A comparison of underwater helicopter-escape lights

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The effectiveness of two types of steady and flashing lights as escape hatch indicators for submerged helicopters was compared. Measurements were taken in moderately and highly turbid water. Response time was faster to the steady lights, and they were more accurately localized. Pairs of steady lights appeared to have some advantage over single lights, but this was not true for flashing lights. Subjects found it very difficult to discern how many different locations were being illuminated.

A PREVIOUS REPORT has detailed the visibility of underwater lights for individuals submerged without a facemask as a function of their distance, the turbidity of the water, and the observer's state of adaptation (1). This followed earlier work on several aspects of visual performance of observers under water without a facemask (2) or simply under conditions of extreme refractive error which mimic the condition of the diver without a facemask (3). This investigation compared the effectiveness of four types of underwater lights in different configurations as escape-hatch indicators in helicopters that have gone down in water. Again, on the assumption that occupants of a helicopter would not have diving masks, visibility of these lights was measured without the use of facemasks in water of both moderate and high turbidity.

MATERIALS AND METHODS

Lights: Two steady and two flashing lights were tested. The steady lights were:

1) The "Bud Diver 400 High Intensity Light" manufactured by Darrell-Allen Corp. This is a hand-held light which gives out a very-high-intensity collimated beam of light and produces a small, bright spot of light even through a considerable distance of turbid water.

2) The 30-minute "Cyalume Lightstick" luminescent chemical illumination manufactured by American Cyanamid Co. This produces a considerably dimmer light than the Diver's light (Fig. 6) but quite visible, even in the most turbid water at our maximum distance.

The flashing lights were:

3) The "Man-Overboard" Xenon strobe, a relatively large unit which produced a very bright flashing light. The usual flash rate was about one flash per second, although this varied from time to time and from unit to unit.

4) The "Personal Xenon Strobe Light", a very small unit which produced a much dimmer flashing light, also with a flash rate of about one flash per second. Both the strobe lights were manufactured by The Guest Corp.

Fig. 1 is a photograph of the four lights.

Testing Location. The experiment was carried out in an above-ground pool. An oval pool, 12x21x4 ft, was se-

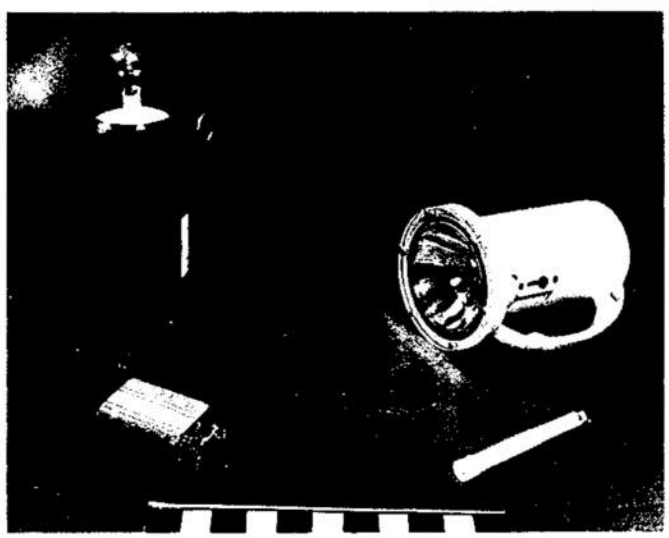

Fig. 1. The four underwater lights. In clockwise order starting with the upper left, they are the Man Overboard Strobe Light, the Bud Diver High Intensity Light, the Cyalume Lightstick, and the Personal Xenon Strobe. The scale in the foreground is graduated in one inch steps.

