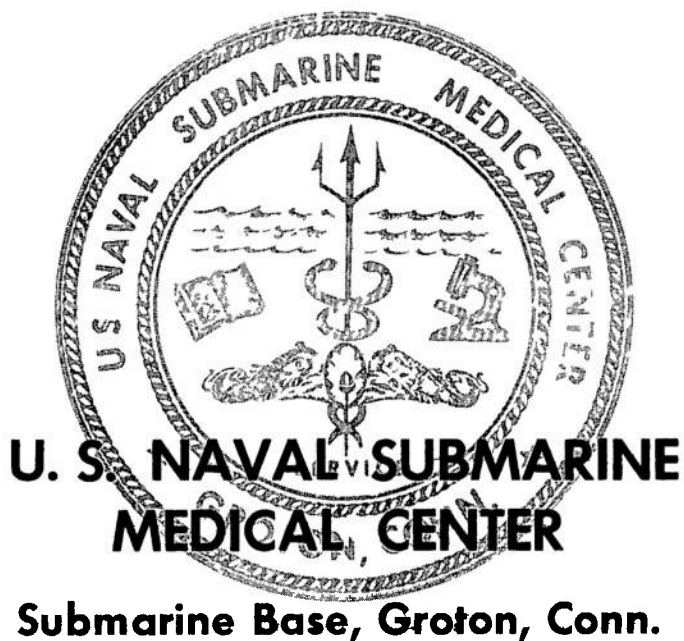




REPORT NUMBER 510

STEREOSCOPIC ACUITY UNDERWATER

by

Saul M Luria

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF022 01 04-9005 03

Released by

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COMMANDING OFFICER
U S Naval Submarine Medical Center

27 February 1968



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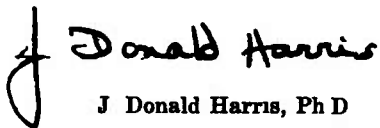
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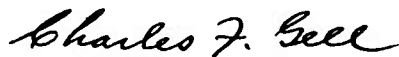
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SUMMARY PAGE

THE PROBLEM

To measure the ability to equate the distances of objects underwater

FINDINGS

The ability to equate the distances of objects deteriorated underwater. As the clarity of the water decreased, this "depth acuity" decreased, in terms of both the size of the error and the reliability of the setting. The decrease in the "depth acuity" was attributed to the loss of visual cues along the edges of the visual field underwater. The further drop in acuity with increased turbidity of the water was attributed to the loss of relative brightness of the targets.

APPLICATION

Divers should know that their ability to tell which of two objects is closer to them deteriorates underwater, increasingly, as the clarity of the water decreases. At low clarities, errors may be ten times as great as in clear water. If the loss of this ability is due largely to a lack of peripheral cues, then it may be possible to improve performance by providing artificial peripheral cues.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF022 01 04-9005, Procedures for Improving Vision, Auditory Communications, and Orientation Under Water. The present report is No. 3 on that Work Unit. It was approved for publication on 27 February 1968 and designated as Submarine Medical Research Laboratory Report No. 510.

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Stereoscopic Acuity Underwater

Introduction

In the underwater conditions normally encountered by divers, visual performance markedly deteriorates. Perception of colors,¹ estimates of size and distance,² and visual acuity suffer. However, under optimal conditions, visual acuity has been shown to improve underwater.³ This is not unexpected, since refraction causes the retinal image of an underwater object to be enlarged if the eye is near the water-air interface — as it is when wearing a face-mask. This finding raised the question: would the ability to judge which of two objects is closer or farther (technically called “stereoacuity”) also be improved? This need not necessarily follow, since visual resolution is apparently not closely related to stereoacuity.^{4, 5} Indeed, when this work was underway, Ross⁶ reported that stereoacuity was degraded by a factor of 3 underwater. The reason for the decline is not clear, however.

An understanding of the cause of the decline of stereoacuity when visual resolution remains unaffected might suggest a way of improving the former to the benefit of divers. With this aim, stereoacuity was compared in water and in air as well as in water of various clarities. In addition, stereoacuity in air was compared under normal and somewhat restricted viewing conditions.

Experiment I

The first experiment compared stereoacuity in air and water.

