Naval Submarine Medical Research Laboratory

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CONSPICUITY OF AIDS TO NAVIGATION:
I. TEMPORAL PATTERNS FOR FLASHING LIGHTS

Kevin Laxar
and
Sandra L. Benoit

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P. K. Weathersby, CAPT, MSC, USN
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Naval Submarine Medical Research Laboratory

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Report 1187

U.S. Coast Guard Research and Development Center
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SUMMARY PAGE

THE PROBLEM

To determine the flash pattern, in terms of frequency and duty cycle, of a blinking light that will be most readily distinguishable from a background of steady lights, for use in lighted aids to navigation.

FINDINGS

The most conspicuous flashing light had the highest frequency tested (3.85 Hz) and the lowest duty cycle (proportion of total time on, .3). Furthermore, this flash pattern consumes the least amount of electrical energy, an important consideration for an aid to navigation.

APPLICATION

These results can serve as guidelines for the 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 Contract No. MIPR Z51100-1-E27A57, Investigation of the conspicuity of illuminated aids to navigation, U.S. Coast Guard Research and Development Center, Groton, CT. The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. The manuscript was approved for publication on 3 May 1993, and designated as NSMRL Report No. 1187.

Abstract

Mariners frequently have trouble picking out lighted aids to navigation in harbors and other areas that have a high density of background lights. The U.S. Coast Guard is seeking ways to enhance the conspicuity, or likelihood of being noticed, of these aids. Literature has shown that a flashing light is more conspicuous than a light that is not flashing. This investigation sought to improve conspicuity by finding the optimal flash characteristics for a light on a background of steady lights. Twenty observers searched for a flashing point source of light among backgrounds of steady lights of various numerosities on a computer controlled CRT screen. They indicated which of the five screen sectors contained the flashing target, and the computer recorded the accuracy and response time. Targets were flashed at the rates of 1, 2, and 3.85 Hz, each at duty cycles of .3, .5, and .8 (proportion of total time on). After a brief practice period, each observer completed 360 trials in a single one-hour session. An ANOVA showed significant effects of frequency, duty cycle, and background light density. Search time increased as the number of background lights increased. Conspicuity improved as frequency increased and as duty cycle decreased. The flash pattern that provides the greatest conspicuity consumes the least amount of electrical energy, an important consideration for an aid to navigation. The results can be used as guidelines for the flash characteristics of lighted aids to navigation.

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CONSPICUITY OF AIDS TO NAVIGATION:
I. TEMPORAL PATTERNS FOR FLASHING LIGHTS

Lights used by the U.S. Coast Guard as aids to navigation are typically point sources that are easily confused with the background clutter of lights on shore. The problem is especially severe along channels and in harbors, where the density of background lights is high (Worthey, 1988) but accurate navigation is most important. This problem is one of conspicuity of signals. Conspicuity refers to the likelihood that a stimulus will be noticed: "Conspicuous objects are easily noticed, whereas inconspicuous ones require as a rule considerable search time" (Engel, 1971).

Over 20 years ago, a working group (Benson, Brown, Douglas, Riney, Taylor, & Duntley, 1971) looked into the problem of conspicuity of navigation lights in harbors, and made two recommendations: first, that research be conducted to improve conspicuity, and second, that legal regulations be instituted that would control the lights that interfere with the conspicuity of navigation lights. The latter has never occurred. The present research supplements previous efforts that have addressed the first recommendation.

To summarize previous results, we see that conspicuity is, not surprisingly, dependent upon such physical characteristics of the target signal as size, luminance, contrast, flashing, movement, and distinctive spatial characteristics, and it is also affected by the characteristics of the surround, such as the number of distractors (Boersema, Zwaga, & Adams, 1989). A difference in size between target and background is more effective in increasing conspicuity than is a difference in luminance (Jenkins & Cole, 1982). And when mean size and luminance are held constant, an increase in the variability of the size of the background stimuli decreases the conspicuity of a given target (Cole & Jenkins, 1984). High density backgrounds cause less reduction in conspicuity of large targets than small ones (Mandler, 1989). Flashing lights have greater conspicuity than fixed lights (continuously on, or steady) (Mandler, 1989). Conspicuity increases with velocity; horizontal movement of a vertical line segment is more effective than horizontal movement of a horizontal line segment or a dot, and horizontal movement increases the conspicuity of a horizontal line and a dot equally (Mori, 1985).