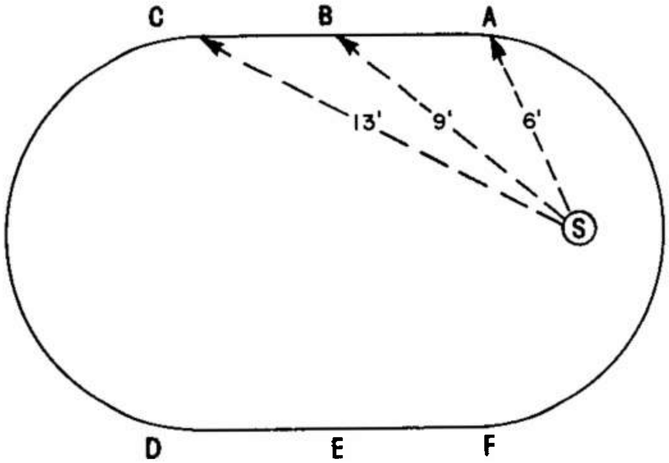

Fig. 2. Diagram of the experimental pool. The subjects were positioned at S. Targets were set up at random at positions A-F, at distances of 6, 9, or 13 ft.

lected as being the closest approximation to the size of the Boeing-Vertol V-107 helicopter troop carrier among the pools which were readily available.

A diagram of the pool is given in Fig. 2. The subject was positioned near one end of the pool, and the lights were presented at six locations around the perimeter of the pool. Since the farthest distance at which a passenger on the helicopter can sit from an escape hatch is about 12 feet, this was approximately the farthest distance from the subjects at which a light was presented.

Water Turbidity: Two levels of turbidity were used in the main experiment. At "moderate" turbidity, a high-contrast black and white grid target was visible up to a distance of about 8 ft to a diver wearing a facemask when the target was facing the sun. At "high" turbidity, the target was visible to a distance of only 3 ft under the same conditions.

The turbidity was controlled by adding corn starch to the water. This material settles very slowly and can easily be kept in suspension by occasionally agitating the water. It has the additional benefit of not irritating the exposed eyes of the subjects. The turbidity was adjusted 2-3 h before the experiment began, just before sunset. All observers were first tested under the moderate turbidity and then in the highly turbid water. In addition, a lower level of turbidity (visibility 14 ft) was later used in a daylight trial.

Procedure: The main experiment was carried out at night. The subjects were adapted to the ambient illumination and were, therefore, relatively dark-adapted. The main aim of the experiment was to compare the effectiveness of the different lights in helping subjects to quickly choose the nearest escape hatch. A second aim was to compare the relative visibility of single lights and pairs of lights; that is, would it be better to illuminate an escape hatch with two lights rather than one? Consequently, subjects were presented with these combinations of lights: two single, three single, and one, two, and three pairs of lights, positioned randomly among the six locations with respect to the subject (Fig. 2). When a pair of lights was presented, the lights were about 2 ft apart.

The subject was positioned near one end of the pool with his hands over his eyes. When the appropriate

TABLE I. MEAN RESPONSE TIME IN SECONDS TO THE DIFFERENT LIGHTS PRESENTED IN VARIOUS COMBINATIONS IN MODERATELY AND HIGHLY TURBID WATER.

No. of Lights	Man Overboard		Strobe		Diver's		Luminescent	
MODERATE TURBIDITY								
1 pair	2.29 ±	0.94	2.35 ±	1.48	1.67 ±	0.57	1.87 ±	0.96
2 pair	2.42	0.80	2.18	0.60	1.73	0.32	1.80	0.94
3 pair	2.90	0.86	2.23	0.81	1.69	0.63	1.96	0.83
2 single	2.85	2.29	2.02	0.90	2.00	0.90	1.73	0.53
3 single	2.93	1.84	2.37	1.12	2.18	1.21	1.73	1.01
MEAN	2.68		2.23		1.86		1.82	
HIGH TURBIDITY								
1 pair	3.46 ±	2.33	2.84 ±	1.04	1.80 ±	0.60	1.82 ±	0.51
2 pair	2.78	0.86	2.87	0.75	2.11	0.86	2.01	0.85
3 pair	2.17	0.61	2.48	0.68	1.45	0.30	2.01	0.64
2 single	2.97	1.70	2.88	0.74	1.61	0.56	2.06	0.54
3 single	2.83	1.61	2.82	1.12	2.23	1.11	1.82	0.83
MEAN	2.84		2.78		1.84		1.94	

