

Naval Submarine Medical Research Laboratory

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FREQUENCY OF A FLASHING LIGHT AS A NAVIGATIONAL RANGE INDICATOR

by

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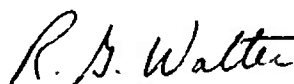
NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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SUMMARY PAGE

THE PROBLEM

To determine the navigation performance of observers using a simulated navigational aid proposed by the U. S. Coast Guard. The aid is a single-station flashing or flickering range indicator, which would indicate lateral position in a channel by varying the flash frequency observed by the vessel operator, with a steady light seen when on the centerline and an increasing flash rate as the edge of the channel is approached.

FINDINGS

The ability of observers to detect motion across a channel's width was measured over a range of flash frequencies. The sensitivity to lateral motion afforded by this type of indicator was found to be potentially quite high, but the magnitude of the uncertainty in the judgments of motion would considerably reduce the operational sensitivity of such a device.

APPLICATION

These findings describe the navigational sensitivity afforded by a frequency-encoded single-station range indicator. They will allow comparison with other proposed single-station range indicators and with current two-station parallax range indicators.

ADMINISTRATIVE INFORMATION

This study was conducted at the Naval Submarine Medical Research Laboratory under Contract No. MIPR Z51100-9-0002 with the U. S. Coast Guard Research and Development Center, Groton, CT. The manuscript was submitted for review on 14 December, 1989, approved for publication on 12 February 1990, and has been designated as NSMRL Report No. 1157.

ABSTRACT

This study is part of a U. S. Coast Guard evaluation of navigational aids for indicating whether a vessel is proceeding properly along a channel or "range." The effectiveness of a single-station flashing or flickering range indicator was examined. This aid would indicate lateral position in the channel by varying the flash frequency, with a steady light seen when on the centerline and an increasing flash rate as the edge of the channel is approached. Positions to the left or right of the centerline would be encoded by the light flashing red or green.

The range indicator was simulated by flashing a light at a 50% duty cycle and a 100% square-wave modulation at one of five base frequencies, from 0.5 Hz to 6.7 Hz. Four observers judged when they could detect a just noticeable change in frequency when the rate was slowly increased or decreased. Results showed that the detectable difference in frequency increased linearly as base frequency increased, and that there were 24 just noticeable differences in the range of flash rates from 0 to 6.7 Hz. When displayed over a 500 ft (152 m) channel width, a maximum sensitivity threshold of 10.6 ft (3.2 m) could be realized. Given the large uncertainty (standard deviations) found in the judgments, however, the operational sensitivity of such a range indicator would be considerably less.

FREQUENCY OF A FLASHING LIGHT AS A NAVIGATIONAL RANGE INDICATOR

The U. S. Coast Guard is evaluating methods for indicating to a navigator whether his ship is proceeding properly along a channel or "range." A general question is whether the two-station or parallax range indicator can be replaced by a single-station device. Previous publications have assessed navigators' performance using several types of parallax ranges (Laxar and Mandler, 1989) and a rotating beam type of single-station range indicator (Luria, 1990).

The present study examines the effectiveness of a single-station flashing or flickering range indicator, which would indicate lateral position in the channel by varying the flash frequency. When on the centerline, the navigator would see a steady light. As he moves off the centerline, the light would start to flash on and off, increasing in frequency with distance from the centerline. Added chromatic information would indicate the left or to the right side of the channel. For example, moving to the right could be signalled by a flashing red light, and moving to the left by a flashing green light. The range centerline position could be indicated by a steady white light.

The basic question to be answered in this study is how well observers can discriminate frequency of a flashing light. Several earlier studies have investigated this problem. Mowbray and Gebhard (1955; Gebhard, Mowbray, & Byham, 1955) had observers view a test stimulus flashing at a standard frequency and then at a comparison frequency. The observer could adjust the comparison frequency to appear equal to the standard, switching between the two to make successive comparisons. The difference threshold, Δf , was measured as the average deviation of the settings from the standard frequency. They found that between 1 and 20 Hz, Δf approximated a monotonically increasing function ranging from 0.01 to 0.61 Hz.

Considerably higher difference thresholds, approximately 0.3 to 2.4 Hz for standard frequencies from 5 to 20 Hz, were found by Brown (1959). The higher thresholds were attributed to the two-alternative forced choice method that Brown used. Comparable results were found by Mandler (1984) using a sinusoidally flickering light and a method similar to Brown's.

The above studies used a relatively large (1° diameter visual angle), bright test stimulus on a large 71° or 24° diameter illuminated field. The difference thresholds, therefore, may not represent those of a single-station range indicator, which would approximate a point source in a dark field.