Method and Procedure

(1) **Apparatus** The thresholds were measured using a three-rod Howard-Dolman type apparatus. The three vertical rods stood in a box with a 16x20 in dark gray front in the center of which was a 5x14 in window. The two outer rods were fixed in position, parallel to the front of the box. The middle rod was movable. The rods were 5/8 in thick, positioned at 3 in intervals, painted flat black, and were seen against a white background.

This apparatus was set up at a distance of

16 ft from the subject (S) in a round, above-ground, metal swimming pool, 20 ft in diameter and 4 ft high. The rods thus subtended 22 min visual angle and were 18° apart. A round window, 8 in in diameter, was cut into the side of the pool about 30 in from the ground. When standing on the floor of the pool, the window of the Howard-Dolman apparatus was at the same height.

(2) **Procedure** The Ss were divided randomly into two groups. One group first observed in air, and the other group first observed in water. The first set of air-thresholds was taken at the beginning of the summer. The apparatus was set up in the pool, before it had been filled with water, and the Ss looked through the window in the side of the pool. When the pool had been filled with water, all the subjects observed as soon as possible, but the second set of air-thresholds was not taken until the end of the summer.

The thresholds were measured with the method of constant stimuli. The middle rod was set at various positions, and, at each setting, S's task was to judge whether it was closer or farther than the outside rods. A frequency of seeing curve was drawn, on cumulative probability paper, and the setting at which the middle rod was judged to be farther (or closer) on 50 percent of the trials was taken as the equidistance-setting. The standard deviations of the thresholds could be read directly off the plot. S was instructed to look away between judgments while the position of the rod was changed.

(3) **Subjects.** Twelve staff members of the laboratory served as Ss, but one of them was not available for the conclusion of the experiment.

Results

The localization errors and standard deviations, in terms of seconds of arc, are given in Table I. The thresholds in air are quite comparable to those reported by Matsubayashi for a 3-rod apparatus.⁷ Stereoacuity is degraded in water by about a factor of four, on the average, close to that found by Ross using a different technique to measure thresholds.

Table I.
Localization Errors Without Regard to
Direction and Standard Deviations in
Seconds of Arc in Air and Water.

S	AIR FIRST			
	Air		Water	
	Error	σ	Error	σ
GS	0 14	1 4	6 40	2 9
ARn	7 20	3 0	7 20	9 4
JK	2 10	3 6	7 20	12 1
HM	0 28	11 8	5 00	22 0
MF	5 40	3 8	8 55	4 3
CC	2 86	1 4	6 40	3 6
Mean	3 00	4 2	6 79	9 0
	WATER FIRST			
	Air		Water	
	Error	σ	Error	σ
LZ	3 58	2 9	7 20	10 7
ARs	1 70	0 7	3 58	10 7
PR	0 72	2 9	22 92	16 5
JW	0 95	1 1	8 55	48 0
RF	7 20	3 0	28 60	12 0
Mean	2 83	2 1	14 17	19 4
Grand Mean	2 92	3 2	10 15	13 8

A practice effect can also be seen. Thresholds are better both in water and in air for those subjects who had first observed in the other condition—who were not, that is, observing for the first time.

Experiment II

In the course of the first experiment, it appeared that the thresholds were influenced by the water clarity, which was not being systematically controlled. The purpose of the second experiment was to study this relationship.

Method

(1) **Apparatus.** The same apparatus was used. In addition, the clarity of the water was measured with the Alpha Meter, Model C-2a, built by Marine Advisors, Inc., La Jolla, Calif. The clarity of the water was increased by filtering the water with a diatomaceous earth-filter and was reduced by turning the filter off and allowing algae to grow for a few days. To produce very low clarities, water was removed from the pool and replaced with unfiltered municipal drinking water. To enable us to study rather turbid water, the apparatus was now positioned 8 ft from the window in the side of the pool.

(2) **Procedure.** Thresholds were measured in water of four levels of clarity, 80, 32, 19 and 10 percent transmission, plus or minus one percent. Over a period of several weeks, the clarity of the water was raised and lowered several times to permit the Ss to be tested in random order at the various levels of clarity. The thresholds were measured with the method of constant stimuli. Testing was always done about the same time of day and only on sunny days.

