Naval Submarine Medical Research Laboratory

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PERCEPTION OF TEMPORAL ORDER OF FLASHING LIGHTS AS A NAVIGATION AID

by

S. M. LURIA

Released by:

R. G. Walter, CAPT, DC, USN
Commanding Officer
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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
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SUMMARY PAGE

THE PROBLEM

To evaluate the effectiveness of a triplet of flashing lights as a navigation beacon. The lights should appear to be flashing simultaneously when viewed from the center of the channel and to flash sequentially when viewed from off center.

THE FINDINGS

The observers could always detect that the lights were not flashing simultaneously and could report their order of appearance when the mean temporal interval between the lights was about 10 msec. This corresponds to a navigation error of 26 yards at a distance of 1000 yards from the beacons and an error of 131 yards at a distance of 5000 yards.

APPLICATION

These results can be compared with similar evaluations for other types of navigation beacons in order to decide which is most effective.

ADMINISTRATIVE INFORMATION

This investigation was conducted under U. S. Coast Guard Work Unit No. NIPR-Z51100-9-0002. It was submitted for review on 9 November 1989, approved for publication on 4 January 1990, and has been designated as Naval Submarine Medical Research Laboratory Report No. 1155.

ABSTRACT

A set of lights flashing either simultaneously or sequentially was tested for effectiveness as a navigation beacon. The temporal interval between sequential flashes required for the perception of non-simultaneity averaged about 10 msec. The change in temporal interval required to see a difference increased as the initial temporal interval increased; it averaged about 18 msec when the lights were initially simultaneous to about 26 msec when the initial temporal interval was 33 msec. The temporal interval between the flashing lights required to perceive non-simultaneity appeared to increase when the lights were very dim and appeared to decrease when the viewing distance increased, although neither change reached statistical significance.

The U.S. Coast Guard Research and Development Command is considering a variety of novel ideas to aid in navigating along channels. Among them is the proposal to use triplets of lights which appear to flash simultaneously while sailing along the proper course in the channel and appear to flash at different times when off course; more specifically, when the ship is too far to the right of the proper course, the right light could appear to flash first, and when the ship is too far to the left, the left light could appear to flash first (Brown, 1982). The occurrence of this asynchrony would alert the navigator that he was off course and in which direction; he would then alter course until the lights were again flashing simultaneously.

Uttal (1970) has pointed out that the notion of simultaneity can have both a "strong" and a "weak" meaning. The weak definition is the set of responses to the question, "Were two stimuli perceived to occur at the same time?". The strong definition implies that stimuli are perceived as simultaneous because the information about their temporal order is actually lost in the nervous system. Uttal (1970) has argued that since there is much evidence that such information is not lost, the perception of simultaneity should not be considered a fundamental biological limitation, but should be defined operationally by the particular method used to measure it.

It is unusual in psychophysical experiments to measure visual thresholds at some fractional rate of perception, often the 50% point. For the present problem, this seems inappropriate. We need to know the minimum temporal interval at which observers reliably recognize that two lights are not simultaneous and can accurately judge which was presented first. Efron (1963) has pointed out that "it is possible for most subjects to be aware that the two stimuli are not simultaneous but yet be unable to identify which one is first", just as Sekuler et al. (1982) have stressed the difference in difficulty between seeing a moving stimulus and the difficulties in assessing its direction.

Several studies have attempted to measure the smallest temporal interval between two stimuli necessary to perceive temporal order. It is not clear how relevant most of them are. Many have used dichoptic (one stimulus to one eye and the second stimulus to the other eye) viewing (Robinson, 1967), or presented the two stimuli to different visual half-fields (Efron, 1963), or presented one stimulus to the fovea and the other in the periphery (Sweet, 1953; Lichtenstein, 1961; Hirsch and Sherrick, 1961; Corwin and Boynton, 1968; Rutschmann, 1966, 1973). Moreover, the temporal interval accepted for perception of non-simultaneity depends on the criteria set by the investigator. For example, Hirsch and Sherrick (1961) found that their subjects could report temporal order about 80% of the time with a temporal interval of 20 msec, but 95% accuracy required an interval of about 50 msec. (It should be noted that Sekuler et al. (1973) criticized Hirsch and Sherrick's report that 20 msec was the shortest temporal interval permitting the perception of temporal order; Sekuler et al. noted that Hirsch and Sherrick had not tested any intervals between 0 and 20 msec.) Mayzner and Agresti (1978) presented two stimuli centered about the fovea. There was a temporal interval of 0 msec, and they were interested simply in response biases. Using these different experimental conditions and criteria, these studies have concluded that the perception of temporal order requires a temporal interval of from 10 to 50 msec.

