Naval Submarine Medical Research Laboratory

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CONSPICUITY OF AIDS TO NAVIGATION: II. SPATIAL CONFIGURATIONS FOR FLASHING LIGHTS

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SUMMARY PAGE

THE PROBLEM

To determine the spatial configuration and flash characteristics of a light that will be most readily distinguishable from a background of steady lights, for use in lighted aids to navigation.

FINDINGS

Simultaneously flashing the target elements of two horizontal bars of light produced the greatest conspicuity of the configurations tested, followed by two diagonal bars and a triad of lights, as measured in a search task. The Flashing (isophase) pattern, in which all segments of the target were on for 120 ms and then off for 120 ms, always produced the quickest response times and the fewest errors. Alternately flashing the elements of the target always produced the longest response times and the greatest number of errors. Overall, search time increased with the density of background lights, with the Flashing targets least affected, and the Alternating-Flashing targets most affected.

APPLICATION

These results can serve as guidelines for the spatial configuration and flash characteristics of lighted aids to navigation that must be used in areas that have a high density of background lights, such as most channels and harbors.

ADMINISTRATIVE INFORMATION

This study was conducted at the Naval Submarine Medical Research Laboratory under U.S. Coast Guard Research and Development Center Contract No. MIPR Z51100-1-E27A57. The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large. This report was approved for publication on 9 August 1996 and designated as NSMRL Report 1202.

Abstract

Lights used as aids to navigation are typically point sources that are easily confused with the background clutter of lights on shore. This study investigated the conspicuity, or how well lights of various spatial configurations stand out from a background of lights, and serves as a basis for the design of lighted aids to navigation. The measure of conspicuity was the response time for an observer to find a flashing target among backgrounds of steady lights on a CRT display. Twenty observers participated. Nine targets were tested, various configurations of pairs, bars, or triads of lights in vertical, horizontal, or triangular arrangements. Each of these targets was tested at three temporal flash patterns and four background densities. The target segments flashed either sequentially; sequentially, with off time between flashes; or simultaneously, with all target segments flashing in unison. The four background densities were 0, 50, 200, and 400 lights. ANOVAS showed significant effects of target, flash pattern, and background. Simultaneously flashing target elements of two horizontal bars of lights produced the greatest conspicuity, followed by two diagonal bars and a triad of lights. Search time increased with the density of background lights.

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CONSPICUITY OF AIDS TO NAVIGATION: II. SPATIAL CONFIGURATIONS FOR FLASHING LIGHTS

As discussed in an earlier report (Laxer & Benoit, 1993), navigational lights used by the U.S. Coast Guard are typically point sources that are easily confused with the background clutter of lights on shore. The problem is especially severe along waterways and in harbors, where the density of background lights is high (Worthey, 1988) and accurate navigation is most important. This problem is one of relative conspicuity of signals, the likelihood that a stimulus will be noticed.

Because legally regulating the appearance of interfering background lights seemed impracticable, the present research was conducted to improve the conspicuity of lighted aids to navigation. Previous studies have shown that conspicuity is affected by such physical characteristics of the target as size, luminance, contrast, movement, distinctive spatial characteristics, and by the characteristics of the surround, such as the number of distractors (Boersema, Zwaga, & Adams, 1989).

Treisman and Gormican (1988) concluded that targets of greater length, number, and contrast, and with line curvature, misaligned orientation, and nonstandard color or shape were detected easily, whereas targets of decreased length, number, and contrast, and targets with straight lines, frame-aligned orientation, and prototypical colors or shapes resulted in slow and apparently serial search.

Practical considerations limit the use of increases in size, luminance, contrast, and motion characteristics for application to navigation lights, however. For example, greater luminance requires more power, perhaps unavailable in an independent floating beacon. In addition, the size of navigation lights can be increased only to a limited extent. Consequently, we must often be satisfied with small improvements in conspicuity using available means.

