Peripheral stimuli and stereoacuity under water*

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A variety of attempts were made to improve stereoacuity under water by providing limited additional peripheral stimulation. It was concluded that acuity is most improved when the peripheral stimuli are at the same distance from the O as the target. As the peripheral stimuli are moved closer to the O than the target, their beneficial effects are decreased, and beyond a certain point, their presence degrades acuity. This effect seems to be enhanced by increasing turbidity of the water, which decreases the contrast of the distant target relative to that of the nearby peripheral stimuli. These and previous findings implicate several distinct processes in the degradation of stereoacuity in the water.

Stereoacuity suffers a marked deterioration under water. This occurs even in the clearest water when the targets appear to be as clearly visible as they are in air (Ross, 1967; Luria & Kinney, 1968). Several lines of evidence suggest that a major cause of this deterioration is the paucity of peripheral visual stimulation in an underwater environment. Whiteside and Gronow (1954) have shown that it is much more difficult to detect a target in an otherwise empty visual field. Goldstein, Clahane, and Sanfilippo (1966) reported that stereoacuity is poor in Os suffering from a restricted visual field resulting from retinitis pigmentosa, and stereoacuity has also been shown to worsen progressively as peripheral stimuli are screened from view (Luria, 1969). Finally, the related phenomenon of "empty field" myopia has long been recognized (Whiteside, 1954; Curtis, 1962).

It seems reasonable to assume, then, that the introduction of stimuli into the periphery of the visual field should improve these visual processes. Indeed, Whiteside and Gronow (1954) have reported that superimposing a reticle on the target area reduces the size of the target needed for detection by half, and Brown (1958) has found slight improvements in the effectiveness of a reticle when its size was increased. This report gives the results of several experiments which investigated the extent to which stereoacuity under water is improved by the addition of a limited number of peripheral stimuli.

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APPARATUS AND GENERAL PROCEDURE

Stereo thresholds were measured with a 3-rod Howard-Dolman apparatus. The three vertical rods stood in a box with a 40 x 50 cm dark gray front in the center of which was a 13 x 36 cm window. The two outer rods were fixed in position in a line parallel to the front of the box. The middle rod was movable. The rods were 1.58 cm thick, positioned at 7.6-cm intervals, painted flat black, and seen against a white background. The fixed rods of the Howard-Dolman apparatus were always 3.05 m (10 ft) from O. The face and window of the apparatus then subtended 7.6 x 9.5 deg and 2.4 and 6.6 deg, respectively.

This apparatus was set up in a round above-ground swimming pool, 6 m in diam and 1.2 m high. A round window, 20 cm in diam, was cut into the side of the pool 76 cm from the ground at the same level as the window of the Howard-Dolman apparatus when it was in the pool. Data were taken on clear afternoons. The white background was illuminated to about 1,500 ftl.

In the experiments to follow, O sometimes viewed the target through the porthole and at other times was actually in the water. When submerged, O was seated in the water with the back of his head held against the side of the pool while breathing through a snorkel. In either case, O wore a face mask and thresholds were measured with the method of constant stimuli. The middle rod was set at various positions, and at each setting, O was forced to judge either 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 on 50% of the trials was taken as the equidistance setting. The standard deviations of the

thresholds could be read directly from the graph.

The results are given in terms of variability, which is more commonly used than localization error (see, e.g., Dwyer & Lit, 1970); it is a more sensitive indicator and is not subject to the systematic shifts which occur in localization error with changes in viewing conditions (Luria & Weissman, 1968).

SIMPLE CUES

The first experiments tested the effect of one or two thin black vertical bars in O's field of view. Bars 1.27 cm in diam and 75 cm high were positioned 60 cm in front of O's frontal plane and as far in the periphery as possible while still permitting them to be seen by each eye individually (about 20-25 deg away from the line of sight).