The studies in which one stimulus was foveal and the other peripheral are not applicable, because it is clear that it takes significantly longer to perceive a stimulus in the periphery than at the fovea. The studies with the stimuli presented to different eyes are wholly inappropriate.

In the situation we are concerned with, the signal lights will be foveal and be seen by both eyes. Only two studies fulfill this condition.

Lichtenstein (1961), in a rather unusual study, presented four lights in a diamond pattern subtending 1.5 deg around the fixation point. The four lights were flashed sequentially in different irregular temporal patterns. Starting with a slow flash rate which allowed the observers to perceive the sequential flashes, the flash rate was increased until the lights appeared to be flashing simultaneously. This occurred when the mean temporal interval was about 30 msec.

The study most relevant to the present problem, since their two stimuli were foveal, was carried out by Westheimer and McKee (1977). They presented two adjacent linear targets to the fovea at various temporal separations. They found that temporal order could be perceived when one was delayed by as little as 3 msec.

To properly design a navigation beacon, we must determine the smallest temporal interval which most viewers can perceive with reasonable reliability. And we must know what magnitude of navigation error can be signalled by such a system.

Experiment 1

Temporal Interval for Perception of Non-Simultaneity

METHOD

Subjects

Ten staff members of the laboratory volunteered to serve as subjects. They ranged in age from 23 to 59. All had 20/25 or better visual acuity with a correction if required. Most had had considerable experience as psychophysical observers.

Apparatus

The observers viewed three lights flashing every two seconds. At the usual viewing distance of 20 ft (6.1 m), the lights were 0.78 deg apart and subtended .01 deg. visual angle. The flash duration was about 50 msec. The three flashing lights were produced by three rotating cylinders. The first was rotated in one direction, and the second and third rotated in the opposite direction. The two outside cylinders rotated at a given speed, x, and presented two flashes for each rotation; the center cylinder rotated at