lights were in position, he knelt below the surface, still with his eyes closed. When the subject signalled that he was ready for the trial to begin, the experimenter started a stopwatch and simultaneously signalled the subject. The subject uncovered his eyes and as quickly as possible pointed to the light he judged to be nearest to him. As soon as he pointed, the experimenter stopped the stopwatch, the lights were immediately extinguished, and his response time was recorded. The subject then stood up in the pool and reported how many lights he had seen and their location.

The various combinations of each light were given in a different random order for each subject. All the presentations of one type were made before presenting the next light. The order of the presentation of the four types of lights was different for each subject.

Subjects: Five men, all staff members of the laboratory, volunteered to serve as subjects. All were aware of the object of the experiment and the details of the experimental procedure.

RESULTS

Response Time: The mean time taken by the subjects to choose and respond to the light they judged to be nearest to them is presented in Table I for the various combinations of each light under both conditions of turbidity. These values are graphed in Fig. 3. The results show quite clearly that response time was faster to the steady lights than to the flashing lights. This was true for every combination of lights presented in water of both moderate and high turbidity. The various combinations are grouped in Fig. 4. According to an analysis of variance, the difference in response times to the different lights are significant in the moderately turbid water ($F(4,12 = 3.94, p < 0.05$) and highly significant in the more turbid water ($F(4,12) = 8.42, p < 0.01$).

Fig. 5 gives the mean response times for the flashing and steady lights as a function of their distance from the subjects. Response time was always slowest when the lights were farthest away, particularly in highly turbid water. Under conditions of moderate turbidity, response time was somewhat faster when the lights were at an intermediate distance than when they were at the closest distance. The reason, presumably, is that at the intermediate distance the lights were in the field of the subjects

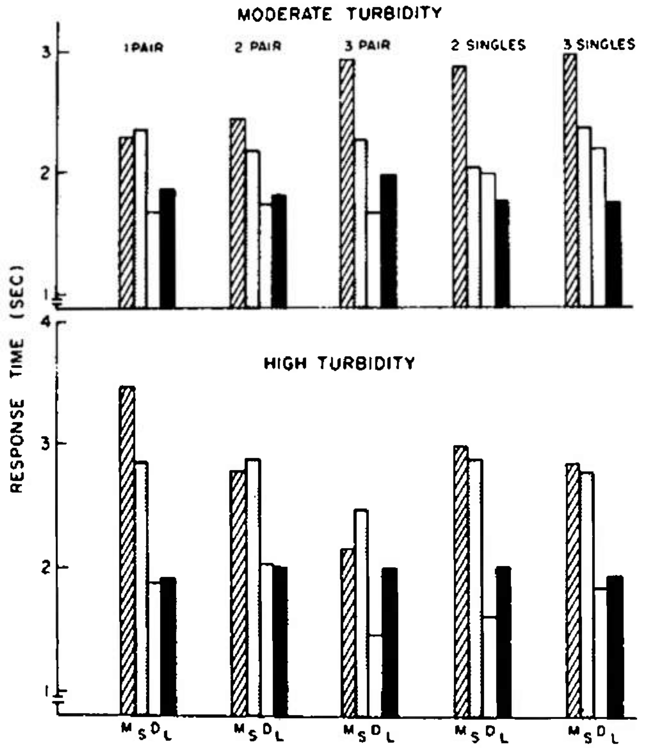

Fig. 3. Mean time required to respond to the different types of lights presented in various combinations in moderately and highly turbid water. (M, Man Overboard Light; S, Strobe Light; D, Diver's Light; L, Luminescent Lightstick.)