In our prior experiment (Laxar and Benoit, 1993), we found that a flash frequency, such as 4 Hz, and a duty cycle (proportion of time lit), such as .5, maximized conspicuity of a point-source target light against a background of small lights. In the present study, we used such a temporal characteristic to investigate the conspicuity of various spatial configurations of lights. Response time to find a target light among background lights was taken as a measure of conspicuity. A less conspicuous light would require a longer search time. Both of these studies are extensions of Mandler's (1989) investigations.

Method

Observers

Twenty volunteers served in this experiment, seven men and 13 women, aged 22 to 62 years (*Mdn* = 31). All had normal or corrected visual acuity and most had experience as psychophysical observers. All observers were used in each experimental condition.

Apparatus and Displays.

White stimuli were presented on a high resolution (1024 x 768 pixels), 48.3 cm (19 inch) color display driven by a Hewlett-Packard Series 9000 Model 320 computer. Each pixel on the display subtended approximately 2.0

arc min at the 61 cm viewing distance. Observers sat in a chair facing the screen, with their head position maintained by a chin-forehead rest.

Targets were in four general configurations of lights (Figure 1). A pair of lights and two parallel bars of light were each arranged in horizontal, vertical, and diagonal orientations; two extended intersecting bars of light were displayed in the shape of a × and a + sign. There was also a triad of lights.

Three types of flash patterns were used, generally following the 4 Hz, .5 duty cycle characteristic. However, the actual stimulus timings were constrained by the 20 ms clock interval of the computer system. Three flash patterns were used (Figure 2). The target segments flashed either sequentially at 4 Hz, producing an apparent motion effect ("Alternating"); sequentially, with each target segment on for 120 ms separated by 120 ms of off time ("Alternating-Flashing"); or simultaneously, with all segments on for 120 ms and then off for 120 ms ("Flashing"). Background lights, always fixed on during each trial, were square and either two or four arc min per side. At these subtenses all background stimuli looked like points of light.

The target was placed randomly within the search area, which is pictured in Figure 3. It consisted of a rectangle 35 cm wide x 10 cm high (32 deg x 9.5 deg), which was divided into five equal-size sectors. Observers searched for the target and indicated the sector in which the target was found by pressing one of five corresponding buttons on a keypad. The computer recorded the response time and sector chosen.

Four levels of background density, 0, 50, 200, or 400 lights per display screen, were

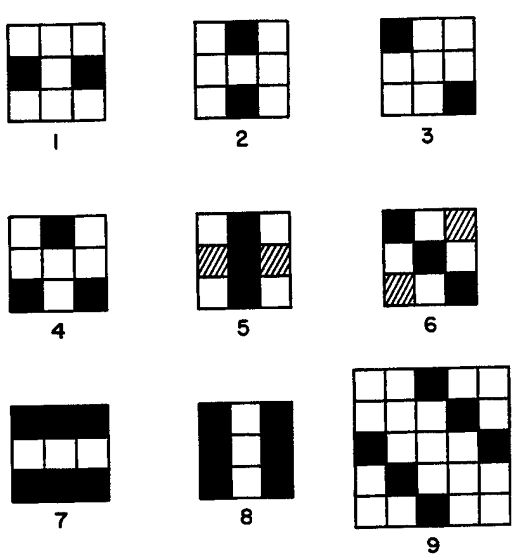

Figure 1. Pixel layouts of the nine targets. The solid black and shaded pixels differentiate the lighted target segments, which either flashed simultaneously or sequentially.