The stereoacuity of six staff members looking through the porthole was tested under three conditions given in counterbalanced order: (1) in the presence of both bars, (2) with only one bar (randomly placed on one side or the other), and (3) with no bar. In clear water, with the rear of the pool visible, the bar produced no general improvements; if anything, there was some slight degradation. The mean precision of stereoacuity ($\eta\sigma$) was 5.7 sec of arc with no bar, 6.5 sec with one bar, and 6.0 sec with two bars.

On the assumption that the visibility of the back of the pool may have provided peripheral cues which were as effective as those of the bars, the experiment was repeated with six other staff members using turbid water. The apparatus now stood near the limit of visibility, thus reducing the contrast of the rods of the test apparatus relative to the bars and eliminating all other peripheral cues in the water. Acuity was degraded more markedly than before. Mean $\eta\sigma$ was 35.3 sec of arc with no bar, 47.5 sec with one bar, and 41.9 sec with two bars, but these differences were not statistically significant according to the Friedman two-way analysis of variance by ranks (Siegel, 1956).

COMPLEX CUES

Since these negative results were conceivably attributable to the fact that two slender bars simply did not constitute enough peripheral stimulation, the next attempts aimed at providing more complex cues.

First, a rectangular wire mesh was suspended perpendicular to O's line of sight. The openings in the mesh measured 5.1 x 6.4 cm; at a distance in the water of 50 cm from O, they subtended visual angles of about 8 x 10 deg. Thus, although the mesh

Table 1
Precision of Stereoacuity ($\eta\sigma$ in Seconds of Arc) with Target Alone in Water or in the Presence of Two Peripheral Vertical Bars at Various Distances from the O

O	No Bars	Bars at 1.2 m	Bars at 1.8 m	Bars at 2.4 m
JK	17.9	9.7	7.5	5.4
AR	8.2	3.6	9.7	5.7
DW	8.6	6.1	2.1	3.9
TS	6.4	6.1	5.7	5.7
FD	7.5	3.6	3.6	1.8
RG	4.7	6.1	4.3	2.9
Mean	8.9	5.9	5.5	4.2

filled the field of view, the entire face of the test apparatus was visible through one of the wire rectangles without a wire impinging on any part of it. Nevertheless, the mesh produced a decrement in precision for each of six Os tested. The mean $\eta\sigma$ was 19.8 sec of arc without the mesh and 28.3 sec of arc with it. The difference was significant ($p < .05$, Wilcoxon, two-tailed).

In subsequent experiments, a massive tripod about 75 cm high and a bull's-eye target, painted on a 45 x 55 cm sheet of metal and set up at a 45-deg angle with O's frontal plane, were used as stimuli in place of the original bars. The target tended to improve acuity of divers in the water, whereas the tripod degraded it, but no differences were significant.

Following this, the pool was filled with a large assortment of objects, leaving, of course, a clear line of sight to the apparatus. The presence of a large number of clearly visible objects throughout the field of view improved mean $\eta\sigma$ from 17.2 to 12.0 sec of arc. Only one of six staff members tested through the porthole failed to show improvement (although this was enough to prevent the difference from being statistically significant).

EFFECT OF DISTANCE

In examining the results at this point, it now seemed that the essential difference between the stimuli that tended to degrade acuity and those that tended to improve it was their position in depth relative to the test apparatus. Peripheral stimuli near O seemed to degrade acuity, whereas stimuli closer to the apparatus improved it. The mesh, which constituted an extensive set of stimuli which was close to the O at all points, significantly degraded acuity. The large assortment of objects, many of which were around the apparatus, improved it for nearly everyone. The easel tended to degrade acuity somewhat because it was closer to O. The bull's-eye tended to improve acuity because it receded from O, and its far edge was a good part of the distance to the test apparatus.

To test this hypothesis, the bars

were once again used as peripheral stimuli in clear water. Six staff members, observing through the porthole, were tested without the bars and with both bars set up 1.22, 1.83, and 2.44 m from O and as far in the periphery as possible. The various conditions were presented in counterbalanced order.