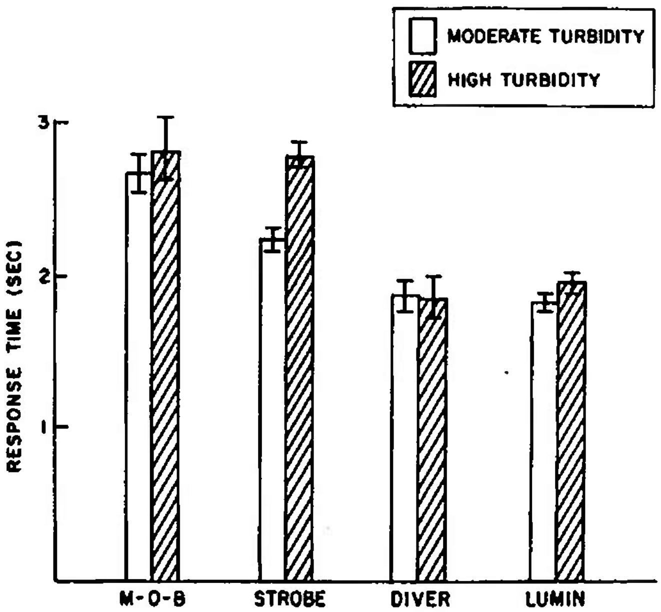

Fig. 4. Mean response time for the four types of lights in moderately and highly turbid water, averaged across all combinations of presentations. The short vertical lines at the top of each bar represent the standard error of the mean.

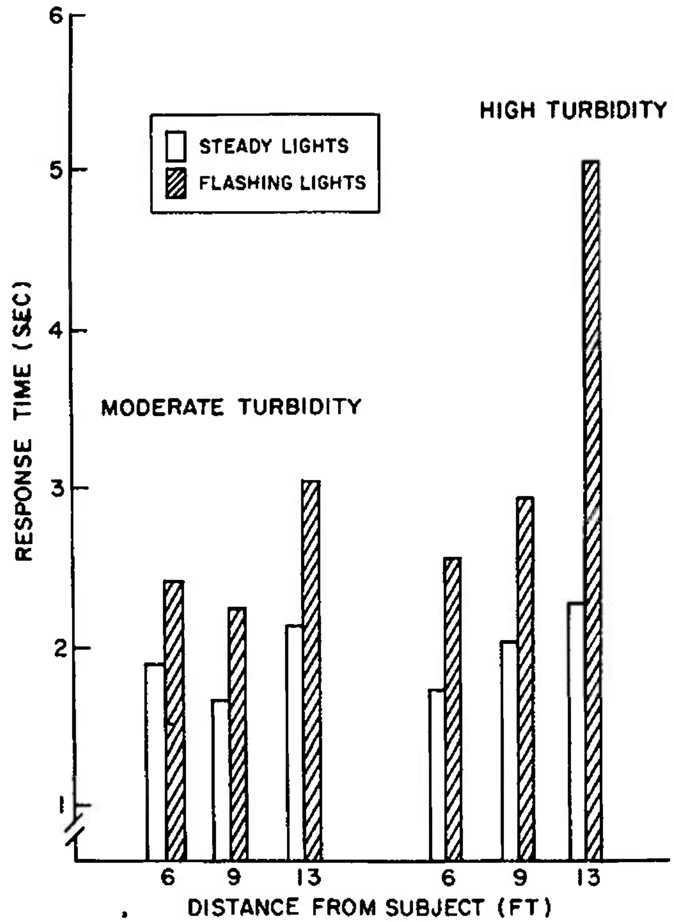

Fig. 5. Mean response time in moderately and highly turbid water to the steady (empty bars) and flashing lights (hatched bars) positioned at different distances from the subjects.

when they were looking straight ahead; when the lights were at the closest distance, they were not in the field of view and the subjects had to turn their heads to see them, which took time.