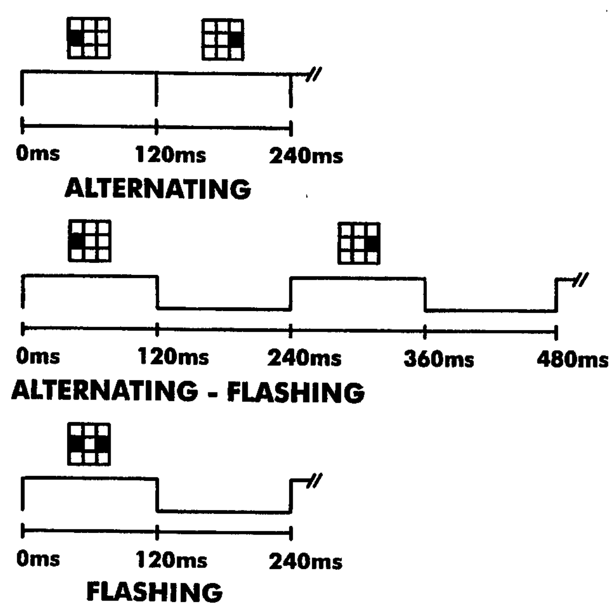

Figure 2. One complete flash cycle for each of the three types of flash patterns, following the approximately 4 Hz, .5 duty cycle characteristic.

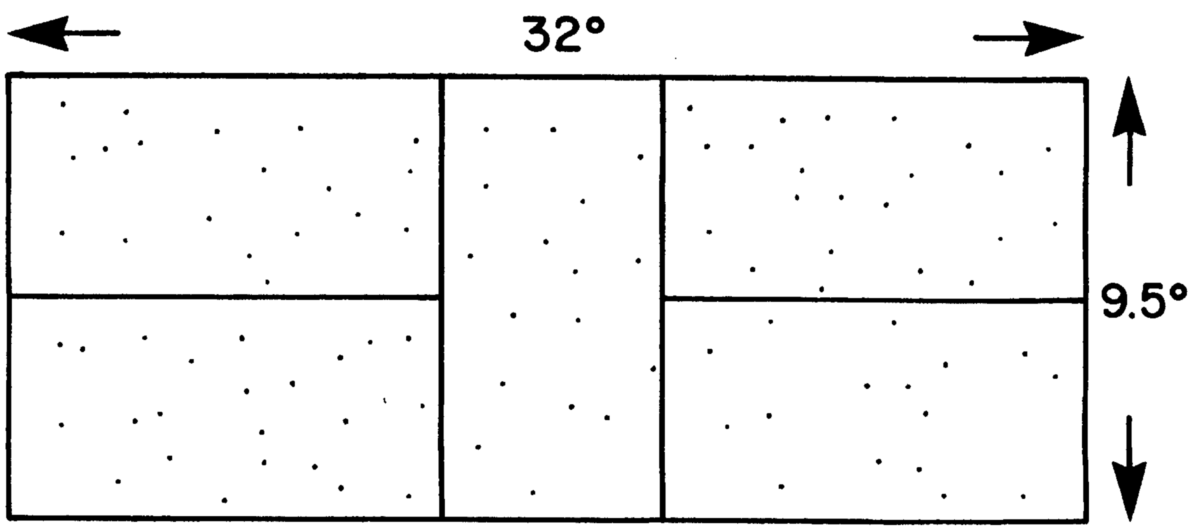

Figure 3. Stimulus display, showing the five search sectors.

presented in random order. To minimize the effects of a spatial summation, all background and target lights were placed randomly within the search area such that each light was at least 12 arc min from its nearest neighbor.

To help ensure that the conspicuity of a target was purely a function of its spatial configuration and/or flash pattern and not confounded by brightness, the luminances of the stimuli were set so that the targets and the background lights had the same average level of detectability. To do this, the mean brightness threshold, the average luminance to just detect the light, was measured in a group of 10 observers. In a single session, thresholds were determined by means of a modified staircase procedure using 1-second stimulus exposures. For the four main experiments, the luminance for each target was set at 30 times its threshold. The luminances of the background lights were randomly set at between 23 and 37 times their respective thresholds so that their mean luminances (13 cd/m for the single pixel and 5 cd/m for the 2 x 2 pixels) were 30 times their thresholds, just as the targets were. The luminance of the screen without any target or background lights was approximately 0.04 cd/m, equivalent to a scene illuminated with a full moon. Luminance levels were measured with a Spectra Prichard Photometer, Model 1980 (Photo Research Division, Kollmorgen Corp.)