Table 1 shows that, whereas the presence of the bars at 0.6 m in the previous experiments had produced no improvement in acuity, their presence at the longer distances in this experiment did result in improved mean acuity. Moreover, the improvement increased as the distance of the bars from O approached that of the test apparatus. These changes were statistically significant according to the Friedman two-way analysis of variance by ranks ($\chi^2 = 9.8$, $df = 3$, $p < .02$).

These results were confirmed in another experiment in which large stimuli were substituted for the bars and the Os were in the water. An arrow, whose shaft measured about 4 x 60 cm, was painted on each of four pieces of sheet metal measuring 30 x 60 cm. Each "arrow" was clamped to a vertical rod like the ones used in the previous experiments. The four arrows could be positioned in pairs so as to form a visual alley converging on the test apparatus. Relatively small gaps between the pieces of metal sufficed to bring the near edge of the two closest arrows to the edge of the binocular visual field at a distance of about 1.5 m from the O.

Two staff members and 16 sailors, who had not yet participated, served as Os. Their acuity was measured without these arrows in place, with all four arrows in position, and with only the two closest arrows in place, thus leaving a gap between the arrows and the test apparatus. These conditions were presented in counterbalanced order.

Table 2 shows that acuity was not changed by the presence of the two closest arrows but much improved by the presence of all four arrows. These results were also significant, according to the Friedman test ($\chi^2 = 8.8$, $df = 2$, $p < .02$).

DISCUSSION

The results clearly show that peripheral cues in the water affect stereoacuity, and a very important variable is their position relative to the target. When the cues are much closer to the O than the target, they degrade acuity relative to the case when there are no cues at all. This phenomenon appears to be somewhat enhanced as the turbidity of the water increases, for then the closer peripheral stimuli are of much greater contrast than the more distant target and can exert an even stronger deleterious effect. As the peripheral cues approach the plane of the target, however, stereoacuity improves.

There have been a number of attempts to improve the ability of pilots to detect other aircraft in an empty sky by giving them peripheral stimuli, such as reticles etched on the canopy. The present results suggest that such attempts have met with so little success because the stimuli on the canopy are not at the same optical distance as the targets to be detected and apparently interfere with target detection. Improvements in target detection have apparently been found only when the peripheral stimuli were optically adjusted to appear at the same distance as the targets, as, for example, in Whiteside and Gronow's (1954) study.

A recent investigation by Hennessy and Leibowitz (1971) bears on the question as to which visual processes are affected by conditions such as those in the present experiment. They

Table 2
Precision of Stereoacuity ($\eta\sigma$ in Seconds of Arc) With and Without the Presence of "Arrow Signs" Measured for Os Immersed in the Water

O	No Signs	Two Signs	Four Signs
AM	28.6	21.5	14.3
FB	19.7	25.1	19.7
BW	34.7	37.6	32.3
RR	*	62.6	43.0
TP	23.3	78.8	35.8
MM	*	98.4	35.8
AD	7.2	26.8	23.3
RW	53.7	*	75.2
MK	32.2	34.0	21.5
JD	37.6	62.6	43.0
CS	30.4	32.2	30.4
RF	150.4	*	50.1
JH	64.4	21.5	46.5
DR	30.4	34.0	25.1
GM	46.5	25.1	32.2
RS	32.2	19.7	19.7
GS	28.6	14.3	14.3
MB	71.6	21.5	28.6
Mean	47.4	46.7	32.8
Median	33.4	33.1	31.3

*Could not be measured due to limitations of apparatus. In computing the mean, the largest value obtained was used.