Errors in Judgment of Closest Light: Not only was response time slower to the flashing lights, but Table II shows that, in moderately turbid water, the subjects made more errors in attempting to localize the flashing lights. They made only one mistake in judging which steady light was closest; every other error was made in response to the flashing lights. No mistakes were made when the flashing lights were at the farthest distance; most errors were made when the lights were at the closest distance. That is, in 7 of the 10 trials with flashing lights at the closest distance, the subjects either pointed to a more distant location or simply did not localize the light correctly: for example, by pointing at some position between the two lights rather than at the closest light. These errors decreased with increasing distance of the

TABLE II. ERRORS IN JUDGMENT OF CLOSEST LIGHT AS A FUNCTION OF THE ACTUAL DISTANCE OF CLOSEST LIGHT.

Lights	Distance of closest light 6 ft	9 ft	13 ft	Total
MODERATE TURBIDITY				
Man Overboard	3	2	0	5
Strobe	4	1	0	5
Diver's	0	0	0	0
Luminescent	1	0	0	1
Total	8	3	0	
HIGH TURBIDITY				
Man Overboard	0	2	1	3
Strobe	1	1	1	3
Diver's	1	2	0	3
Luminescent	2	1	0	3
Total	4	6	2	

lights. That is, the subjects could localize a distant light but often could not tell that a flashing light was close by.

In water of high turbidity, there was an equal number of errors for each light, but the distribution of errors was different than in water of moderate turbidity. Errors were again fewest when the lights were at the greatest distance, but there were no differences in the number of errors for the different lights. Although it took longer to localize a flashing light, accuracy was as good as for the steady lights in water of high turbidity.

Judgments of number of lights and location: The subjects were also instructed to report how many lights were on during each trial and their location. These results are given in Table III. Each subject had 25 trials in each condition of turbidity. On each trial, the subject had to determine how many lights were on at each location. There could, of course, be one or two lights at each location, with lights at more than one location. In judging the number of locations illuminated, the subjects made 46 errors in moderately turbid water, 30 of those errors with the steady lights. In highly turbid water, they made 64 errors, again mostly with steady lights. Since each subject had a total of 125 trials in each condition, errors in the more turbid water occurred on more than 50% of the trials.

TABLE III. ERRORS IN JUDGMENTS OF NUMBER OF POSITIONS ILLUMINATED AND NUMBER OF LIGHTS AT A GIVEN POSITION (SINGLE vs. PAIR).

Lights	Errors of position		single vs. pair	
	Moderate turbidity	High turbidity	Moderate turbidity	High turbidity
Man Overboard	8	15	11	12
Strobe	8	14	11	11
Diver's	18	18	11	14
Luminescent	12	17	9	14
TOTAL	46	64	42	51

The subjects' ability to discriminate a single light from a double light at a given location was also analyzed (Table III). In water of moderate turbidity, there were 42 errors, evenly distributed among the four lights. In highly turbid water, there were 51 errors, with slightly more errors for the steady lights. Almost all errors were the result of the subject judging pairs of lights to be single lights. Since there were 65 trials with pairs of lights, if every error involved judging a pair to be a single light, then the error rate would be 65% in moderately turbid water and 78% in highly turbid water. Thus, the subjects were not able to tell either how many different locations were illuminated at a given time or how many lights were at each location. It proved to be virtually impossible for the subjects to tell whether there were one or two lights at a given location.

Effectiveness of double lights: Although the subjects could not distinguish a single light from a pair of lights, the question remains as to whether or not their response time and accuracy of localization was improved by the presence of a second light at a given location. Table I shows mean response time to the various lights presented as pairs or singles. These response times are averaged for different numbers of pairs or singles in Table IV. Response time tended to be faster to pairs of lights than to single lights, although these differences fell short of statistical significance.

TABLE IV. RESPONSE TIME IN SECONDS TO SINGLE LIGHTS AND TO PAIRS.

Lights	Moderate turbidity		High turbidity	
	single	pair	single	pair
Man Overboard	2.89	2.54	2.90	2.80
Strobe	2.20	2.25	2.85	2.73
Diver's	2.09	1.70	1.92	1.79
Luminescent	1.73	1.88	1.94	1.95
MEAN	2.28	2.09	2.40	2.32

TABLE V. ERRORS OF LOCALIZATION IN RESPONSE TO SINGLE LIGHTS AND PAIRS OF LIGHTS.