Procedure

After instructions and five minutes in a darkened room to adapt to the low level of screen luminance, the observer was given a series of practice trials. The test session consisted of each target of the particular spatial configuration being tested at three flash patterns and at four background densities, completely randomized within each of 10 repetitions (blocks). The experiment consisted of one session for each of the four general spatial configurations, pairs of lights, triad, + and × , and parallel bars of light. The order in which the configurations were tested was randomized for each observer.

A tone sounded to alert the observer at the start of each trial, whereupon the background lights and target came on the screen simultaneously and the observer started searching for the target. When the target was found, the observer pressed the key corresponding to the sector in which it was located. The stimulus and background lights were then extinguished and the computer recorded the data. If an incorrect sector was chosen, the computer sounded a tone to inform the observer, and that trial was rerun later in the session. If the target was not found in 20 seconds, the background lights were extinguished and the target remained on the screen for several seconds to show the observer its location. The trial was then terminated and a response time of 20 seconds was recorded.

Results

Response Time

For each display, mean response times (RTs) of all observers were calculated for each experimental condition in each of the 10 blocks of trials. The means were then logarithmically transformed. This brought the RT distributions closer to normal for subsequent parametric analyses.

Four repeated-measures analyses of variance (ANOVAs) were computed, one for each general spatial configuration. The main effects in all ANOVAs were target orientation (horizontal, vertical, and diagonal), except on the triad; flash pattern (Alternating, Alternating-Flashing, and Flashing); and background (0, 50, 200, and 400 lights). Each subject x effect mean square was used as the respective error term. The results of the ANOVAs are summarized in Tables 1-4.

All main effects were significant at the $p < .001$ level for all spatial configurations. For all targets, the mean response time for the zero background was approximately 0.7 seconds. Response time increased markedly for the background of 50 lights, and was slightly higher still for 200 and 400 lights. Figure 4 illustrates this effect for Target 7, the pair of horizontal, parallel bars of light, typical of the results for the other target configurations.

For all spatial configurations, the Flash Pattern x Background interactions were significant. Figure 4 illustrates that the Flashing targets were least affected by the number of background lights. Plots for the other targets looked essentially the same.

The Flashing targets produced significantly quicker response times, followed by the Alternating-Flashing and Alternating targets (see Figures 5-8). Four Scheffé tests examined the main effect of flash pattern for each type of spatial configuration. Flashing, Alternating-Flashing, and Alternating were all

Table 1
Summary of ANOVAs for Response Times for Pairs of Lights

Source	*df*	*F*
Target	2, 38	94.41**
Flashpat	2, 38	559.37**
Bkgnd	3, 57	212.14**
Target x Flashpat	4, 76	38.75**
Target x Bkgnd	6, 114	13.28**
Flashpat x Bkgnd	6, 114	164.77**
Target x Flashpat x Bkgnd	12, 228	6.37**

*$p < .0050$. **$p < .0001$.

Table 2
Summary of ANOVAs for Response Times for the Triad

Source	*df*	*F*
Flashpat	2, 38	323.19**
Bkgnd	3, 57	131.79**
Flashpat x Bkgnd	6, 114	55.99**

*$p < .0050$. **$p < .0001$.

Table 3
Summary of ANOVAs for Response Times for the + and × configurations

Source	*df*	*F*
Target	1, 19	51.20**
Flashpat	2, 38	1068.37**
Bkgnd	3, 57	526.99**
Target x Flashpat	2, 38	6.11*
Target x Bkgnd	3, 57	2.42
Flashpat x Bkgnd	6, 114	296.72**
Target x Flashpat x Bkgnd	6, 114	0.76

*$p < .0050$. **$p < .0001$.

Table 4
Summary of ANOVAs for Response Times for the Parallel Bars of Light

Source	*df*	*F*
Target	2, 38	64.74**
Flashpat	2, 38	245.86**
Bkgnd	3, 57	231.16**
Target x Flashpat	4, 76	44.59**
Target x Bkgnd	6, 114	6.61**
Flashpat x Bkgnd	6, 114	111.81**
Target x Flashpat x Bkgnd	12, 228	5.92**

*$p < .0050$. **$p < .0001$.