Other studies in the literature (for example, Gebhard, Duffy, Mowbray, & Byham, 1956) have used electrical stimulation

of the retina rather than photic stimuli to assess frequency discrimination of the visual sense modality. The monotonic functions and values of Δf typically found for standard frequencies up to approximately 20 Hz are similar to those found in photic studies. However, their relevance to the specific conditions of interest here are, like the previously mentioned studies, questionable.

Equally important is that none of the above methods studied the difference thresholds of a constantly flashing light as it slowly changed frequency, as would be the case with a flashing range indicator when a vessel traveled across the width of the range. The present study, therefore, was conducted to measure frequency difference thresholds under conditions simulating the appearance of a flashing range indicator.

Method

Observers

Four men, ages 23 to 59 (median = 39.5 years), served as observers. All had 20/25 or better visual acuity, with correction if required, and had considerable psychophysical experience.

Apparatus

The light source was a diffused white beam that subtended a visual angle of 1.9 arc min at the 6 meter viewing distance. The steady-state luminance of the light was 41 cd/m². The 0.5 duty cycle of the light was modulated by a rotating half-sector disk mounted on a rheostat-controlled electric motor. By adjusting the speed of the motor, the light could be made to flicker at the desired frequency, which was calibrated at the slower speeds by a stop watch and at the higher speeds by a Strobotac (General Radio Corp.). Five base frequencies were used: 0.5, 1.0, 2.0, 4.0, and 6.7 Hz.

Procedure

The observer sat in a dark room that was dimly illuminated by a 15-Watt lamp in one corner to reduce the autokinetic effect. The apparatus, viewed binocularly, was set to one of the five base frequencies. The frequency was then slowly increased or decreased, at the rate of approximately 1 Hz in 30 sec, until the observer correctly reported "faster" or "slower," and the change in frequency was recorded. On the average, it took 9 sec for the observer to detect the change in frequency on each trial. A minimum of three such thresholds was determined for both faster and slower flicker rates at each base frequency. The base frequencies were chosen as representative of a useful range of discriminability, and their order of presentation was randomized

across observers. Observers were run in single sessions that lasted approximately one hour.

Results

The mean faster and slower frequency difference thresholds for all observers at each base frequency were calculated. Since the two thresholds were similar, their mean was calculated, and these difference thresholds (Δf) are shown as a function of base frequency in Figure 1. These mean thresholds, and their standard deviations across the four observers, are given in Table 1. As is typical with psychophysical studies of this type, the difference thresholds increase nearly linearly as base frequency increased over the range tested. The standard deviations also increase at the higher base frequencies. These results mean that the observer's sensitivity to changes in frequency decreases as the frequency of the flashing light increases. The increased flash rate would indicate being near the edge of the channel.

Table 1

Mean Difference Thresholds (Δf), their Standard Deviations, and Cumulative jnds for Base Frequencies (Hz) for Four Observers

<u>Base</u> <u>Frequency</u>	<u>Mean</u> <u>Difference</u> <u>Threshold</u>	<u>Standard</u> <u>Deviation</u>	<u>Cumulative</u> <u>jnds</u>
0.5	0.15	0.04	4
1.0	0.20	0.05	7
2.0	0.26	0.03	11
4.0	0.37	0.15	18
6.7	0.48	0.19	24

The mean difference threshold can be termed a just noticeable difference (jnd) in frequency. To determine the number of jnds within the range of 0 to 6.7 Hz, a linear regression function was fit to the threshold data shown in Figure 1, and smoothed values for thresholds were obtained for that range of frequencies. These jnds, which increased with frequency, were then summed up, resulting in 24 jnds within the 0 to 6.7 Hz range. The cumulative jnds are given by base frequency in Table 1.

Discussion

In order to relate the obtained frequency discrimination data to navigational performance, let us assume a range configuration as follows: channel width = 500 ft (152 m); distance from the navigational aid to the near end of the range = 2000 ft (610 m); distance to the far end = 6000 ft (1829 m) (see Figure 2). A lateral sensitivity factor, K, can be calculated as