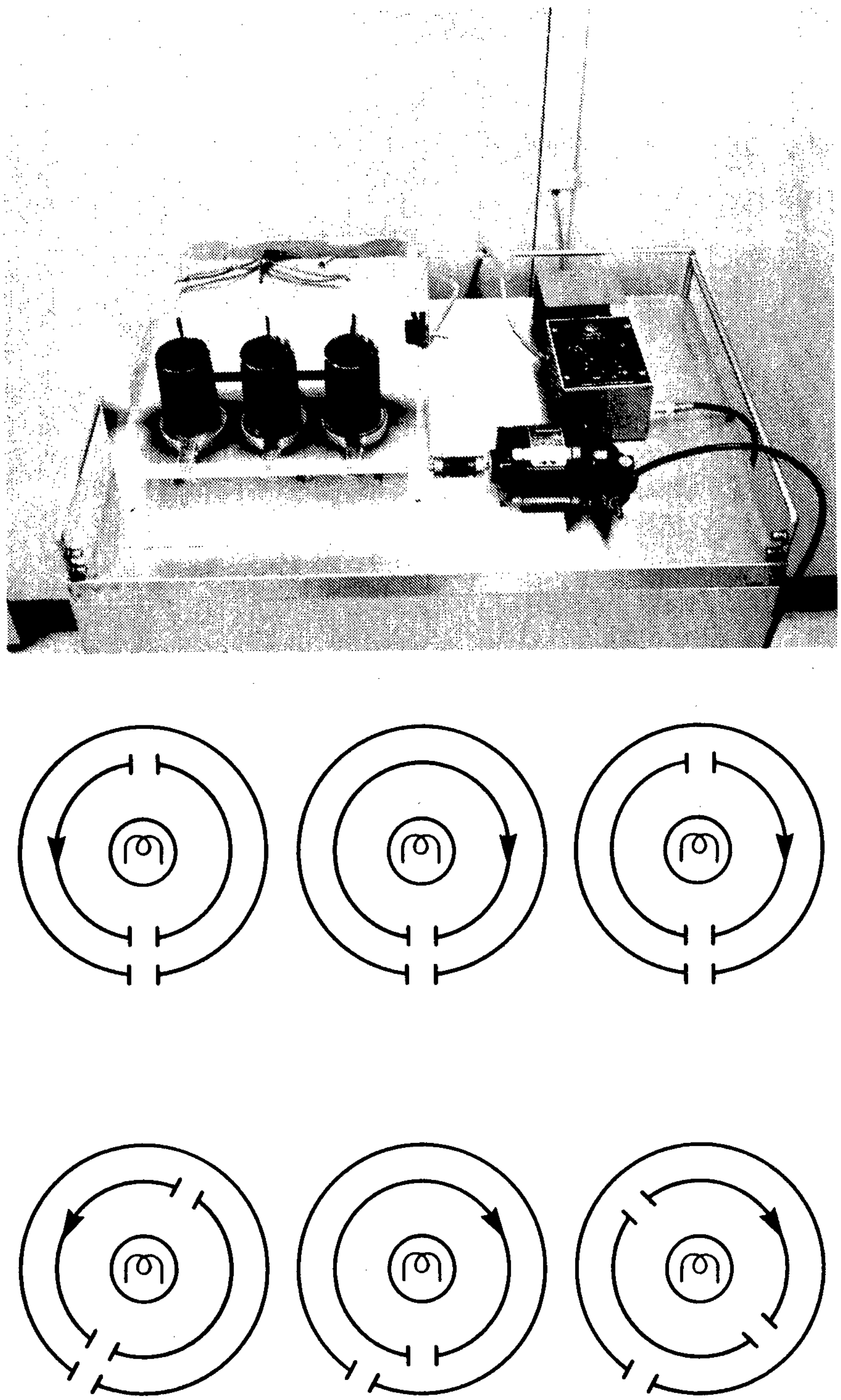

Figure 1. (Top) The apparatus. (Bottom) Operation of the sequential beacons. The interior cylinder on the left rotates counter-clockwise to produce one flash every two seconds through the two openings. The interior cylinder in the center rotates clockwise at twice that speed to produce one flash every two seconds with only one opening. The interior cylinder on the right rotates clockwise at the same speed at the left cylinder. The exterior cylinders can be rotated together to a given angle of off-center viewing. When they are rotated to simulate viewing from the left of center (bottom row), the left light will be seen first; the center light will be seen later but before the right light, since the center cylinder is rotating more rapidly.

twice that speed, 2x, and presented only one flash per rotation. This arrangement produced simultaneous flashes when viewed head-on and sequential flashing of the three lights when viewed from off center. Figure 1a shows a photograph of the apparatus, and Figure 1b explains its operation. The experiments were carried out in a room illuminated by a 15 watt bulb facing one wall. This provided a small amount of ambient illumination which precluded the autokinetic illusion.

Procedure

Although most of the subjects in this study had had considerable experience as observers in psychophysical experiments, each first participated in several practice sessions prior to the study.

The observers were adapted to the ambient illumination for two minutes. They viewed the set of lights either directly head-on or at various eccentric angles. Rather than move the observers back and forth, the apparatus itself was angled to produce the off-center viewing angle. The magnitude of the temporal interval between the flashes needed for a correct judgment of temporal order (left light first vs. right light first) was measured. All thresholds were obtained with the method of constant stimuli. A given angle of view was set and the flashing lights exposed until the observer made a judgment. The lights were occluded while a new angle of view was set, and so on. Two thresholds were calculated; one was the viewing angle at which the observer correctly identified the temporal order on every presentation. In addition, a probit analysis was carried out to determine the 95% threshold.

RESULTS

Table 1 gives the mean temporal intervals between the adjacent flashes required to identify the temporal order.

Table 1
Mean temporal intervals (msec) between adjacent flashes required to identify temporal order on 100% and 95% of the trials with a display of three sequential lights

	100%	95%
MEAN	9.8	8.4
S.D.	4.36	4.21
UPPER RANGE	16.02	15.04

Experiment 2

Difference Thresholds for Various Disparities

I next measured the amount of change in the temporal interval between the flashing lights which the observers needed to perceive a change. Starting with various degrees of non-simultaneity in the three flashing lights, I measured the difference threshold for both increasing and decreasing temporal intervals. This simulated a situation in which the navigator was off course when he first saw the beacons. How much of a change in course is required before he can detect a change in the flashing display?

