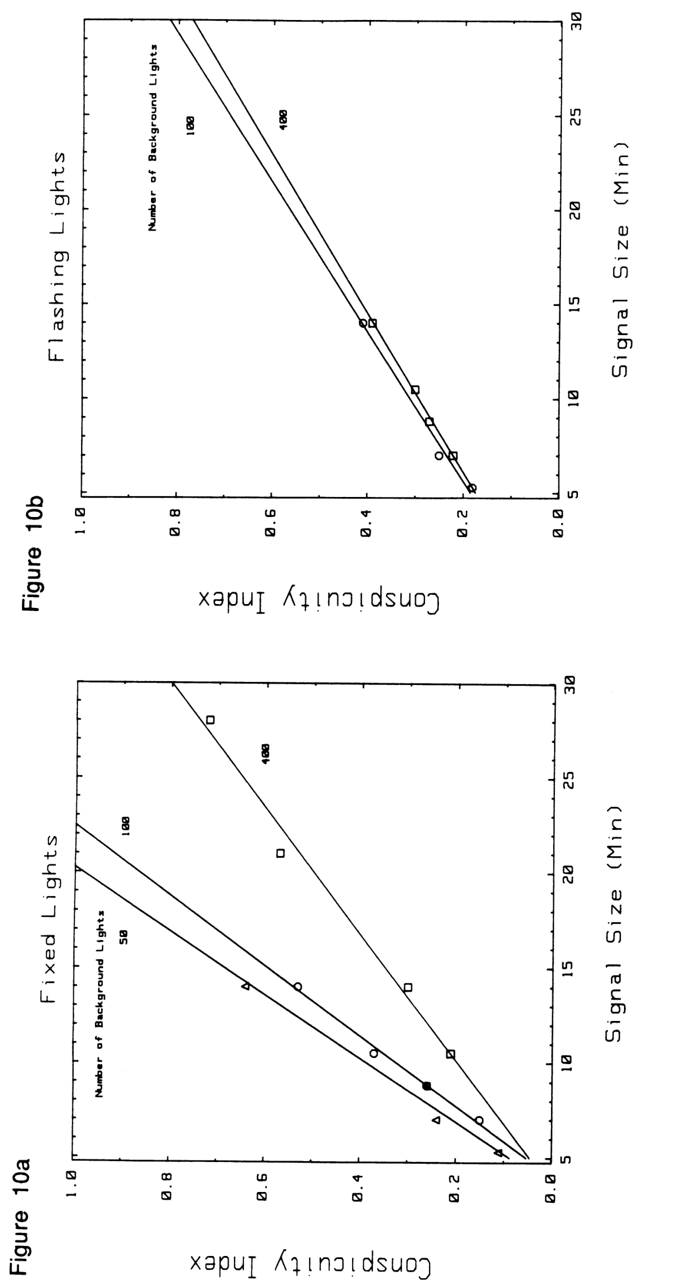

Figure 10. Conspicuity indexes for fixed and flashing lights.

Number of background lights is shown as the parameter of each curve. Figure 10a is for fixed lights and 10b for flashing lights. Lines are the least-square fit to the data.

flashing (Figure 10b) lights. Lines are least-square f its to the data **3**. The conspicuity indexes are well-fit by straight lines. Theslopes and intercepts of the fitted lines are shown in Table 3.

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TABLE 3
Conspicuity Index Least Square Fits

Fixed	**Slope**	**Intercept**
50 Background Lights	0.060	-0.212
100 Background Lights	0.054	-0.218
400 Background Lights	0.030	-0.105
Flashing		
100 Background Lights	0.025	0.057
400 Background Lights	0.024	0.054

As density of background lights increases the slope of the fitted line decreases. This means that conspicuity increases more slowly with size against high density backgrounds than against low density backgrounds. For flashing lights the slope of the best fitting line is less than for fixed lights.

5.2 FIXED vs FLASHING

An interesting result of this experiment is that flashing enhances conspicuity for some targets but reduces conspicuity for others. Flashing signals have higher conspicuity then fixed signals when they are small (less than approximately 7 min arc) or when they are viewed against the densest background lighting conditions (400 lights). For signals greater than 7 min arc viewed against a moderate density of background lights, flashing reduces conspicuity.

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There were many instances where the signal was not found in the 20 second search time. When the signal was not found, reaction time was recorded as 20 sec even though it had to be greater than 20 sec. This has the effect of overestimating conspicuity of the signals that were most difficult to find. The greatest impact was on signals with conspicuities less than 0.1. Therefore cospicuity indexes less than 0.1 are not included in the fits.

One explanation for this is that when a light flashes it is unavailable to the observer for a significant portion of the time. The flash rate used in the laboratory experiment was that of a quick flash characteristic (0.3 sec on, 0.7 sec off). Seventy percent of the time the signal was not illuminated and thus unavailable for detection. When the conspicuity provided purely by the size of the signal is much greater than that provided by the flashing, the impact of the 70% off time of the light will be to reduce conspicuity. When the contribution of flashing to conspicuity is greater than the contribution of size, flashing will enhance conspicuity. In a future experiment the effect of flash rate on conspicuity will be investigated.

5.3 SIZE OF EXTENDED SOURCES

The data show that conspicuity increases with the angular size of a signal. In constructing an extended source for field use, the angular size, a (in minutes of arc), of the signal is computed with the equation:

$$a = \mathbf{3438\ (s\ /\ d)}$$

where s is the size of the signal in feet, and d is the distance from the signal in feet. Table 4 shows how angular size varies with signal size and distance from the signal. A 20-ft long signal viewed from 1.0 nautical mile has an angular size of 11.3 min arc.