Lights	Moderate turbidity		High turbidity	
	single	pair	single	pair
Man Overboard	2	3	0	3
Strobe	2	3	2	1
Diver's	0	0	2	1
Luminescent	1	0	1	2
Total	5	6	5	7

Table V presents the errors of localization for pairs and singles: that is, did the subjects point more accurately to the closest illuminated location when there were two lights rather than one?

In general, pointing accuracy was poor and the double lights did not reduce these errors. Indeed, with the Man Overboard Light there was an increase in errors with two lights at a given location.

Subjective Reports: At the conclusion of the experiment, the subjects completed a questionnaire designed to elicit their subjective impressions concerning the effectiveness of the four lights. Of primary interest was the ability of the subject to orient himself with the help of the lights, to determine how many lights were on, their location, and which was closest to him.

The five subjects were in almost complete agreement in their evaluation of the lights. Moreover, their ratings of the lights scarcely changed from the moderately turbid to the highly turbid condition. The most visible light was judged to be the very bright diver's light. The least visible lights were the small strobe light and the luminescent light. Nevertheless, the two flashing lights were rated as the most confusing and the luminescent light as the least confusing. The subjects, therefore, were most confident that their performance had been best in response to the luminescent and diver's lights and poorest with the flashing lights. All the subjects agreed that these constant lights were the most desirable lights.

After the experiment, three of the subjects reported that, on their first exposure to the flashing light they had had noticeable difficulty in localizing the lights and had felt a considerable degree of disorientation. But with a little practice they felt they had been able to overcome these difficulties. The other two subjects did not report any disorientation but merely judged that the flashing lights were more confusing and less desirable. A comparison of the mean response times to the first presentation of the flashing lights with the mean response times for all presentations of these lights showed no reliable differences.

Visibility in Daylight: The preceding results were obtained at night under conditions in which there was no extraneous illumination. Measurements were also made to determine the visibility of the four lights in daylight. For these measurements, the range of visibility, as defined above, was increased to 12-14 ft.

With the surface of the experimental pool exposed to sunlight, the four lights were virtually invisible. The luminescent light could not be seen until the subject was about 2 ft away and the flashing lights were invisible at distances beyond 3-4 ft. The diver's light was visible at greater distances, up to 6-8 ft, but only if the light was pointed directly at the subject.

These results are of limited practical significance since it is unlikely that there would be a great deal of illumination inside a downed, underwater helicopter, but the results show that these lights will not be effective when ambient light levels are high.

Luminance of the Chemical Lightstick Over Time: The chemical lightstick is unique among the lights tested in that its luminance perceptibly changed with time. Fig. 6 shows that there was a very marked drop in luminance during the first few minutes, followed by a more moderate decrease.

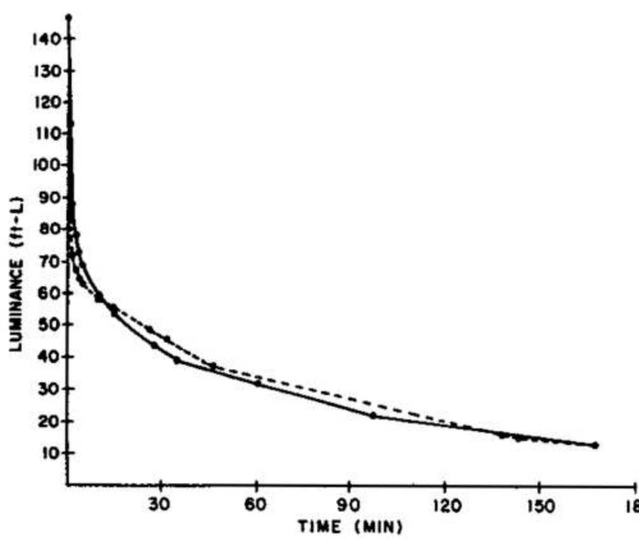

Fig. 6. Luminance of the chemical lightstick over time.