METHOD

Subjects

Ten staff members observed. Their ages ranged from 23 to 50. Eight had participated in the first experiment.

Procedure

The three-light display was flashed every two seconds. It was exposed at a viewing angle of either 0, 1, 2, 4, or 6 deg to the right or left of the line of sight perpendicular to the display. (These corresponded to calculated temporal intervals of 0, 5.6, 11.1, 22.2, and 33.4 msec.) The viewing angle remained constant for a random variable period between 5 and 10 seconds, after which it was either reduced or increased at the rate of 5 deg/minute. The subject was not told when this change began or in which direction it would be changed. He reported when he detected a change in the flash pattern and also whether the change was toward more or less simultaneity. Incorrect responses were not recorded; the trial was repeated at some random time later in the session.

RESULTS

Figure 2 shows the mean difference thresholds both in terms of the change in the viewing angle and in the temporal interval for each of the five starting positions. Table 2 gives the standard deviations of these values showing the variability between subjects. There are, of course, no data for decreasing temporal interval when the starting point is 0^{o} off center, which is simultaneity.

It should be noted at once that these results are the means of only nine observers. Although all the observers reported that it was a difficult judgment, there were wide individual differences. One observer could not do it at the 4 and 6^{o} conditions. He was not replaced as a subject, because his difficulties constitute an important statement about this type of navigation aid.