(3) **Subjects.** Seven of the Ss who had observed in the first experiment observed in this one. Four Ss, however, (JK, AR, DW, and HM) were highly experienced in psychophysical observations.

Results. The localization errors and standard deviations in seconds of arc are shown for each S at each level of clarity in Table II.

Table II.
Stereo Thresholds in Seconds of Arc
as a Function of Water-Clarity.
TRANSMISSION OF WATER

S	80	32	19	10
JK	+11 44 $\pm$ 5 70	+11 44 $\pm$ 11 44	+17 18 $\pm$ 18 90	+57 10 $\pm$ 25 78
AR	+ 5 71 $\pm$ 5 70	+21 70 $\pm$ 4 56	+28 55 $\pm$ 14 25	+28 55 $\pm$ 63 02
LZ	+ 6 85 $\pm$ 2 86	+ 8 56 $\pm$ 9 12	+21 13 $\pm$ 15 90	+14 28 $\pm$ 58 55
GS	- 3 44 $\pm$ 1 14	-28 55 $\pm$ 11 44	0 00 $\pm$ 12 50	+28 55 $\pm$ 17 18
CC	+28 55 $\pm$ 6 75	+11 44 $\pm$ 4 00	+51 39 $\pm$ 17 18	+34 38 $\pm$ 28 60
Mean	+ 9 82	+ 4 91	+23 60	+32 60
DW	+10 28 $\pm$ 3 44	+ 8 56 $\pm$ 9 65	0 00 $\pm$ 8 50	-11 44 $\pm$ 51 57
HM	+ 7 99 $\pm$ 5 16	- 7 42 $\pm$ 6 75	-19 99 $\pm$ 34 38	-37 12 $\pm$ 40 11
Mean	+ 9 14	+ 0 57	-10 00	-24 28
Mean S D	$\pm$ 4 3	$\pm$ 8 15	$\pm$ 17 35	$\pm$ 40 68

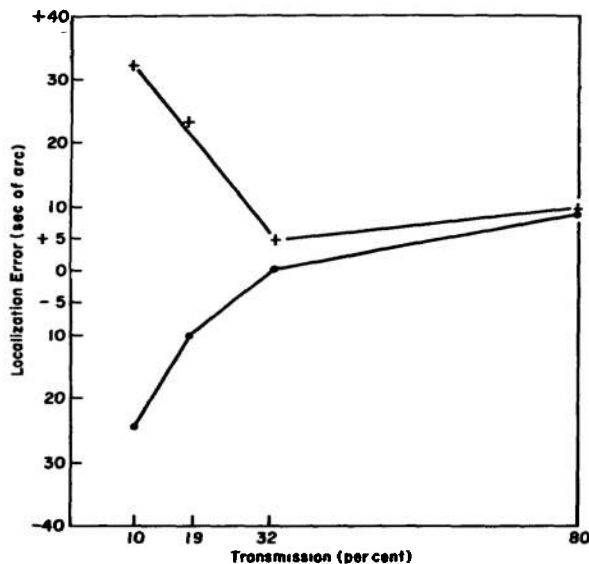


Fig 1 Localization errors as a function of water-transmission. Five Ss made increasingly positive (far) errors with increasing turbidity, while 2 Ss made increasingly negative errors.

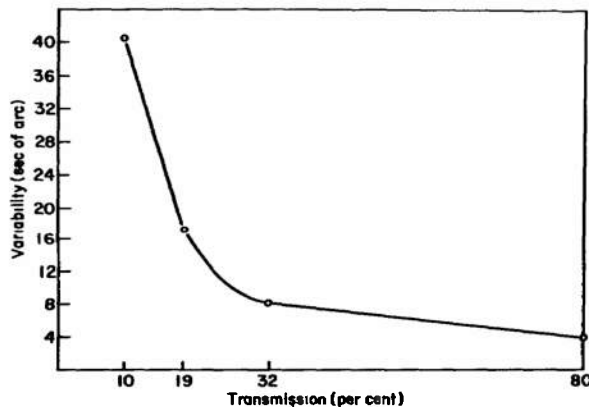


Fig 2 Standard deviations of the localization errors as a function of water-transmission.