TABLE 4
ANGULAR SIZE OF EXTENDED SOURCES
(Minutes of Arc)

Source Size (feet)	Distance (nautical mile) 0.5	1.0	2.0	3.0	4.0
4	4.5	2.3	1.1	0.8	0.6
8	9.0	4.5	2.3	1.5	1.1
12	13.6	6.8	3.4	2.3	1.7
16	18.1	9.0	4.5	3.0	2.3
20	22.6	11.3	5.7	3.8	2.8
24	27.1	13.6	6.8	4.5	3.4
28	31.7	15.8	7.9	5.3	4.0
32	36.2	18.1	9.0	6.0	4.5
36	40.7	20.4	10.2	6.8	5.1
40	45.2	22.6	11.3	7.5	5.7

Table 5 shows similar computations for determining signal size from angular size and distance. These tables are useful in showing how large signals have to be in order to have a particular angular size, and thus a particular conspicuity.

TABLE 5
PHYSICAL SIZE OF EXTENDED SOURCES
(Feet)

Angular Size (min arc)	Distance (nautical mile) 0.5	1.0	2.0	3.0	4.0
5	4.4	8.8	17.7	26.5	35.4
6	5.3	10.6	21.2	31.8	42.4
7	6.2	12.4	24.8	37.1	49.5
8	7.1	14.1	28.3	42.4	56.6
9	8.0	15.9	31.8	47.7	63.6
10	8.8	17.7	35.4	53.1	70.7
12	10.6	21.2	42.4	63.7	84.9
14	12.4	24.8	49.5	74.3	99.0
16	14.1	28.3	56.6	84.9	113.2
18	15.9	31.8	63.7	95.5	127.3
20	17.7	35.4	70.7	106.1	141.4
25	22.1	44.2	88.4	132.6	176.8
30	26.5	53.1	106.1	159.2	212.2

Ideally one would like to provide signals with maximum conspicuity. The largest signals in the laboratory experiment, 21.0 and 28.0 min arc, which showed the best conspicuity, may not be practically achieved in the field. Table 5 shows a signal subtending 25 min arc at 2.0 nautical miles must have a physical size of more than 88 feet.

Tables 4 and 5 can be used in the design of new aids to navigation. As an example, assume that we wish to improve the conspicuity of an important aid. The light is a quick flash viewed against a moderate background. From Figure 10, or the slopes and intercepts of Table 3, a 5 min arc (nearly point source) flashing light has a conspicuity of 0.19. To improve the conspicuity by a factor of two to 0.38, Figure 10 or Table 3, show that a 13 min arc signal is required. Given a viewing distance of 1.0 miles, Table 5 shows that the signal would have to be about 23 feet tall. For a viewing distance of 2.0 miles, the signal would have to be about 46 feet tall.

5.4 APPLICATION OF EXTENDED SOURCES

Extended sources can provide a conspicuity advantage over point sources in most applications where background lighting is present. Extended sources may see their greatest benefit as range lights, where it is necessary to acquire and reacquire a light several times during a single transit. The conspicuity advantage of extended sources means that less time must be spent in searching for the signal. In the case of range lights, this may result in a real improvement in navigation safety by enabling mariners to spend more time piloting their vessel than in searching for a navigation light, especially in a meeting traffic situation.

5.5 GENERALITY OF BACKGROUNDS

The laboratory experiment used simulated backgrounds for measuring times to locate various sized signals. The generality of the data reported here depends on whether or not the simulated backgrounds can be considered a valid representation of real backgrounds. Worthey (1988) measured the background lights of New York Harbor from three vantage points to provide histograms of background light density and illuminance. Measurements were made from Sandy Hook looking north through the Verrazano Narrows, as well as from Governor's Island looking both north toward Manhattan and south toward New Jersey and Staten Island.

Over the areas that were measured, Worthey reported that densities of lights varied between 1.8 to 2.4 lights per square degree. In the present experiments, the number of background lights was limited to 400 randomly placed in a 240 square degree area to give a density of 1.7 lights per square degree. This density is comparable to that of New York Harbor.

5.6 EXTENDED SOURCE ORIENTATION

In a background of only point sources, extended sources oriented horizontally, vertically or obliquely should have the same conspicuity. In harbors all background lights are not point sources. Lights in windows of buildings, reflections off light posts, and reflections off calm water, to name a few, are typically oriented either horizontally or vertically. During one evening of the field experiment we found that the vertically oriented reflections off the calm water were occasionally mistaken for light signals.

While orientation of the signal lights was not an experimental variable, the impression was formed that extended sources oriented obliquely would be better than those oriented vertically or horizontally because there would be less confusion with some of the background lights.

6.0 CONCLUSIONS

Extended sources provide a substantial improvement in conspicuity over that of point sources. Signal conspicuity depends on angular size of the signal and the density of background lighting against which the signal is viewed. As signal size increases, conspicuity also increases. As the density of background lighting increases, conspicuity decreases. The density of background lighting reduced the conspicuity of small signals more than that of large signals. Flashing enhanced the conspicuity of small targets more than large targets.

Extended sources will improve the conspicuity of aids to navigation in situations where background lighting is a problem. The practical application of extended sources depends on the distances over which a conspicuity improvement is required. Extended sources provide adequate conspicuity improvement when they exceed about 8 min arc in angular subtense. This corresponds to an extended source length of more than 14 feet when viewed from one nautical mile or 28 feet when viewed from two nautical miles. As distance increases the physical size of extended sources must increase to obtain a given angular size.

Extended sources will be most effective as range lights where mariners must acquire and reacquire the light many times to make a successful transit.

7.0 REFERENCES

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3.1.6

CONSPICUITY OF AIDS TO NAVIGATION: EXTENDED LIGHT SOURCES

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