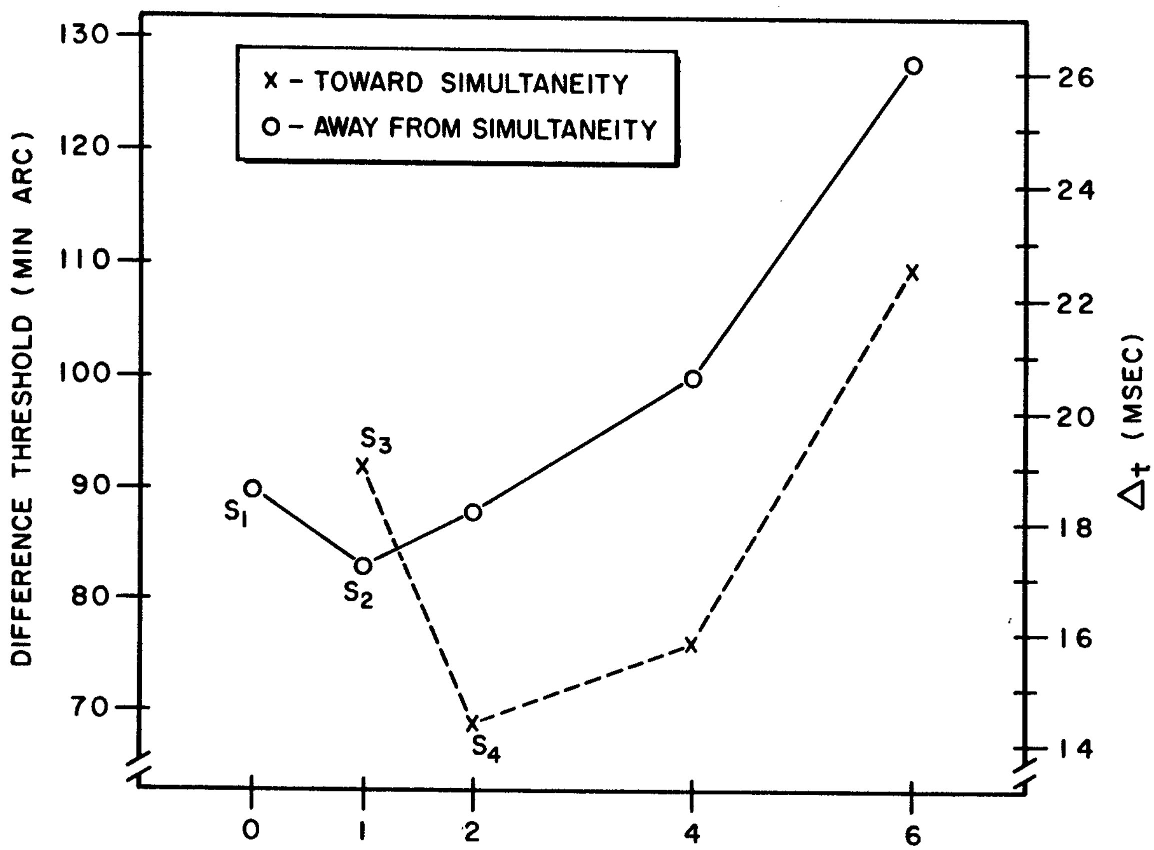

Figure 2. Difference thresholds in either minutes of arc of viewing angle or milliseconds of temporal interval as a function of initial degrees of off-center viewing for changes toward or away from simultaneity. S1, S2, S3, and S4 are referred to in Figure 3.

Table 2
Difference Thresholds (Mean and S.D.) for
Various Initial Temporal Intervals (msec)

Initial Temporal Interval	Toward Simultaneity	Away from Simultaneity	Mean
0	-	18.4 ± 5.3	18.4 ± 5.3
5.6	18.7 ± 5.8	17.0 ± 7.2	17.8 ± 5.7
11.1	14.1 ± 12.1	18.0 ± 9.1	16.0 ± 8.4
22.2	15.5 ± 4.3	20.3 ± 7.1	17.8 ± 5.3
33.4	22.4 ± 9.5	26.1 ± 14.2	24.2 ± 10.2

Table 3
Mean Difference Thresholds (min arc)
for Various Starting Positions
from the Center Line (Mean and S.D.)

Initial Position	Toward Simultaneity	Away from Simultaneity	Mean
0°	-	90 ± 26	90 ± 26
1°	92 ± 28	83 ± 35	87 ± 28
2°	69 ± 59	88 ± 44	79 ± 41
4°	76 ± 21	100 ± 35	88 ± 26
6°	110 ± 46	128 ± 70	119 ± 50

As the angle of the starting position from the center line increased (and, therefore, the magnitude of the temporal interval between the flashes increased), it generally became more difficult for the subjects to detect a change in the flash pattern. The overall change was highly significant ($X^2 = 11.93$, $p < .01$) according to the Friedman Analysis of Variance by Ranks. Judgments of decreasing temporal interval appear to be easier than judgments of increasing temporal interval, but these differences were significant ($T = 6$, $p < .05$) only for the 4° data according to the Wilcoxon

Matched-Pairs Signed-Ranks Test.

The mean change in viewing angle varied from about 80 min arc for a starting position of 2^{o} off center to 119 min arc when the starting position was 6^{o} off center. These corresponded to changes in the temporal interval of 14 and 26 msec.