In considering these findings for application to navigation lights, there are practical limits to their use. The size of navigation lights can be increased only to a very limited extent. For example, at a distance of only two nautical miles, a beacon subtending a visual angle of only 10 min arc would have to be 10.8 m (35 ft) long. As noted above, there is usually no control over the clutter of background lights, and producing a moving beacon is expensive. Consequently, we must often be satisfied with small increments when making improvements in conspicuity.

One obvious method for improving conspicuity is to increase the luminance or contrast of a light compared with the background lights, but this too can be done only within rather narrow limits. Unless the lights are ashore, increasing their intensity often requires larger batteries and solar panels to provide the energy. The Coast Guard therefore desires signals with greater attention getting power without the consumption of more electrical power.

Literature suggests that another method for improving the conspicuity of a signal is to have it blink, or flash, which could also decrease power consumption. The following studies have shown that flashing lights can be an effective attention getting device, although little research has been done to date on their use as navigation lights in harbors.

In a series of studies, Gerathewohl determined conspicuity by measuring the observer's speed of response to a light signal while performing visual and auditory distractor tasks. In one study (Gerathewohl, 1953), he found that conspicuity of a signal flashing at 1 Hz with a duty cycle (the proportion of time that the light is on during its total cycle) of .2 on a background of distractor lights was better than a steady signal, but only under low brightness contrast conditions. In a subsequent study, Gerathewohl (1954) found that at low contrast, conspicuity increased as frequency increased from 1 Hz to 4 Hz at a 0.5 duty cycle. At higher contrast levels, the frequency effect was not significant. In a third study Gerathewohl (1957) investigated the conspicuity of lights flashing at 0.33 Hz, 1 Hz, and 3 Hz at each of two flash durations, 0.1 s and 0.2 s. Increases in both frequency and contrast, but not duration, produced significant increases in conspicuity. At either high contrast or high frequency, a change in the other factor had little effect on conspicuity. The flash durations that were used confounded the effect of duty cycle.

Katchmar and Azrin (1956) studied the effectiveness of warning lights in a paired comparison paradigm. Subjects viewed a side-by-side pair of 1.8 deg diameter stroboscopic lights that flashed at 1 to 60 Hz and made judgments of which was the more effective warning signal. Maximum judged effectiveness was at 10 Hz. The effects of flash intensity, duty cycle, or background were not investigated.

As part of a display coding study, Smith and Goodwin (1971) compared search times for finding blinking versus non-blinking targets in CRT displays of alphanumeric items of four characters each. A 3 Hz flash rate at 0.5 duty cycle was used for the targets. A significant reduction in search time was found with blink coding for each of the three display densities tested, 20, 60, and 100 items.

Response time for observers to distinguish whether a large single light was flashing or steady was measured by Markowitz (1971). Flash rates ranged from 0.31 to 10 Hz, each at duty cycles of 0.2, 0.5, and 0.8. As one would expect, he found that signals that gave flash information earlier after trial onset afforded faster response times, which decreased with increasing flash rate and lower duty cycle.

Connors (1975) studied the conspicuity of point source steady and flashing lights of several brightnesses seen against a simulated star background. She found that flashing lights were acquired more frequently and more quickly than steady lights, although no differences were found for the four flash rates used, 1 Hz through 4 Hz, all at a duty cycle of .5. Increasing target luminance consistently improved performance.

In their study of air traffic control displays, Thackray and Touchstone (1991) redundantly coded target shape with flashing and/or color and measured detection time. The targets flashed at 4 Hz with a duty cycle of 0.5, and the screen background contained numerous changing symbols. Results showed that flashing targets were detected significantly faster than the non-flashing or colored targets.