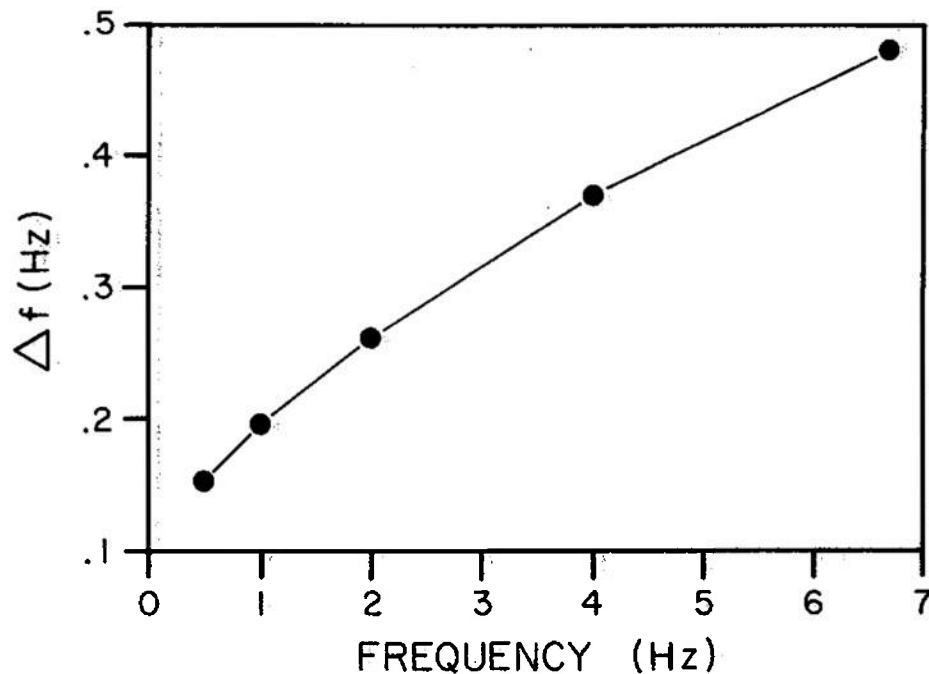


Figure 1. Frequency difference thresholds (Δf) by base frequency for four observers.

a function of channel width and the observer's distance from the range centerline and from the range lights (Commandant, U.S. Coast Guard, 1980; Laxar & Mandler, 1989). If this were a two-station parallax range, with appropriate choice of other parameters such a range would span the optimal sensitivity factors of from $K = 1.5$ at the far end to $K = 4.5$ at the near end. If the range of flash frequency 0 to 6.7 Hz were displayed across each side of the 500 ft channel width (one side red, the other green) at the far end of the range, as shown in Figure 2, each half would contain a 0 Hz segment around the range axis plus 23 jnds, $1 + 2*(23) = 47$ jnds across the channel width. This would provide a sensitivity threshold of 10.6 ft (3.2 m) perpendicular to the range axis. At the near end of the range, the same angular display would subtend 167 ft (50.8 m), with a threshold sensitivity of 3.6 ft (1.1 m).

Any angular display, as described here, reduces the width of the channel encompassed by the display proportionally as one approaches the navigational aid. In the present case, the displayed channel width would decrease from 500 ft to 167 ft, which in many instances would be impracticably narrow. To expand the displayed width, it would be possible to use a wider angle of display and a greater range of flash frequencies. Previous studies have shown that the frequency difference threshold increases nearly linearly with base frequency up to about 20 Hz (Brown, 1959; Gebhard et al., 1955; Mandler, 1984; Mowbray &