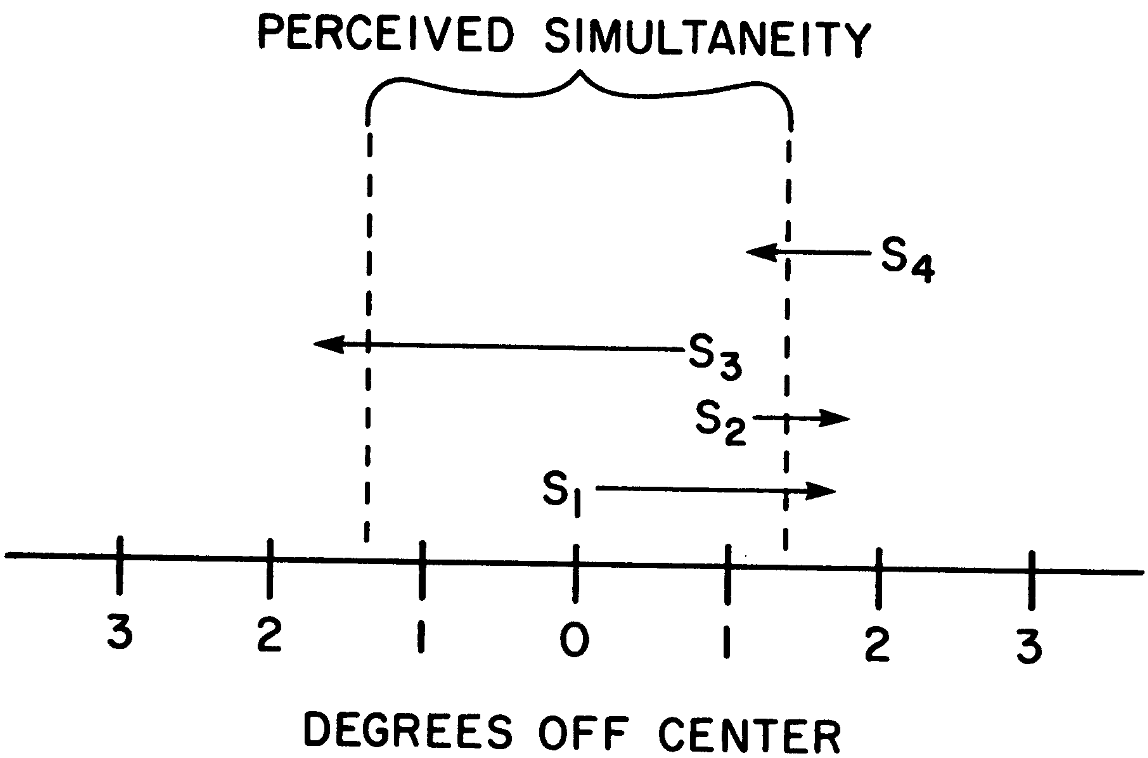

Figure 3. Explanation of non-monotonic curves in Figure 2. The lights are seen as flashing simultaneously through a certain range of temporal intervals (or degrees off the center line). If the starting point is simultaneity (S1), a certain increment of temporal interval is required to see a change. If the starting point is near the threshold of non-simultaneity (S2), then a smaller temporal increment is required. Similarly, if the starting point is just inside the threshold value (S3), a large temporal decrement is required to see a change. If the starting point is just outside the threshold value (S4), a smaller temporal decrement is necessary.

The curves are, of course, not monotonic. There is a drop in the thresholds around 1^{o} and 2^{o} after which the thresholds rise continuously. The explanation seems to be quite clear. It is diagrammed in Figure 3. There is a range of temporal intervals around simultaneity which a given subject cannot discriminate. When this range is exceeded, the subject does detect that the flashes are not simultaneous. For most subjects, this range encompasses a viewing angle of between 1^{o} and 2^{o}. If the starting position is 1^{o} off center, the resulting temporal interval is typically too small for the subjects to detect. However, only a small change is generally required for the subject to respond that the lights are no longer simultaneous. If the starting position is simultaneity, then, a larger change is required in order to get out of the range of perceptual simultaneity.

If the starting position is 2^{o} off center, this is typically just outside the range of perceptual simultaneity. Thus only a small decrease in temporal interval results in the subjects quickly reporting simultaneity. A much larger change is required if the temporal interval is increasing.

Experiment 3

Effects of Selected Variables

Several questions arise concerning the effectiveness of such a navigation aid. These studies were carried out at a constant viewing distance and at a constant luminance. As a practical matter, the beacons will of course be viewed at different distances. This will alter the separation of the lights and the extent of their projection on the retina. Similarly, the beacons may at times be viewed through a haze which would reduce their brightness. The following series of experiments sought to determine the effects of such variables on the temporal interval threshold.

It seemed desirable to conduct these studies with a simplified display of only two lights for several reasons. Several observers reported that the three lights did not always appear to be the same brightness. There were comments at times that the temporal intervals between the three lights sometimes seemed to vary. Other perceptual illusions were sometimes reported.

In order to see if the temporal threshold was different, a two-light display was first compared with the three-light display.

Two Lights vs Three Lights

Subjects

Ten staff members observed. They did not have the extended preliminary trials of the observers in Experiments 1 and 2.

Procedure

To present two lights, the right light was masked. Half the observers were tested first with the two light display, half with the three light display. The observers simply judged which of the two remaining lights flashed first. All thresholds were measured with the method of constant stimuli.