Laxar and Luria (1993) studied a range of flash rates and duty cycles in a task in which observers searched for a flashing annulus within a field of 49 steady annuli of the same size. Flash rates were 1, 2, and 4 Hz at each of five duty cycles, from .1 to .9. Results showed that search time was significantly less with faster flash rates and lower duty cycles with the relatively large stimuli used in that study.

In a laboratory study to directly investigate a signal light's conspicuity on a background of lights, Mandler (1989) measured search time to find a small horizontal bar of light of various sizes within a background of point source lights on a CRT screen. Targets subtended 1.8 arc min in thickness and from 5.3 to 28.0 arc min in length, and were either fixed on, as were the background lights, or flashing at 1 Hz with a duty cycle of 0.3, the typical Quick Flashing characteristic of lighted aids to navigation. It was found that search time significantly increased (conspicuity was reduced) with smaller target lengths and as the number of background lights increased from 0 to 400 lights per display screen. A greater number of background lights markedly increased search time for small targets, but had minimal effect on the largest targets. Flashing targets showed increased conspicuity over fixed targets at the smaller lengths, but not at the greater lengths. In addition, the number of background lights reduced conspicuity of the fixed targets much more than of the flashing lights. It was suggested that flash patterns other than the one used here be studied in the future to see if reducing the time between flashes improves conspicuity.

In a field study associated with the above experiment, Mandler (1989) installed seven target lights, consisting of vertical bars of light from 5 to 14 min arc, on the waterfront of a harbor. Conspicuity was measured by the proportion of observers that correctly located a target within a set period of time from target onset. Targets that were larger or that were viewed against a lower density of background lights yielded a higher probability of detection. It was noted that background lights in a harbor are not all point sources, but that there are a great number of vertical and horizontal light sources caused by reflections off various surfaces. It was therefore suggested that targets with oblique orientations, as well, be examined in future studies to see if they afford increased conspicuity.

As an extension of Mandler's (1989) investigations, the present studies were conducted with the objective of determining the conspicuity of lights of various flash characteristics and spatial configurations against backgrounds of small lights. In the first experiment, described here, the conspicuity of a small light on backgrounds of various numbers of steady lights was determined for nine different flash patterns. Response time to find a target was taken as a measure of conspicuity. This study was conducted to determine the optimal flash patterns for use on aids to navigation and in ensuing investigations of the conspicuity of various spatial configurations of lights, to be reported subsequently.

Method

Observers

Twenty volunteers served in this experiment, six men and fourteen women, nine of whom were paid subjects and the remainder laboratory staff. Their ages ranged from 21 to 62 years, with a median age of 32 years. All had normal visual acuity or were corrected for the eye-to-screen viewing distance. Most had experience as psychophysical observers.

Apparatus and Display

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. All stimuli were white in color. 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 single flashing pixels, 2 arc min per side. On any given trial they were flashed in one of nine flash patterns, combinations of three frequencies, 1 Hz, 2 Hz, and 3.85 Hz, and three duty cycles, approximately 0.3, 0.5, or 0.8. The actual timings are given in Table 1, and were constrained by the 20 ms clock interval of the computer system. Background lights, always fixed on, were square and either 2 or 4 arc min per side. At these subtenses all stimuli looked like points of light.

The target was placed randomly within the search area, 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 response buttons on a keypad. The computer recorded the response time and sector chosen.

Four levels of background, 0, 50, 200, or 400 lights per display screen, were presented in random order. These lights were placed randomly within the search area such that each light was at least 12 arc min (6 pixels) from its nearest neighbor. This separation minimized the effects of spatial summation, by which nearby lights can summate and produce an area that appears brighter than the individual lights. Target lights were also randomly placed on the screen, and were at least 12 arc min from any background light. An example of a stimulus display is shown in Figure 1.