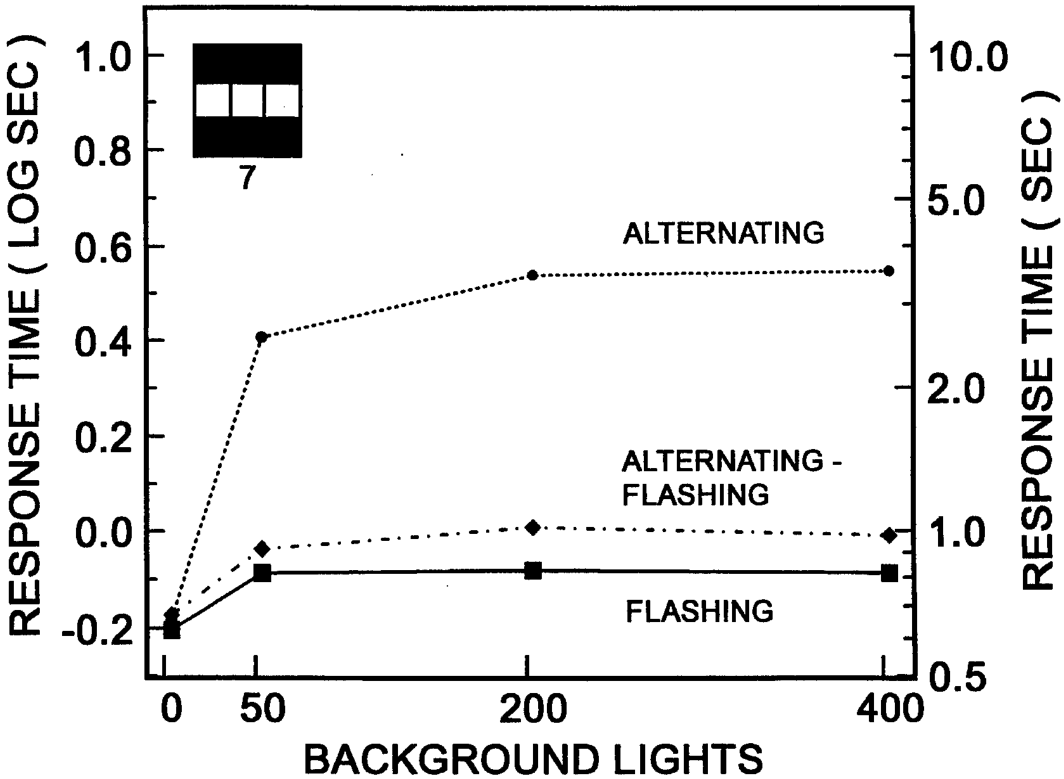

Figure 4. Mean response time for three flash patterns (Flashing, Alternating-Flashing, or Alternating) by number of background lights, for Target 7.

significantly different from each other at the $p < .05$ level for each configuration type. Flashing, Alternating-Flashing, and Alternating were all significantly different from each other at the $p < .01$ level in all configurations except the parallel bars. In this one, Alternating was different from Flashing and Alternating-Flashing, which were not different from each other.

Figures 5, 7, and 8 also illustrate the significant Target x Flash Pattern interactions. For the Flashing and Alternating-Flashing patterns, response times for vertical, horizontal, and diagonal (oblique) target elements were nearly identical. For the Alternating pattern, however, response times for diagonal target elements were substantially faster than for the horizontal and vertical elements.

Four Scheffé tests examined the triple interaction of Target x Flash Pattern x Background for all spatial configurations except the triad, in which the double interaction of Flash Pattern x Background was examined. Except for the zero background condition, all the Flashing targets were significantly faster than any of the Alternating-Flashing targets ($p < .05$), with all of the Alternating targets slowest. With just one exception, there was no overlap of the response times of the Alternating targets with the Flashing and Alternating-Flashing, except in the zero background condition.