RESULTS

Table 4 gives the mean temporal intervals at which the subjects always reported correctly and the interval for the 95% threshold. There was no significant difference between the two and three light displays. For 100% accuracy, the mean temporal interval was about 18 msec; for 95% accuracy, it was about 15 msec. It should be noted that the required interval ranged from 8 msec to 26 msec. Although the mean intervals were about the same, the variability was less with the three lights. The differences were not significant, however, according to the Wilcoxon Matched-Pairs Signed-Ranks test.

Table 4

Mean temporal intervals (msec) required to perceive temporal order with two and three light displays

	Two Lights		Three Lights	
	100%	95%	100%	95%
Mean	17.2	14.7	18.4	15.8
S.D.	1.85	2.03	1.37	1.34
Range	7.8- 23.4	7.0- 25.5	10.4- 26.0	7.3- 20.8

Effect of Visual Angle

We next tested the effect of visual angle, again using only two lights. The display would not, of course, subtend the same visual angle at all times. As an observer approached, the visual angle subtended by the flashing lights would increase. What is the effect of the change in spatial separation of the lights on the required temporal interval?

A number of investigators have reported that the perceived temporal interval between two flashes varies inversely with their spatial separation (cf. Parks, 1968). But these studies do not bear on the question of whether or not the threshold for perceiving order varies with spatial separation. Westheimer and McKee (1977) reported that the identification of temporal order depends critically on the separation of the two flashes. They found that the threshold was best when the separation was only 2-6'.

Ten observers viewed the two-flash display from two distances. Half viewed the display first from 20 ft and then from 60 ft; the other half first viewed the display from 60 ft. At a distance of 20 ft, the separation of the two lights was 47'; at 60 ft, it was 16'.

RESULTS

Table 5 gives the mean temporal intervals needed for each observer to identify the temporal order correctly on every trial as well as the mean 95% threshold.

Table 5

Mean temporal interval (msec) required to identify the temporal order at two spatial separations

	47' Separation		16' Separation	
	100%	95%	100%	95%
Mean	11.7	9.1	10.4	8.32
S.D.	4.73	4.83	3.58	3.87

The temporal interval required to identify the temporal order declined slightly at the smaller separation, but neither the differences or the 100% or the 95% thresholds were significant according to the Wilcoxon Matched-Pairs Signed-Ranks test.

Effect of luminance

The brightness of the signal lights will vary with the haziness of the atmosphere. It has long been agreed that perceptual lag increases as the intensity of the light decreases (Roufs, 1963). With the signal lights, however, the brightness of all of them will probably be diminished equally, as in fog. It is not clear what effect changes in luminance have on the temporal interval required for perception of temporal order.

We presented the two-light display at four intensities in different orders to the 10 subjects. Table 6 gives the mean temporal interval needed to identify the temporal order at each luminance level.

Table 6

Mean temporal interval (msec) needed to perceive temporal order at different luminance levels

	Luminance Level							
	230 C/m^2		34 C/m^2		1.4 C/m^2		.65 C/m^2	
	100%	95%	100%	95%	100%	95%	100%	95%
Mean	13.3	11.8	11.7	10.0	19.0	16.9	20.0	17.2
S.D.	9.8	9.4	8.8	7.1	13.1	11.8	17.1	16.7

There is no increase in the temporal interval or the variability as the luminance is dimmed from 230 to 34 C/m^2, but they rise when dimmed to 1.4 C/m^2 and rise still more when the flashing lights are dimmed to .65 C/m^2. The temporal interval differences fall just short of significance, however, according to the Friedman Analysis of Variance by Ranks (X^2Idf=3) = 6.03, $p<.10$).

Effect of flash rate

Finally, we compared performance when the display was flashed at twice the flash rate (once per second) and at half the flash rate (once every four seconds) with that presented in the previous experiments (once every two seconds). With our apparatus, changing the flash rate also changed the flash duration. The question was whether or not the temporal interval required for the perception of temporal order would remain constant.

We used the three-light display again. The three flash rates were presented to nine subjects in counter-balanced order. Thresholds were measured with the method of constant stimuli. The standard 50% point was taken as threshold. Table 7 gives both the mean number of degrees off the center line and the corresponding temporal interval at which the subjects perceived the temporal order on half the presentations.