The luminances of the stimuli were set so that the target light and the two sizes of background lights had the same average level of detectability. This was done to help ensure that the conspicuity of a target was purely a function of its flash pattern and not confounded by brightness. To do this, the mean brightness threshold, the average luminance to just detect the light, was measured beforehand in a group of 10 observers. In separate sessions, thresholds were determined by means of a modified staircase procedure using 1-second stimulus exposures. For the experiment, the luminance for all targets was 13

Table 1

Flash Characteristics of Target

Frequency (Hz)	Duration On (ms)	Duration Off (ms)	Total (Period) (ms)	Duty Cycle
3.85	80	180	260	.31
2.0	160	340	500	.32
1.0	300	700	1000	.30
3.85	120	140	260	.46
2.0	240	260	500	.48
1.0	500	500	1000	.50
3.85	200	60	260	.77
2.0	400	100	500	.80
1.0	800	200	1000	.80

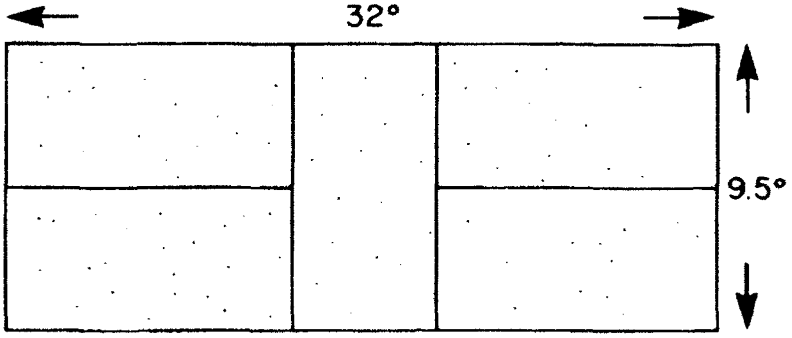

Figure 1. Stimulus display, showing the five search sectors.

cd/m^2, 30 times the single pixel threshold. The luminances of the background lights were randomly set at between 23 and 47 times their respective thresholds so that their mean luminances (13 cd/m^2 for the single pixel and 5 cd/m^2 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^2, 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

Instructions were presented and the observer was seated in a darkened room for five minutes to adapt to the low level of screen luminance. After 36 practice trials to familiarize the observer with the task, the experiment was begun. The session consisted of 360 trials, combinations of 3 frequencies x 3 duty cycles x 4 background densities x 10 repetitions (blocks).

At the start of each trial, a tone sounded to alert the observer. 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, and the computer recorded the sector chosen and the response time to the nearest 20 ms. 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 inform the observer of its location. The trial was then terminated and a response time of 20 seconds was recorded. The experimental session took approximately 55 minutes to complete.

Results

Response Time

Mean response times (RTs) of all 20 observers were calculated for each experimental condition in each of the 10 blocks of trials. The means were then subjected to a logarithm$_{10}$ transformation to bring the RT distributions closer to normal distributions. This is often done on RT data to reduce skewness and make the variances of the distribution homogeneous, as required for subsequent parametric analyses.

A repeated measures analysis of variance (ANOVA) with main effects of duty cycle, frequency, background, and block was computed on the log mean RT data from the 20

Table 2

Summary of ANOVA for Response Times

Source	*df*	*F*
Duty Cycle (D)	2, 38	97.7**
Frequency (F)	2, 38	158.0**
Background (B)	3, 57	176.3**
Block	9, 181	2.2*
D x F	4, 76	12.1**
D x B	6, 114	34.5**
F x B	6, 114	40.3**
D x F x B	12, 228	5.8**

$^*p < .05$. $^{**}p < .001$.

observers. All main effects were significant. Table 2 summarizes the results of this ANOVA. Figure 2 shows the response time by duty cycle for the four background densities. In this figure, as well as in Figures 3 and 4, each data point represents the mean of 600 observations. At a background of 0 (no background lights) RT for all duty cycles was -0.13 log s (0.74 s, typical for choice RT). With any number of background lights present, however, RT increased markedly, and showed slight increases from 50 to 400 lights. Duty cycles of .3 and .5 produced very similar RTs, whereas the 0.8 duty cycle produced much longer RTs, and was the source of the significant Duty Cycle x Background interaction.

As a post hoc test of the differences among the four background means, the Peritz technique (Martin & Toothaker, 1989), a refinement of the Newman-Keuls procedure, was used. This showed that all means were significantly different from each other (p < .01) except for the 200 and 400 lights. The Peritz test also showed that the duty cycles of .3 and .5 were not significantly different from each other, but were both significantly different from the .8 duty cycle (p < .01).