Because the Flashing targets were shown to produce faster response times than the Alternating-Flashing or Alternating, the data for the nine Flashing targets were aggregated for a Target x Background ANOVA. The main

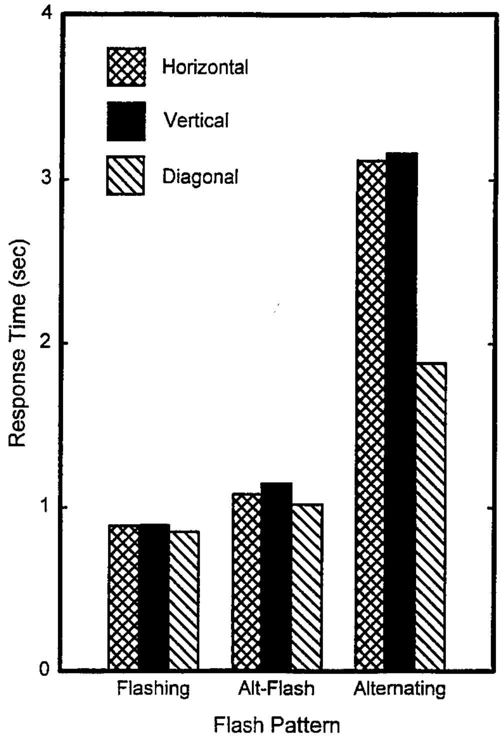

Figure 5. Mean response times for the horizontal, vertical, and diagonal pairs of lights in the Flashing, Alternating-Flashing, and Alternating conditions.

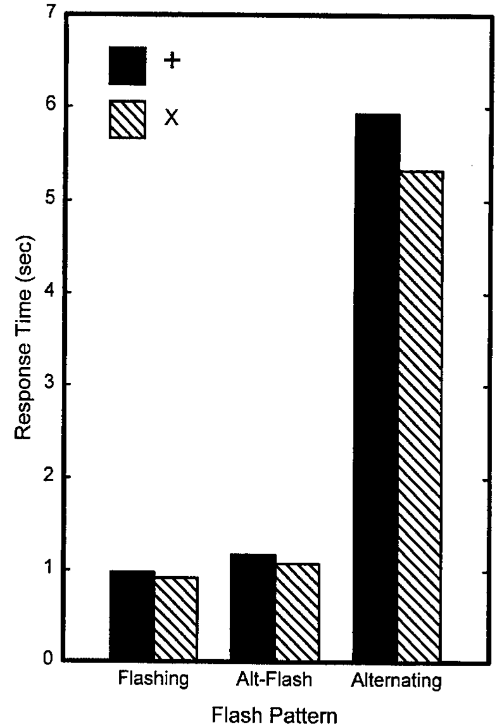

Figure 7. Mean response times for the + and the × in the Flashing, Alternating-Flashing, and Alternating conditions.

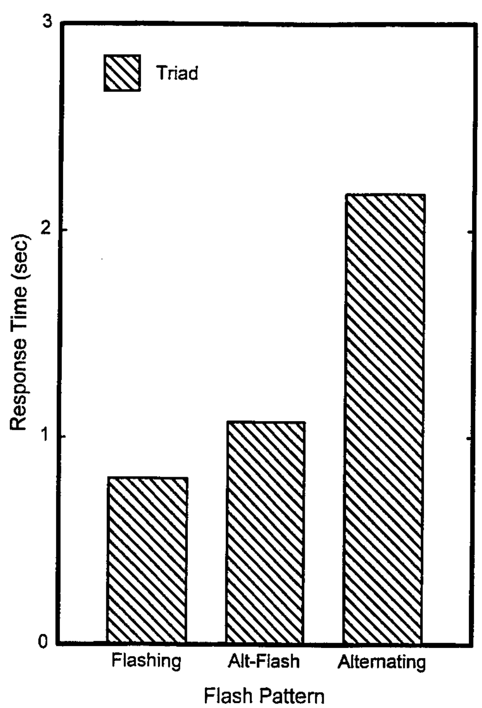

Figure 6. Mean response times for the triad of lights in the Flashing, Alternating-Flashing, and Alternating conditions.