Stereoacuity generally gets worse with increasing turbidity. As expected, the localization errors go in both directions, five Ss set the variable rod increasingly nearer as clarity decreased, and two Ss set it increasingly farther. The average errors for this division of Ss are shown in Figure 1. Both the errors and the variability (Figure 2) of the settings increase only slightly as the transmission de-

creases from 80 to 30 percent, but below that level there is a much sharper increase. The functions are much more regular for the experienced than for the inexperienced Ss.

Three Ss (GS, DW, and HM) made localization errors in one direction at low levels of turbidity and errors in the opposite direction at high levels of turbidity. This is not uncommon.⁸ It is not clear, however, why the average error for both groups of Ss at the highest transmission is around 9 seconds of arc, rather than zero. It seems unlikely that the apparatus was incorrectly positioned each time it was set up in the clearest water. These "cross-overs," furthermore, impart an unwarranted irregularity to the average results; the function for the larger group of Ss, for example, appears much more regular when the data for GS are omitted. The average errors as a function of increasing turbidity then become 13.14, 13.28, 29.56, and 33.58 sec of arc.

DISCUSSION

There are two questions which merit discussion. Why does stereoacuity fall in water? Why does it fall with increasing turbidity of the water? The answer to the latter question seems to be more apparent. Lit and Vicars⁹ have recently reported stereoacuity thresholds as a function of the brightness-contrast of the target. They have found that both localization error and its standard deviation are degraded little (if any) through a large range of brightness contrasts. Only when contrast is very low are error and precision sharply degraded. For example, with a stationary target, the precision of Lit's two Ss averaged about 25 sec of arc as the contrast ratio ranged from log 4.0 to 1.0. Below that ratio, the precision sharply worsened, and at a contrast ratio of about log 2.5, it averaged about 65 sec of arc. These values are comparable to ours. Since the most notable change in the appearance of the target with increasing turbidity is a loss of brightness contrast, it seems reasonable to assume that the change in contrast is largely responsible for the change in thresholds.

Why, however, should there be such a deterioration in threshold simply as a result of putting the target underwater? When im-

mersed in clear water, there is, after all, little, if any, loss of contrast. Several reasons for a degradation of threshold come to mind. First, as the light rays leave the water, they are refracted away from the incident-normal. As a result, the eyes must converge more than would be necessary for a target at the same distance in air, and the target appears to be closer than it actually is. It has been reported that stereoacuity is worse at distances of 25 m than at 15 m,¹⁰ and so we would expect a slight drop in stereoacuity under these conditions. Second, as noted above, the retinal image is somewhat enlarged for an underwater target.¹¹ Thus, the rods would appear to be somewhat thicker than in air, and it has also been reported that best stereoacuity is found for rather thin rods, 2.4 mm.¹² At a distance of 16 ft, the thickness of our rods was 11 mm, and again we would expect thicker rods to produce a poorer acuity.

These two effects, however, are reported to be rather small, not as great as the drop in stereoacuity underwater. The most notable characteristic of underwater viewing is, perhaps, its ganzfeld effect. The distorting effects of the ganzfeld have been pointed out for many visual functions, but not for any form of acuity.¹³ It is possible, however, that such distorting effects may occur. We know that certain functions, which are generally thought to be primarily foveal in nature—such as reading—suffer in the absence of peripheral cues.¹⁴ Such may also be the case with more basic processes.

Experiment III

This experiment was carried out to test the effect of the loss of a good part of the peripheral field on foveal stereoacuity.

Method

(1) **Apparatus.** Thresholds were again measured using the 3-rod Howard-Dolman apparatus* set at 16 ft from S. To restrict his field of vision, S looked through a pair of goggles with white paper tubes 6 in. long. These tubes gave him a circular field of vision of 10° visual angle, twice the width of the front of the apparatus. The room was lighted by overhead fluorescent lights.

(2) **Procedure.** The Ss were randomly divided into two groups. One group observed first under normal viewing conditions, after which they were immediately tested again under restricted viewing conditions. The second group first observed wearing the goggles and then without them. Thresholds were again measured with the method of constant stimuli.