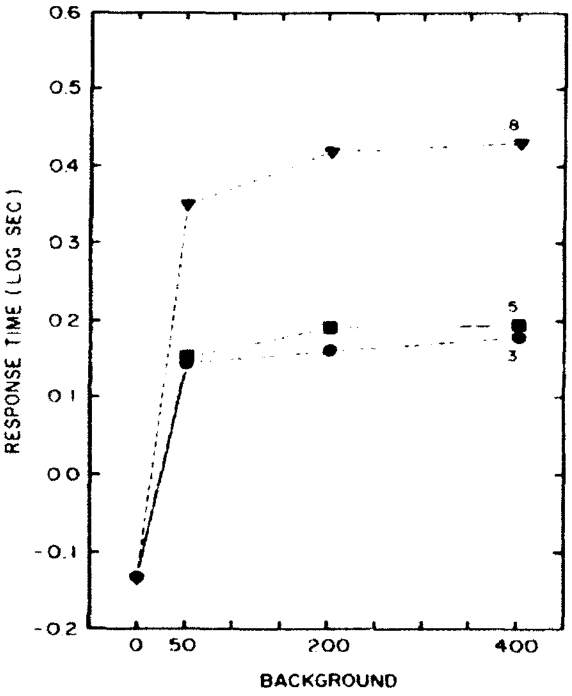

Figure 2. Mean response time for three duty cycles by number of background lights, collapsed across frequency.

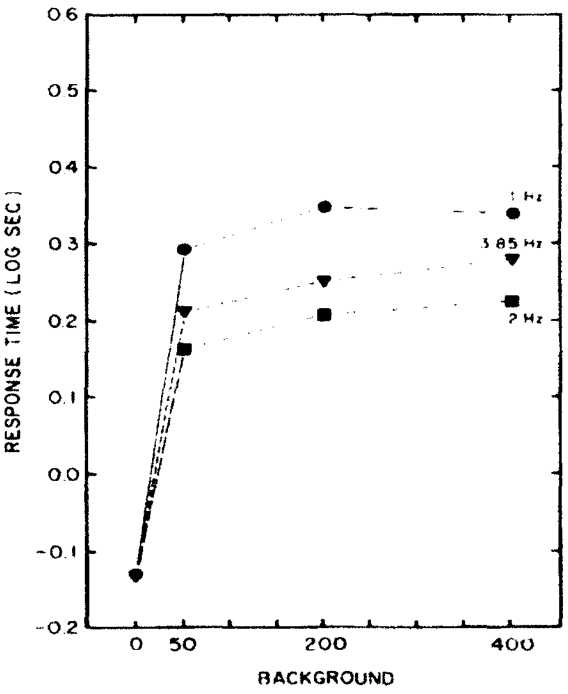

Figure 3. Mean response time for three frequencies by number of background lights, collapsed across duty cycle.

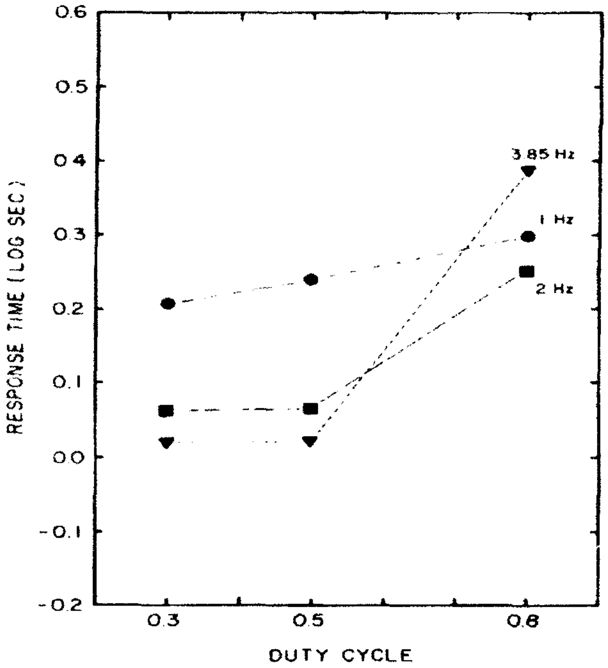

Figure 4. Mean response time for three frequencies by duty cycle, collapsed across background.