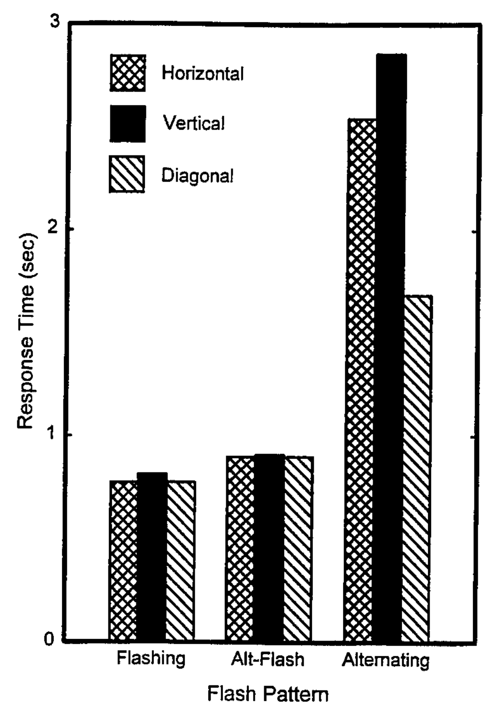

Figure 8. Mean response times for the horizontal, vertical, and diagonal parallel bars in the Flashing, Alternating-Flashing, and Alternating conditions.

effects of target, $F(8,152) = 7.82, p < .001$, and background, $F(3,57) = 138.31, p < .001$, were significant, and there was no significant interaction.

Figure 9 shows response times for the Flashing pattern only, the pattern with the fastest search times. In this figure, the height of each bar represents the mean of 800 observations (20 subjects x 10 blocks x four backgrounds). Targets 7 and 9 (horizontal and diagonal parallel bars) produced the shortest response times. However, a Scheffé test showed that they were not significantly different from each other or from the remaining targets at the $p < .05$ level, except targets 5 and 6. Targets 5 and 6 (+ and ×) were not different from each other, but they were significantly different from Targets 7 and 9. Target 5 was also different from 4 (the triad) and 8 (vertical parallel bars). Target 5 was different from Targets 7, 9, and 4 at the $p < .01$ level.

Error Rate

The errors and timeouts were extremely few in this experiment, less than 2%, except in the cases of Targets 5 and 6, which were approximately 10%. Error rates for the latter two targets paralleled the poor performance evidenced by their long search times. Almost all errors and timeouts were found in the Alternating condition. The Flashing condition always resulted in the fewest errors and the fewest timeouts.

Discussion and Conclusion

The results of this study show that for all spatial configurations, the Flashing temporal pattern, in which all segments of the target were on for 120 ms and then off for 120 ms, yielded the best conspicuity, followed by the Alternating-Flashing pattern, with the Alternating pattern producing the longest search times and highest time-out and error rates. Furthermore, the Flashing targets were least affected by an increase in the number of background lights. The apparent motion effect