Table 7
Mean deviation from center line (deg)
and mean temporal interval (msec)
needed to perceive temporal order
at different flash rates

	1 fps	0.5 fps	0.25 fps
Mean deviation	0.88	0.45	0.23
Mean S.D.	0.36	0.21	0.21
Interval	5.4	5.6	5.7
Mean S.D.	2.2	2.6	5.2

The mean temporal interval required to identify the temporal order remains quite constant, although the precision with which the judgments were made declined as the flash rate decreased. The increase in the standard deviation for the slowest flash rate was significant according to the Friedman Analysis of Variance by Ranks (X^2 (df=2) = 12.00, $p < .01$).

The significant aspect of these results is that although the temporal interval remained constant, the deviation from the center line at which the observers can perceive non-simultaneity decreases as the flash rate decreases. The subjects preferred a flash rate which was not too slow, however, and the optimal flash rate remains to be determined.

DISCUSSION

The sensitivity of an observer to changes in the temporal aspects of this flashing display depends markedly on the initial temporal interval and to some extent on various other factors such as the direction of change of the flash rate and the distance and brightness of the beacons. It appears that observers can tell that the lights in this display -- if the viewing angle is not changing -- are not flashing simultaneously and can identify which side of the channel they are on if there is a 10 msec interval between the flashes. If, however, they must report if the interval is getting shorter or longer -- that is, if they are heading toward or away from the center of the channel -- they require a bigger increment or decrement. How much longer depends on the initial interval to which they must make comparisons. It is much easier to perceive changes in a small interval than in a large one. This means that the observers will perform better around the center of the channel than they will off center. Nine observers required a mean change in the temporal interval of 26 msec for the 6^o condition before they perceived that the interval was getting longer; two observers required a change of almost 40 msec, and one observer (not included in the mean) could not make the judgment at all.

The mean threshold interval was smaller when the observers had to report the temporal order with a static display than when they had to view a temporal interval that was constantly changing and judge when the temporal interval had changed. One reason, of course, is that when the observers chose to delay their response in order to be more certain, the final interval had in the meantime increased.

These times must be converted to distance measures. The relationship between temporal interval and the angular thresholds depends on the specific operational details of the machine being used. The rotating cylinders used in this apparatus produced 50 msec flashes about every two seconds. This seems to be a reasonable rate of presentation. For this device, each degree of eccentricity from the central line of sight results in an increase in the temporal interval between the flashes of about 12 msec. Thus, if an observer requires an 18 msec interval to see that he is off course, that will result in a navigation error of 90 minutes of arc. At a distance of 1000 yards, the observer will be 26 yards from the center of the channel; at a distance of 5000 yards, he will be 131 yards from the center of the channel.

Figure 2 shows that sensitivity for changes toward the center of the channel appeared to be better than sensitivity for changes away from the center. This was statistically significant for the judgments at 4^{o} from the center.

The series of experiments comparing the two- and three-light displays and the effects of distance and brightness showed a progressive increase in the sensitivity of the observers who were repeatedly tested. The experiments involved a large number of judgments, of course, and the observers received feedback during the practice trials at the start of each new study. It is not clear if practical experience will provide the same degree of training. Nevertheless, performance can improve with training, and it might be worthwhile to set up training facilities.

The evaluation of this device can be compared with similar measurements on other navigational aids (Laxar and Mandler, 1989) in order to determine their relative effectiveness.

In summary, all 10 observers, ranging in age from 23 to 59, could detect that the three beacons were not flashing simultaneously and could correctly report their order when there was about a 10 msec interval between the flashes. This corresponded to a deviation of about 50 min arc from the central line of sight. It was much more difficult for them to detect changes in the temporal interval -- particularly changes in a sizable temporal interval.

This mean interval will change somewhat with distance, brightness, and it should be noted that there are very large individual differences.

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A set of lights flashing either simultaneously or sequentially was tested for effectiveness as a navigation beacon. The temporal interval between sequential flashes required for the perception of non-simultaneity averaged about 10 msec. The change in temporal interval required to see a difference increased as the initial temporal interval increased; it averaged about 18 msec when the lights were initially simultaneous to about 26 msec when the initial temporal interval was 33 msec. The temporal interval between the flashing lights required to perceive non-simultaneity appeared to increase when the lights were very dim and appeared to decrease when the viewing distance increased, although neither change reached statistical significance.

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