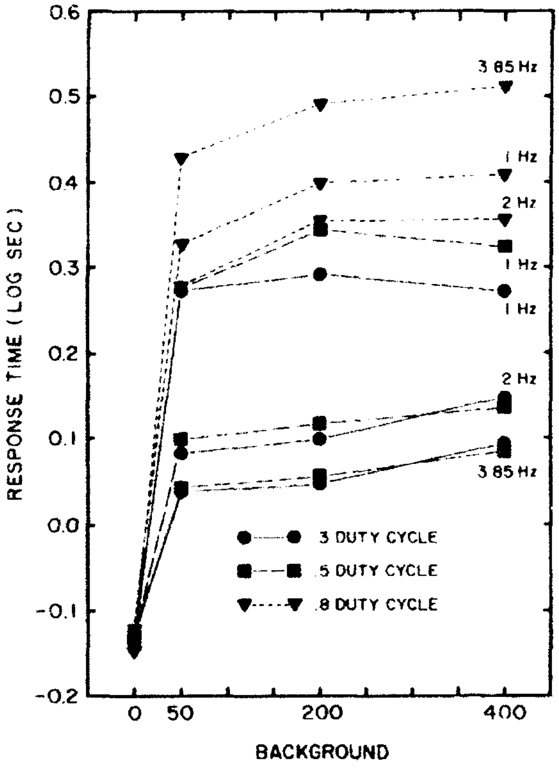

Figure 5. Mean response time for three frequencies at three duty cycles by number of background lights.

Figure 3 presents the three frequencies as a function of background. The Peritz test indicated that the means for all three frequencies were significantly different from each other ($p < .01$). The 3.85 Hz frequency, however, fell between the other two, a result that was unexpected. We then examined the significant Duty Cycle x Frequency interaction, as illustrated in Figure 4. We see that, generally, RT increases with both duty cycle and frequency, but because the 3.85 Hz frequency at the .8 duty cycle produces the longest RT of all, the mean RT for that frequency was pulled above that of 2 Hz.

The triple interaction of Duty Cycle x Frequency x Background is illustrated in Figure 5. Here, each data point represents the mean of 200 observations. RTs for duty cycles of .3 and .5 at frequencies of 2 Hz and 3.85 Hz are substantially faster than the rest, with the .8 duty cycle at the 3.85 Hz frequency slower than the rest.

RT means showed a small (12%) increase over blocks during the experimental session, suggesting a slight fatigue effect. There was no interaction of block with flash characteristics, however.

Prior to these analyses, the data were examined to determine the frequency of time-outs, that is, trials in which the observer could not find the target and for which a search time of 20 s was assigned. The time-out rate was extremely low, only 14 out of the 7200 trials. Interestingly, all were at the .8 duty cycle. Since they were so infrequent and approximately equally distributed across flash frequency and background density, their effect was negligible on the means reported here.

Error Rate

Errors, trials on which the observer indicated the wrong sector as containing the target,

Table 3

Error Frequency and Percent by Flash Condition

	Duty Cycle				
Frequency	.3	.5	.8	Total	
1.0 Hz	24	27	34	85	(48%)
2.0 Hz	12	16	14	42	(24%)
3.85 Hz	12	03	35	50	(28%)
Total	48 (27%)	46 (26%)	83 (47%)	177	(100%)

were rerun later in that block so that all observers had an RT score for every trial. The computer kept track of the errors, however. The error rate was low, 2.5%, with the highest number of errors occurring at the .8 duty cycle and at the flash frequency of 1 Hz. Table 3 gives the error frequencies by flash condition. While error rate was nearly evenly distributed across the three background light conditions, even the 0 background condition showed errors, evidence of the observers trying to minimize their RTs. This may have been the cause of many of the errors, especially at the 1 Hz frequency, where observers may have been trying to "jump the gun."