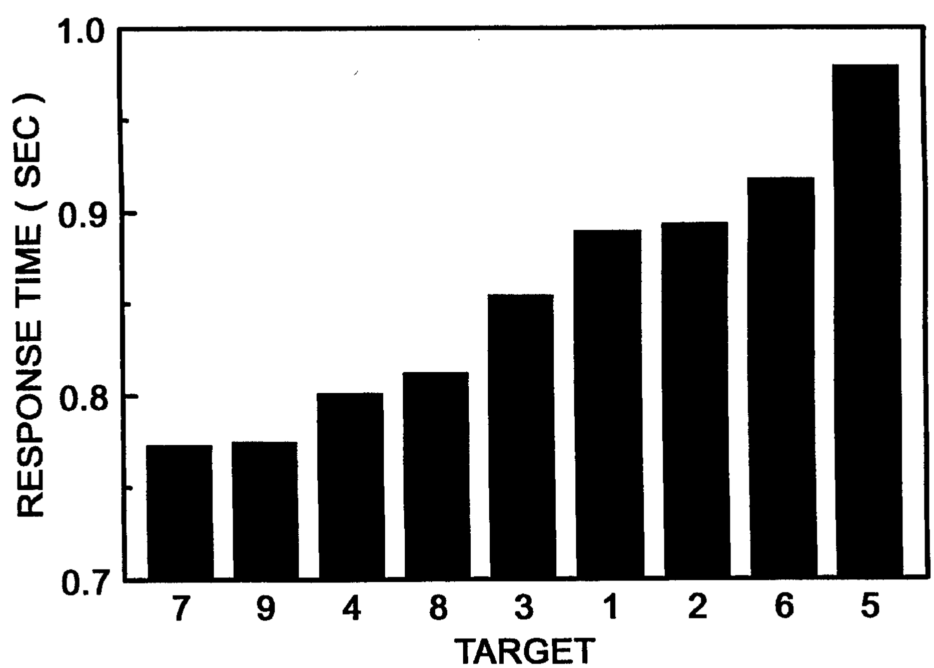

Figure 9. Mean response times for the nine Flashing targets.

produced by the Alternating temporal pattern did not produce high conspicuity in this study.

Of all the Flashing targets, the fastest search times were produced by the pairs of horizontal, vertical, and diagonal parallel bars of light (Targets 7, 8, and 9) and the triad of lights (Target 4). Apparently the shape of the intersecting perpendicular bars of light (Targets 5 and 6) were not distinctive at the subtense used, and blended in with the background lights. The pairs of lights (Targets 1, 2, and 3), having the smallest number of pixels lit of all of the configurations (two), were not as conspicuous as the parallel bars, made up of six pixels each, and the triad, made up of three pixels, even though all were matched in luminance for detectability.

For the Alternating flash patterns, the substantially reduced search times for targets made up of diagonal elements, as compared with targets of horizontal or vertical elements, shown in Figures 5, 7, and 8, is the opposite from what would be expected on the basis of the classical "oblique effect." This effect refers to the fact that horizontal and vertical lines are perceived more readily than oblique ones (see Appelle, 1972, for a review; Long & Tuck, 1991). In this study, the results may be due simply to the small stimuli used, or to the positions or spacing of the pixels on the screen. With such few pixels lit, their alignment and non-continuity may have altered the oblique effect. There may be practical implications, however, that could be tested in a field study. Diagonal targets might be less frequent and therefore more conspicuous in a real-world harbor scene, which is likely to contain many elongated light patterns made up of reflections from the water's surface and from vertical and horizontal surfaces from man-made objects.

The results obtained in this study are consistent with those of Jenkins and Cole (1982), who found that size contrast is effective in increasing conspicuity. Our findings also agree with those of Mandler (1989), who showed that conspicuity increases with size of extended light sources and decreases with density of background lights. The effects of the various background densities found here are the same as those found previously by Laxar and Benoit (1993).

In conclusion, our results suggest that parallel bars of lights (Targets 7 and 9), flashing at a frequency of 4 Hz and a duty cycle of .5, afford the best conspicuity of the configurations tested. These targets, however, as tested at a visual angle of 6 arc min, would have to be 3.2 m (10.6 ft) long at only one nautical mile distance. This may be approaching or exceeding a size limit for an aid to navigation in order to improve conspicuity, yet may be practical where conditions permit and conspicuity of the aid is critical.

Acknowledgment

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Lights used as aids to navigation are typically point sources that are easily confused with the background clutter of lights on shore. This study investigated the conspicuity, or how well lights of various spatial configurations stand out from a background of lights, and serves as a basis for the design of lighted aids to navigation. The measure of conspicuity was the response time for an observer to find a flashing target among backgrounds of steady lights on a CRT display. Twenty observers participated. There were nine targets tested, each at three temporal flash patterns and four background light densities. ANOVAs showed significant effects of target, flash pattern, and background. Simultaneously flashing the target elements of two horizontal bars of lights produced the greatest conspicuity, followed by two diagonal bars and a triad of lights. Search time increased with the density of background lights.

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