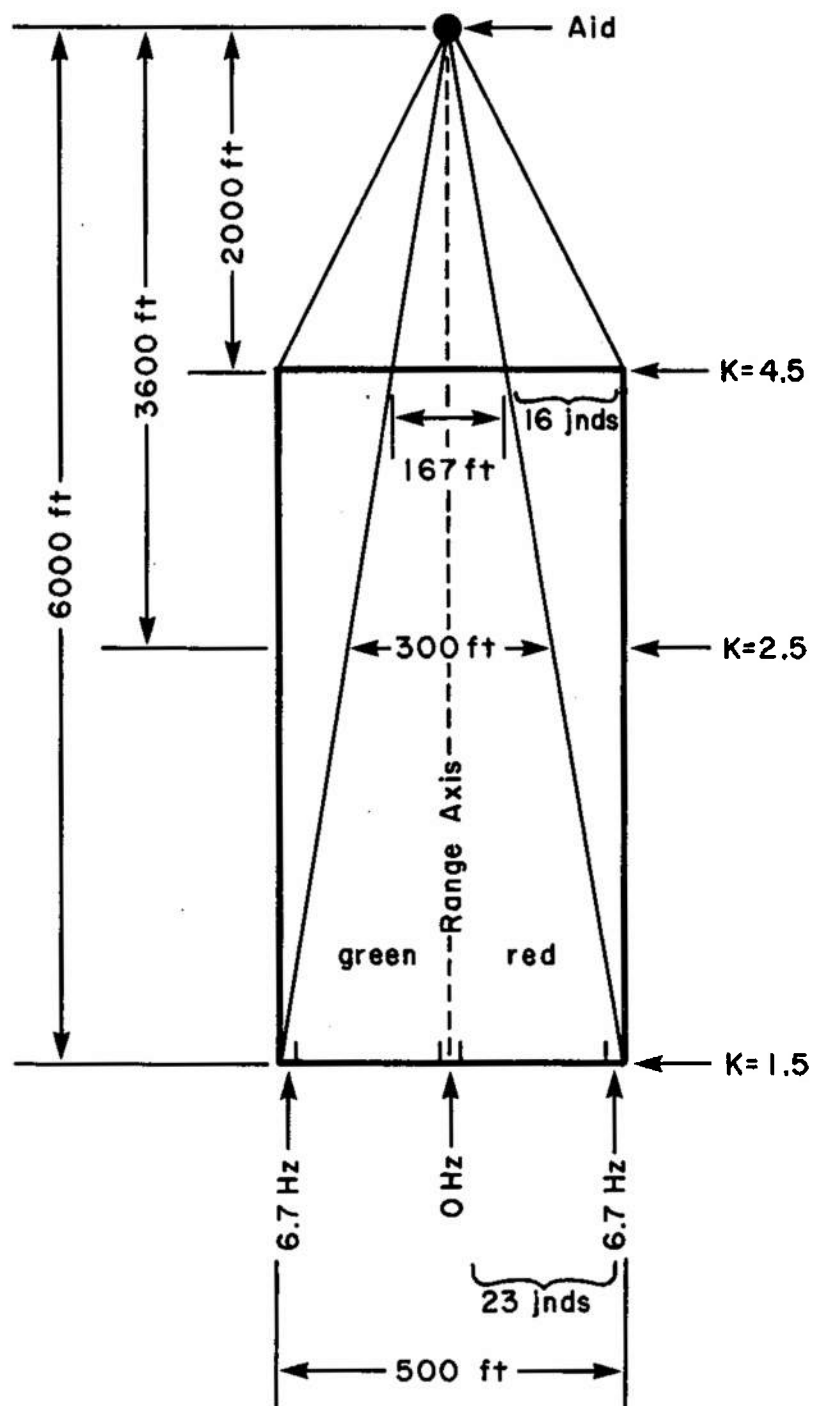


Figure 2. Single-station flash frequency range indicator display on an assumed range. K: equivalent range sensitivity factor.

Gebhard, 1955). In addition, the results of the present study show marked linearity between 0.5 and 6.7 Hz, and so it is reasonable to extrapolate these data up to 20 Hz as well. This would result in an additional 16 jnds on each side of the 167 ft central sector, for a sensitivity of 10.4 ft (3.2 m) at the outside segments of the range.

Rather than extending the angle of coverage of the range indicator, it might be more feasible to simply limit the dimensions of the range. For example, in the range shown in Figure 2, with full beam coverage of 500 ft channel width at a distance of 6000 ft, the indicator beam would cover 300 ft at a 3600 ft distance. This may be wide enough for many situations. The equivalent sensitivity factor in this case would be $K = 2.5$.

These results appear to indicate that a frequency encoded range indicator could provide lateral sensitivity equal to or greater than that of the current parallax range indicators. Several precautions should be taken, however, in interpreting the results obtained here. There are many factors that affect the perception of flicker which could influence the frequency difference thresholds and alter our conclusions. These include the luminance, size, and color of the light, the duty cycle, the waveform (e.g., square wave or sinusoidal) and amplitude of flicker, and the background luminance (see Brown, 1965, for a review of such factors). Operationally, factors such as atmospheric conditions and sea state could decrease an observer's sensitivity.

It should also be noted that not only the difference thresholds but their standard deviations increase with increasing frequency, as shown in Table 1. This would further tend to decrease sensitivity and increase uncertainty as one approached the edge of the channel. For these reasons, the results of this study can be taken only as tentative. The sensitivity afforded by an operational range indicator may be considerably less than that found here. Further simulations should be conducted to refine these conclusions.

The color coding of the two sides of the channel, as with any color coding, should be carefully considered. An appropriate red and green can be chosen so that most color defectives in the general boating public would not confuse the two, but either color might still be confused with other lights in the background. The flash characteristics may afford distinguishability for all observers.

Another aspect of color coding is to ensure preserving compatibility with the present lateral system of buoys. In keeping with the "red right returning" rule, the right half of the channel should be displayed in red and the left half in green for proceeding along channels leading in to port or up rivers.

For ranges displayed in the opposite direction, the right half of the channel should be displayed in green and the left half in red.

It may not be feasible to build a range display that shows a gradually increasing frequency of flash over an angle of subtense. It may be possible, however, to build a sectorized range indicator that displays a different flash frequency in sectors that are based on the 47 jnds determined in this study. Navigation performance would likely be similar to an indicator which displayed a gradual change in frequency.

This report describes the sensitivity of observers to gradual changes in the frequency of a flashing light, and relates this sensitivity to changes in lateral position in a navigational channel. A future report will compare these results with those from other proposed single-station navigational range indicators and from the current two-station range indicators.

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