DISCUSSION

We have measured the ability of subjects submerged without facemasks to perceive the presence of various numbers of underwater lights at different distances and to respond to the closest one. Four different lights were compared under two conditions of water turbidity.

Response time was appreciably faster to the steady lights than to the flashing lights. It may be argued that the reason for this is that the flashing lights are not on all the time, and the subject must, therefore, wait until the light is on before making a response. There is no question that this is part of the picture, but there are three reasons for concluding that there are more important reasons.

First, all the subjects reported that the flashing lights were more confusing and difficult to localize than the steady lights. Three of the subjects maintained that they had found the flashing lights to be somewhat disorienting on their first exposure, although they quickly adapted to them. There is no question, however, that it is only the first exposure that is of importance since, in the event of a crash, there will be no time to adapt. Although response times were not reliably longer on the first exposure to the flashing lights than to the subsequent presentations, one must consider that a small degree of confusion in the benign experimental situation may be greatly potentiated in the event of a helicopter crash.

Second, response time increases with the distance of the light from the observer, more so apparently for the flashing lights in turbid water.

Third, whereas in highly turbid water the subjects could not respond quickly to the flashing lights, in moderately turbid water they could not accurately determine which of the lights they saw was the closest. In other words, with the flashing lights, the subjects suffered from one type of handicap in clearer water and another handicap in turbid water.

Whereas in moderately turbid water there were many errors of localization with the flashing lights, in highly turbid water there was an equal number of errors for every light. The reason for this difference is that in highly turbid water it is much easier to tell when a light is farther away because of the marked attenuation in brightness with increasing distance. When the water is not so turbid, this cue is not as effective. The marked increase in errors of which light is closest, therefore, indicates the difficulty of localizing the flashing light where there are no helpful cues, such as brightness attenuation. And this also underscores the argument that the increase in reaction time to the flashing lights is due to more than simply having to wait for the light to flash.

The only perceptual advantage the flashing lights afford is that they make it easier to tell how many lights are on and how many separate locations are being illuminated. The reason for this is that the lights did not flash in synchrony. It was thus possible to see that flashes at different times were coming from different locations, because the light from one source did not mask the light from another source as was clearly the case with the bright, steady diver's lights. But even with the flashing lights, the error rate was no less than one-third.

Finally, although the subjects could not distinguish a single light from a pair of lights at a given position, response time did tend to be shorter to the pairs of lights, probably because of the increased luminance. It also turned out, however, that errors in localization increased for the large flashing light (MOB) when it was exposed in pairs. It is probable that this was due to an increased degree of confusion resulting from the increased number of flashes of an exceptionally bright light.

CONCLUSIONS AND RECOMMENDATIONS

Both the subjects' reports and the experimental results indicate that the steady lights are preferable to flashing lights as indicators of the emergency escape hatches on a submerged helicopter. Response time is faster to the steady lights—particularly in turbid water—and the flashing lights are more difficult to localize accurately. Flashing lights appear to have only one perceptual advantage: they may make it easier to determine how many different locations are illuminated at once.

Of the four lights, all subjects agreed that the luminescent lights (chemical lightsticks) were the most desirable, and could be made even more desirable if they were somewhat brighter.

In marking the escape hatches, it appears advantageous to have more than one steady light, but not flashing lights. Although it is virtually impossible to perceive how many lights are grouped at one location, response time tends to be faster when there are two lights rather than one unless the lights are flashing, when there is the danger of added confusion.

The final question is whether a flashing light is preferable to no light at all. Even though there was a high error rate in choosing the nearest flashing light, there were more correct choices than errors. Although 3 of the 5 subjects reported being disoriented the first time they saw the flashing lights, they soon learned to adapt, and response times were not appreciably longer on the first presentation. A rather brief training session could accustom all helicopter passengers to the use of such lights. We conclude that a flashing light is better than no light at all.

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