(3) **Subjects.** Six staff members observed. Four had already participated in the previous experiments.

Results. The thresholds under both conditions are given in Table III. Both the average localization error and standard deviation increased to a small extent under the restricted viewing condition. In no case did the precision improve under restriction, although it remained constant for one S. It may seem that for one S (DW), the localization error has decreased under restriction, but this is spurious. It should be noted that this change is the same which occurred for him in Experiment II, under the best viewing condition, he made a positive (near) localization error, but as the viewing conditions deteriorated, his error progressively shifted in a negative (far) direction.

Table III.
Stereo Thresholds in Seconds of Arc under
Normal and Restricted Viewing.

S	Unrestricted Viewing First	
	UNR	RES
HM	-71 ± 35	-107 ± 35
ARs	-26 ± 100	+57 ± 107
CS	+06 ± 10	+35 ± 28
	Restricted Viewing First	
	UNR	RES
DW	+14 ± 21	00 ± 28
JW	+40 ± 14	+68 ± 32
DR	-17 ± 25	+35 ± 43
Grand Mean*	29 ± 34	50 ± 46

*Without regard to direction of error.

*The rods were now painted flat white and seen against a black background, as a result of a previous attempt to perform this experiment in dim light with luminous rods.

DISCUSSION

The localization errors did not decline as much in this experiment as they did when the target was submerged, but the standard deviations are about the same magnitude as they were in Experiment II when measured in the clearest water. The underwater condition, even at its greatest clarity, undoubtedly provided fewer peripheral cues than did the 10° field in air. These results suggest that the increase in the localization errors resulted from the loss of peripheral cues while the standard deviations remained small because the contrast remained high. In addition, the cumulative effects of the other variables—enlarged retinal image, increased convergence, as well as much less information as to the location of the apparatus underwater—might well serve to increase the error. We conclude, however, that the ganzfeld effect plays a significant role in degrading stereoacuity underwater.

The results of this experiment are of particular interest since we are not aware of previous demonstrations that the peripheral visual field plays a role in stereoacuity for essentially foveal targets. It would be of great interest to see if such other visual processes as resolution acuity, vernier acuity, depth perception, perhaps even color-matching and the like, may be similarly affected.

It seems likely that the peripheral field of view is important only for those visual processes which require both eyes. Its importance may lie in the cues which it provides for aligning the two eyes correctly on the target. For those processes in which best performance of the best eye, optimal alignment may not be necessary, and performance may not suffer when the peripheral field is lost.

These results suggest that stereoacuity underwater may be improved if the featureless peripheral field of view underwater is structured with some reference objects. It is possible that the introduction of only one or two fixation-points in the peripheral of the visual field may provide enough help in aligning the eyes to bring stereoacuity of divers up to normal.

SUMMARY

Stereoscopic acuity was compared for a target in air and underwater, and in a second study it was measured in water of varying clarity. Stereoacuity was found to be degraded in water, increasingly so as the clarity of the water decreased. The function of acuity vs. clarity was found to be similar to that reported for stereoacuity vs. brightness contrast, suggesting that a main cause of the drop in stereoacuity with decreasing water-clarity is the decrease in target-contrast. In a third experiment, stereoacuity was found to decrease in air when there was a loss of peripheral visual cues. It was concluded that the loss of peripheral cues in water is a significant cause of the drop in stereoacuity underwater.

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13 ABSTRACT The ability of individuals to tell which of several objects is closer or farther away was tested in water of varying clarity and compared with the same performance in air. It was found that, even when the water was very clear, performance was worse than it was in air, and it became poorer as the water got more turbid. When the subjects were working near the limits of visibility, the difference in distance which had to exist between two targets before the subjects could see what the targets were not at the same distance was around ten times as great as in clear water, and much greater than that when compared with performance in air. The decrease in the "depth acuity" was attributed to the loss of visual cues along the edges of the visual field underwater. The further drop in acuity with increased turbidity of the water was attributed to the loss of relative brightness of the targets. Divers should be made aware that their ability to tell which of two objects is closer to them deteriorates underwater, --increasingly, as the clarity of the water decreases. Performance of divers may be improved, if artificial cues can be provided.			

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