Discussion and Conclusion

The results obtained in this study are in keeping with those found previously by Gerathewohl (1954, 1957) and by Laxar and Luria (1993), which indicate that conspicuity improves with an increase in frequency and with a decrease in duty cycle . Both of these studies were quite different than the one reported here, however. Gerathewohl had observers indicate the appearance of a relatively large light stimulus in a known location while performing auditory and visual distractor tasks. In his study of flash characteristics (Gerathewohl, 1957), frequency was confounded with duty cycle, so that conclusions about the optimal duty cycle can not be drawn.

In the Laxar and Luria (1993) experiment, the stimuli used were large (0.23 deg to 1.26 deg) annuli, very different from the small points of light seen along a shoreline. In addition, only one small number (49) of background stimuli were used, rather than the high numerosity typically encountered in a marine navigation setting.

The results of the present study show that when there are no background lights, conspicuity of a flashing light as measured by search time is virtually the same for the nine flash patterns tested. With the presence of background lights, however, it is clear that duty cycles of .3 and .5 afford superior conspicuity to the .8 duty cycle (Figure 2). This result is fortunate in regard to electrical energy requirements, an important consideration for an aid for navigation. The duty cycle that is most conspicuous also consumes the least energy, since the light is on for the smallest proportion of time.

Figure 4 shows that for duty cycles of both .3 and .5, the 3.85 Hz frequency yields slightly faster search times than the 2 Hz, both of which are much faster than the 1 Hz. Figure 5 shows that this holds true over all densities of background lights. The reason for the unusually long search time for the 3.85 Hz frequency at a duty cycle of .8 can be seen in Table 1. Here, we see that the light is on for

200 ms and off for only 60 ms during its cycle. Evidently, that 60 ms off time was too short to be readily perceived by the observers. This condition produced not only the longest search times, to the point of causing the only time-outs in the experiment, but also produced the highest error rate, as shown in Table 3. The timing of the stimuli on the display screen was verified by measurements using a fast-response photodiode and oscilloscope. They indicated that the appearance of the stimuli was not influenced by artifacts due to computer timing or persistence of the display screen phosphors.

We conclude that for maximum conspicuity of a lighted aid to navigation used against a background of small steady lights, a higher frequency, such as 4 Hz, and a lower duty cycle, such as .3 should be used. With the use of different experimental apparatus, this study could be extended to include higher frequencies and lower duty cycles, as suggested by the Katchmar and Azrin (1956) study, which found that stroboscopic flashes of 10 Hz were judged better warning signals.

The high frequency and low duty cycles found here will be used for the subsequent study of the conspicuity of various spatial patterns of flashing lights. These results will be reported in a subsequent publication.

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FIELD	GROUP	SUB-GROUP

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Aids to navigation; conspicuity; target detection; flashing stimulu; flash rate; visual displays; visual search; vision

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

Mariners frequently have trouble picking out lighted aids to navigation in harbors and other areas that have a high density of background lights. The U.S. Coast Guard is seeking ways to enhance the conspicuity, or likelihood of being noticed, of these aids. Literature has shown that a flashing light is more conspicuous than a light that is not flashing. This investigation sought to improve conspicuity by finding the optimal flash characteristics for a light on a background of steady lights. Twenty observers searched for a flashing point source of light among backgrounds of steady lights of various numerosities on a computer controlled CRT screen. They indicated which of the five screen sectors contained the flashing target, and the computer recorded the accuracy and response time. Targets were flashed at the rates of 1, 2, and 3.85 Hz, each at duty cycles of .3, .5, and .8 (proportion of total time on). After a brief practice period, each observer completed 360 trials in a single one-hour session. An ANOVA showed significant effects of frequency, duty cycle, and background light density. Search time increased as the number of background lights increased. Conspicuity improved as frequency increased and as duty cycle decreased. The flash pattern that provides the greatest conspicuity consumes the least amount of electrical energy, an important consideration for an aid to navigation. The results can be used as guidelines for the flash characteristics of lighted aids to navigation.

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