Table 3
Precision of Stereoacuity (η_G in Seconds of Arc) Through a Standard Face Mask and Through Goggles

O*	Standard Face Mask	Goggles
WI	12.5	50.0
EV	21.4	25.0
SI	12.5	12.5
MA	10.6	10.6
KE	16.0	8.9
NO	7.0	14.3
SA	5.6	7.0
NE	12.5	16.0
HI	3.8	9.2
DR	5.3	3.6
Mean	10.7	15.7

*The first five Os observed through the standard face mask first.

showed that when an O views a target through an aperture, the magnitude of accommodation is related to both the distance of the target and the distance of the aperture. As the distance of the aperture changes while the target distance remains constant, the state of accommodation changes to reflect a compromise between the two distances. These findings complement previous ones that accommodation is disturbed in an empty field (Whiteside & Campbell, 1953). They also suggest the possibility that in the present experiment, stereoacuity was degraded by the presence of the peripheral stimuli close to the O because the proper accommodation was altered in an attempt to strike a balance between the two sets of stimuli in the visual field.

It is further conceivable that the rim of the face mask may play a part in the decline of stereoacuity in the water. It may induce a form of "instrument myopia" (Schober, Dehler, & Kassel, 1970)—the unnecessary accommodation which occurs when looking through an optical instrument—discussed in some detail by Hennessy and Leibowitz.

It is difficult to compare acuity in the water with and without a face mask rim because some aperture is essential to provide the air interface in front of the eyes. We have, however, compared stereoacuity through the standard mask with that through a pair of underwater goggles which further reduce the field of view by about 15% and whose rims are more obtrusive. Table 3 shows that 6 of the 10 Os did better through the standard mask and only 2 were worse. These results fall short of significance ($p < .08$, Wilcoxon, one-tailed), but the trend is clear. When, however, the comparison was made outside the pool between the goggles (with no glass in them) and no mask, there was no mean difference at all, perhaps because the large

number of visual cues around the target in the air were decisive.

To show that changes in accommodation do affect stereoacuity, six Os were tested in air with and without a pair of -2 diopter spherical lenses. Table 4 shows that, although every O reported the ability to focus the test rods, the acuity of every O was markedly reduced by the lenses ($p < .025$, Wilcoxon, one-tailed). This is completely analogous to the decrements in stereoacuity reported for reduction in observation distance under ordinary viewing conditions (Amigo, 1963; Jameson & Hurvich, 1959; see Ogle, 1958, for other references). It appears, then, that not only faulty accommodation but simply changes in accommodation under ordinary viewing conditions affect stereoacuity.

In conclusion, it appears that several distinct processes are involved in the reduction of stereoacuity in the water. The present results show that the introduction of nearby peripheral stimuli into a relatively featureless field of view reduces it—more so in turbid water which reduces the visibility of the target and any visual cues bear it—probably by inducing faulty accommodation. The results with the -2 diopter lenses suggest that the state of accommodation (with the changes that that entails) plays a role in the level of stereoacuity.

In addition, our previous findings (Luria, 1969) indicated that the mere absence of peripheral stimulation (resulting from the removal of distant peripheral cues) degraded stereoacuity. Since, however, resolution acuity remained unchanged, it was presumably not accommodation which was affected but rather some other process—perhaps the ability to maintain binocular fixation (Ogle, 1950). This seems reasonable, since care was taken in the previous study to match the peripheral screen to the target surround in color and brightness and make it as unobtrusive as possible; in the present study (as in the Hennessy and Leibowitz experiment), of course, the nearby peripheral cues contrasted clearly with the target surround.

The sizeable loss of stereoacuity in water compared to air is probably the result of all these different factors acting together. Jameson and Hurvich (1959) pointed out that they had found several factors contributing in simple summative fashion to changes in stereoacuity as a function of target distance.

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Table 4
Precision of Stereoacuity (η_G in Seconds of Arc) With and Without a -2 Diopter Spherical Lens

O*	No Lens	-2Δ Spherical Lens
SL	1.27	5.82
SW	1.36	8.95
AS	2.70	3.95
CM	0.63	1.90
RS	0.90	1.54
EG	2.25	14.30
Mean	1.52	6.08

*First three Os observed first with no lens.

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